A Novel Virtual Motor Rehabilitation System for Guillain-Barré Syndrome

Two Single Case Studies

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Guillain-Barré, postural control, balance disorders, virtual motor rehabilitation, virtual reality, balance rehabilitation

Summary

Introduction: This article is part of the Focus Theme of Methods of Information in Medicine on "New Methodologies for Patients Rehabilitation".

Objectives: For Guillain-Barré patients, motor rehabilitation programs are helpful at the onset to prevent the complications of paralysis and in cases of persistent motor impairment. Traditional motor rehabilitation programs may be tedious and monotonous, resulting in low adherence to the treatments. A Virtual Motor Rehabilitation system has been tested in Guillain-Barré patients to increase patient adherence and to improve clinical results.

Methods: Two people with Guillain-Barré performed 20 rehabilitation sessions. We tested a novel system based on Motor Virtual Rehabilitation in three periods of time (baseline evaluation, final evaluation, and follow-up. In the training program, the participants carried out a specific treatment using the Active Balance Rehabilitation system (ABAR). The system is composed of customizable virtual games to perform static and dynamic balance rehabilitation.

Results: Significant improvements in clinical results were obtained by both participants, with significant results in the static balance clinical test of the Anterior Reach test in the standing position and unipedal stance time. Other significant results were found in dynamic balance clinical tests in the Berg Balance Scale test and the 30-second Sit-to-Stand test. With regard to acceptance of the system, both patients enjoyed the experience, and both patients thought that this system was helpful for their rehabilitation.

Conclusions: The results show that Virtual Motor Rehabilitation for Guillain-Barré patients provides clinical improvements in an entertaining way.

1. Introduction

Guillain-Barré syndrome (GBS) is an inflammatory demyelinating polyradiculoneuropathy. In this, syndrome the etiology is not established, but there is progressive symmetrical weakness, mild sensory motor disorders and areflexia [1]. Worldwide incidence rates for GBS vary from 1.1 to 1.8 per 100,000 adults per year, with rates of 0.6 per 100,000 children per year [2], and an increase of 20% in age-specific incidence rate GBS for each ten-year increment in age [3]. The cardinal clinical features of GBS consist of sensory motor disturbances, relatively progressive limb weakness [4], and areflexia [5]. Due to these disturbances, GBS patients suffer muscle weakness in: 1) lower limbs; 2) trunk; 3) upper extremities; 4) bilateral facial palsy [6]; bulbar muscles [7]; cranial nerve disorders [8]; and respiratory disorders.

About 30% of GBS patients have severe weaknesses, producing disorders in respiratory muscles and requiring mechanical ventilation [9]. Approximately 20% of GBS patients have dysautonomia [10], such as labile hypertension, orthostatic hypotension, and sinus tachycardia. In an initial phase (in the first hours), GBS patients show a progression in muscle weakness, with loss of feeling in the toes or fingertips. In the first two-three weeks, half of the GBS patients manifest symmetric limb weakness and bilateral weakness of facial muscles. The muscle weakness is reached
in the fourth week in 90% of GBS patients, with this weakness decreasing beyond this period of time [11, 12]. Different clinical studies have classified GBS patients into the following pathological categories: acute inflammatory demyelinating polyradiculo-neuropathy (AIDP) [13], Miller Fisher syndrome (MFS) [14, 15], and axonal forms such as acute motor axonal neuropathy (AMAN) [16], and acute motor sensory axonal neuropathy (AMSAN) [17]. AIDP incidence is common in developed countries (North America, Europe [18], and Australia). AMAN incidence is frequent in Japan, China, and South America [19], while AMSAN is more common in South Asia [20] and Northern India [21].

AIDP is characterized by different symptoms such as the presence of muscle weakness, paralysis, and decreased tendon reflexes. AMAN is a motor disorder that produces an acute symmetrical paralysis, with brisk reflexes in the acute phase [22], increasing the protein levels in cerebrospinal fluid (CSF). AMSAN is a motor and sensory nerve disorder that is related to this polyneuropathy, with distal sensory weakness, areflexia, and respiratory insufficiency [23]. MFS has specific clinical characteristics such as ataxia of a cerebellar type, external ophthalmoplegia, and decreased/absent deep tendon reflexes [24].

As a result of an unpredictable progression of the disease, a careful clinical presentation is mandatory in hospital admissions. To obtain a correct diagnosis of GBS, clinical specialists have to evaluate if the CFS analysis indicates high protein levels, and if so, they must carry out neurophysiological studies.

Disorders associated with muscle weakness symptoms in GBS are postural control, gait, balance, and also high rates of fatigue [25]. Due to balance disorders, the risk of falls increases, and, therefore, the therapeutic process in GBS is focused on balance rehabilitation. The rehabilitation process is composed of a customizable program, with therapeutic exercises including: 1) isometrics (with mechanical or manual resistances) and muscle setting; 2) isometric exercises, performing muscle contractions based on low resistances; 3) and progressive activities related to resistances [26].

Physical rehabilitation should include specific mobility treatment that covers postural control, partial body weight, use of ankle foot orthotics (AFO) in gait treatments, and muscle strengthening [27]. After the acute phase, patients with similar symptoms of Guillain-Barré (Acquired Brain Injury, Parkinson’s disease, Multiple Sclerosis disease), the rehabilitation process is focused on a specific treatment to recover motor and sensory disorder and to improve the muscle tone and proprioceptive sense. This process is composed of clinical specialists [28] (therapists, nurses, neurologists, rehabilitation physicians, etc.) and a technological system that is focused on a specific treatment.

On the other hand, Khan et al. [29] published a novel systematic review with a summary of different rehabilitation techniques in adults with GBS. The review found a large number of articles indicating that it is possible to obtain a reduction in the impairment of GBS patients. To do this, a multidisciplinary team is necessary (nurses, occupational therapists, social workers, and also physical therapists) together with occupational, social, psychological, or speech sessions. However, there are few studies focused on treatments to increase balance, postural control, or gait disorders in GBS patients.

Garsen et al. [30] tested the efficacy of a 12-week bicycle training program (and a follow-up period) in 16 Guillain-Barré patients with severe fatigue and in four patients with polyneuropathy. The results showed improvements in physical fitness and muscle strength and a 20% reduction in the fatigue score (p = 0.001).

Mhandi et al. [31] studied six patients with GBS with an adapted treatment in accordance with their pathology. They observed improvements in muscle strength and functional motor independence in the first 6 months and also at 18 months.

Gait disorders in Guillain-Barré patients are key points in restoring balance, together with exercises related to activities of daily living (ADL).

Traditional rehabilitation techniques are tedious, monotonous, and boring, with low adherence to the treatment. New technologies using Virtual Motor Rehabilitation (VMR) are used to improve balance and postural control [32, 33]. Low-cost devices provide a tool where patients interact by simulating traditional methods and obtaining significant results [34–36].

Nintendo® Wii Balance Board (WBB) is an interesting device for obtaining balance and postural control improvements in VMR [37]. In the last few years, novel software tools that are specifically designed for patients with balance and postural control disorders have been tested for different pathologies [38–40]. The use of technology based on VMR in Guillain-Barré patients is a novel option to improve balance and postural control disorders.

2. Objectives

Although there are studies that have validated the effectiveness of traditional rehabilitation in patients with GBS [29–31, 41], no study to date has tested balance disorders aimed at improving the patient’s motor recovery using VMR. Therefore, in this paper, a novel and customizable tool is presented and tested in two patients with GBS. The Active Balance Rehabilitation system (ABAR) [40] was designed for patients with balance and gait disorders.

3. Methods

3.1 Active Balance Rehabilitation (ABAR)

The ABAR system is characterized by the use of different Virtual Environments (VE) that focus on weight transferences and specific movements in the rehabilitation process. The goal of the ABAR system is to obtain improvements in pathologies that have balance and postural control disorders.

The most important and representative characteristics of the ABAR system are that it is: 1) a flexible system for the recovery of postural control and for reducing fractures and the risk of falls; 2) a suitable system that improves the patient’s motivation and treatment adherence; 3) a reinforcement system that allows the results obtained in each session to be monitored and the appropriate action taken; 4) a robust system that is able to make a good recovery in parameters such as balance, postural control, muscle tone, and stability in the standing/sitting position in Guillain-Barré patients;
5) a portable system that can be used at home to reinforce the acute and sub-acute stages; 6) a customizable system that offers multiple levels of difficulty that are based on the patients’ progression.

The ABAR system has two levels of difficulty (low and medium) with six games. The lowest level has two virtual environments (VE) for sitting training. At this level, the participants can perform medio-lateral and antero-posterior weight transfers in the sitting position. ABAR provides different parameters to customize the level of difficulty: the number of virtual sessions, the rest period between virtual sessions, the session time, the target speed, and the target display time.

The medium level has four VE for standing training. These are classified by the type of balance rehabilitation: static balance rehabilitation and dynamic balance rehabilitation. In static balance rehabilitation, Guillain-Barré patients can train medio-lateral and antero-posterior weight transfers in the standing or tandem position. In dynamic balance rehabilitation, the system offers two movements in the standing position: to step on the WBB and the sitting-standing movement. The characteristics of the ABAR system are shown in Table 1.

The ABAR system is composed of low-cost hardware devices: a large 47” TV, a standard PC, a WBB, and a bluetooth dongle for the communication between our system and the WBB.

3.2 Case Presentation

In this study, two GBS patients performed gait and balance by means of traditional and virtual motor rehabilitation. We used a low-cost force platform (the Nintendo® Wii Balance Board) and our specific Virtual Environment tool (ABAR).

3.2.1 Case One

A 54-year-old patient with GBS was admitted to our hospital. His medical history was the following: 5 feet and 74 inches in height, with a body-mass index of 24.65, a weight of 75.5 kg, a calf circumference of 35 cm, a personal history of bronchiectasis due to a pertussis childhood disease, and a nasal polypectomy (twice) in the year 2007. In June 2012, he suddenly presented different symptoms: 1) diplopia; 2) instability; 3) weakness in the upper extremities; 4) symmetrical hypoesthesia in the lower and upper limbs, hypoesthesia in the eye, and a feeling of tightness in his throat; 5) binocular ophthalmoplegia in every eye position; 6) bilateral palpebral ptosis at rest-time; 7) mandibular nerve paresthesia; 8) tetraparesis around 2+/5 in lower limbs; 9) severe bilateral dysmetria (more severe on the left side of his body); 10) severe impairment with arthrokerinetic sensibility; 11) absence of postural control in the sitting position; 12) absence of tendon reflexes in the lower and upper limbs; 13) dysphagia to drink fluids; 14) sweating and difficulty to start urination. He did not have dysarthria.

3.2.1.1 Admission

Upon hospital admission, the GBS patient experienced acute respiratory failure,

**Table 1** Weight-transferences/movements in the ABAR system. This table shows the different weight-transferences and movements in the intervention period.

<table>
<thead>
<tr>
<th>Sitting Position</th>
<th>Weight-transferences/movements</th>
<th>Visual Aspect</th>
<th>Weight-transferences/movements</th>
<th>Visual Aspect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The patient performs weight transfers in the medio-lateral or antero-posterior direction in the sitting position.</td>
<td>Sitting on the WBB</td>
<td>The patient performs medio-lateral weight transfers in the sitting position.</td>
<td>Sitting on the WBB</td>
</tr>
<tr>
<td>Standing Position</td>
<td>Weight-transferences/movements</td>
<td>Visual Aspect</td>
<td>Weight-transferences/movements</td>
<td>Visual Aspect</td>
</tr>
<tr>
<td></td>
<td>The patient makes a step with his right or left foot onto the WBB in the standing position.</td>
<td>Standing on the floor</td>
<td>The patient moves in the standing or sitting position.</td>
<td>Standing on the floor</td>
</tr>
<tr>
<td></td>
<td>The patient makes a step with his right or left foot onto the WBB in the standing position.</td>
<td>Standing in tandem position</td>
<td>The patient moves in the standing or sitting position.</td>
<td>Standing in tandem position</td>
</tr>
</tbody>
</table>
Table 2 Characteristics of the participants. This table shows the global information of the two Guillain-Barré patients: age, time since injury, weight, and height.

<table>
<thead>
<tr>
<th>Issue</th>
<th>Patient one</th>
<th>Patient two</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>Male</td>
<td>Male</td>
</tr>
<tr>
<td>Age (years)</td>
<td>54</td>
<td>33</td>
</tr>
<tr>
<td>Time since injury (months)</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Weight</td>
<td>75.5</td>
<td>94</td>
</tr>
<tr>
<td>Height</td>
<td>5.74</td>
<td>5.54</td>
</tr>
</tbody>
</table>

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requiring mechanical ventilation in the Intensive Care Unit (ICU). Afterwards, Nuclear Magnetic Resonance (NMR) showed occupancy of maxillary sinuses, right front, right ethmoid cells, gadolinium-enhanced, and diffusion restriction on the right side. These results suggested an inflammatory process. At the same time, a neurophysiological study was performed, indicating asymmetric bilateral disease in upper and lower limb nerves, with a greater illness in sensory nerves, which is compatible with multiple axonal neuropathies. Based on these conditions, together with the presence of ophthalmoplegia, ataxia, arreflexia, and a gradually favorable evolution, the patient was diagnosed as having Miller-Fisher syndrome.

3.2.2.2 Intervention
In the acute phase in the hospital, a corticoid and an immunoglobulin therapy were performed. After the first month of the rehabilitation process, we saw improvements in palpebral ptosis. The GBS patient started eye vertical movements, with improvements in the sitting position and decreased dysmetria, obtaining improvements in fine-hand movement, but needing visual control.

In a second phase of the rehabilitation process, physiotherapy techniques were performed progressively; namely, active-passive movements with coordination exercises, proprioception, transfers and gait retraining, Frenkel and Kabat techniques, stationary bicycle, massage therapy, and activities of daily living (ADL).

Two months after intervention, the GBS patient showed improvements in the standing position with assistance, keeping distal and proximal tetraparesis. Four months later, the GBS patient could walk using a walker, with personal assistance. Finally, five months after hospital admission, the clinical specialist suggested completing traditional motor rehabilitation (TMR) with VMR using the ABAR system.

3.2.2 Case Two
A 33-year-old patient with GBS was admitted to our hospital. His medical history was the following: 5 feet and 54 inches in height, with a body-mass index of 32.91, a weight of 94 kg, a calf circumference of 42 cm, a personal history of fracture of the middle-third right clavicle that required surgery due to a motorcycle accident (seven years before).

3.2.2.1 Admission
The patient experienced gait disorders for four days, with repeated falls and headaches, and was attended to in hospital emergency. He had paresthesia and hyposthesia in lower extremities until the inguinal region as well as a decrease in sensitivity in the hands, the lower face, peribuccal area, and cheeks. There was no disturbance in the level of awareness nor were there sphincter disorders. Neurological examination showed asymmetric tetraparesis, proximal 4/5 in lower limbs, and distal 4/5 in upper extremities, without osteomuscular reflex in lower limbs, and loss of sensitivity in hands, feet, and jaw. After the first week of admission, the GBS patient got worse, with a 3/5 of proximal and distal tetraparesia, and asymmetric facial paresis on the left side. The patient was mobility-impaired, with severe monopodal-balance disturbances. The information on electroneystagmography (ENG) and the cytology in CSF confirmed the Guillain-Barré diagnosis with disease/pain of the cranial nerves.

3.2.2.2 Intervention
In the first phase, the rehabilitation process consisted of a treatment with i.v. immunoglobulins, and the patient showed improvement at the end of the first month. The process was based on techniques such as: muscle tone and strength, coordination, balance, walking, articular balance, ADL, global and analytic muscle enhancement of the hands, superficial and deep sensitive stimulation in hands/feet, oral praxis, and phonatory.

In a second phase, the participant was able to ambulate with the manual contact of a clinical specialist, with gait instability, and remaining paresthesia and hyposthesia (both superficial and deep) on the left side on the face. However, there was a loss of tendon reflexes with a strong asthenia and a global muscle balance of 4/5. Finally, four months after his initial presentation, the GBS patient started a specific treatment based on gait, postural control and ambulation using the ABAR system and the WBB [40]. The characteristics of the two Guillain-Barré patients are shown in Table 2.

3.3 Training Program
The present study was carried out in the San José metropolitan hospital. The Guillain-Barré patients performed a total of 20 rehabilitation sessions, distributed in three sessions per week. The rehabilitation sessions were composed of 30 minutes for traditional rehabilitation, and afterwards, 30 minutes for VMR using the ABAR system. The traditional therapy and VMR using our system were composed of static and dynamic balance rehabilitation. In static balance rehabilitation, the GBS patients performed medio-lateral and anteroposterior weight transfers. In dynamic balance rehabilitation, the GBS patients performed left-monopodal and right-monopodal stance, and sit-to-stand movements. During the sessions, the participants were told to take rest periods of five minutes between virtual games. Figure 1 shows a Guillain-Barré patient playing with the ABAR system. The study was approved by the Research Ethics Committee of the Clínica de Aragón (CEICA), Zaragoza, Spain, following the ethical standards of the Declaration of Helsinki (DoH).

Both participants were given the same static and dynamic clinical tests at three points in time (baseline evaluation-T0, final evaluation-T1, and follow-up evaluation-T2). The clinical tests were related to cognitive and functional impairment, static balance, and dynamic balance.
The motor impairment clinical tests were measured at baseline evaluation: 1) an adapted and tested version of the Mini-Mental state examination (MEC-Lobo) [42], with a score of > 24 for both patients; 2) the Barthel index [43], with a score of ≥ 60 for both patients; 3) Lawton’s Philadelphia Geriatric Center Morale Scale (PGCMS) [44], (subject one = 10, subject two = 3); 4) Charlson comorbidity index (CCI) [45].

The static balance clinical tests were: 1) Unipedal stance time (UST) [46]; 2) the Anterior Reach Test (ART) [47]. The dynamic balance clinical tests were: 1) the Berg Balance Scale Test (BBS) [48]; 2) the Time “Up and Go” Test (TUG) [49]; 3) the Timed 10-Meter Walking Test (10 MT) [52]; 4) the Tinetti Test (TT) [53]; and 5) the 30-second Sit-to-Stand Test (30SST) [54].

At the end of the first training session, the patients were requested to fill out the Suitability Evaluation Questionnaire (SEQ) [55] in order to measure the usability of the ABAR system.

**Berg Balance Scale.** The BBS measures static/dynamic balance and fall risk using a 14-item objective measure, with a five-point attitude Likert scale, ranging from 0 to 4, and a maximum score of 56 points. In general, patients that have scores lower than 41 have disorders such as balance and postural control (0–20 have a high probability of falls; 21–40 have a moderate probability of falls; 41–56 have a low probability of falls).

**Time “up and go” test.** The TUG measures the total time in seconds that a patient needs to stand up from a chair, walk straight 3 meters, turn around, return to the chair, and sit down. In this test, scores greater than or equal to 20 seconds suggest that patients have problems with maintaining their balance, asymmetrical gait speed, and a high probability of falls [49] (< 20 seconds indicates good mobility; 20–29 indicates normal mobility; > 29 indicates high rates of falls). The TUG is composed of a balance section and a gait section. In this test, scores lower than 24 indicate that patients have a risk of falls (scores lower than 19 have a high probability of falls; 19–24 have a moderate probability of falls; > 24 have a low probability of falls).

**Timed 10-Meter Walking Test.** The 10 MT measures the time in seconds that a patient needs to walk straight for 10 meters. In this test, if patients have scores greater than 13 seconds, it suggests that they have limited walking ability with a high probability of falls (scores between 10 and 12.5 seconds require using walking aids; scores lower than 7 indicate patients have normal walking ability).

**Tinetti test.** The TT measures gait and balance abilities to perform specific tasks; it is composed of a balance section and a gait section. In this test, scores lower than 24 indicate that patients have a risk of falls (scores lower than 19 have a high probability of falls; 19–24 have a moderate probability of falls; > 24 have a low probability of falls).

**30-second Sit-to-Stand test.** The 30SST counts the number of times that a patient performs the movement sitting-standing-sitting without use his/her arms in 30 seconds. Outcomes for this test depend on the gender and the age of the subjects [50]. Normal scores for men ranged from 14–19 sit-to-stand cycles (60–64 years old) to 7–12 sit-to-stand cycles (90–94 years old). Normal scores for women ranged from 12–17 sit-to-stand cycles (60–64 years old) to 4–11 sit-to-stand cycles (90–94 years old).

**Unipedal stance time.** The UST measures the time in seconds that a patient stands up on one foot. Outcomes of the UST test in healthy subjects depend on age [51]. Normal scores with eyes opened ranged from 30 seconds (20–29 years old) to 14.2 seconds (70 –79 years old).

**Anterior reach test.** The ART measures the furthest distance that a patient can reach with arms outstretched without moving his feet. Scores for this test between 0 and 12 cm suggest a significant risk of falls (scores lower than 12 cm have a high probability of falls; 13–25 have a moderate probability of falls; > 25 have a low probability of falls).

**Suitability Evaluation Questionnaire.** The SEQ [55] is composed of 14 questions where the first 13 questions are answered by using a five-point Likert attitude scale (from 1 – Not at all to 5 – Very much) and the last question is an open response (Yes or No response). The SEQ tests the suitability of VMR systems on a scale ranging from 13 (poor suitability) to 65 (excellent suitability), using questions based on the enjoyment of using the system (Q1), discomfort (Q9), helpfulness in VMR (Q11), or the difficulty of performing the task (Q12). Questions Q1, Q11, and Q12 (enjoyment, helpfulness, and difficulty) have been highlighted by clinical specialists as being particularly important for the motivation of the patient. For this reason, we also wanted to highlight these particular items.

After the intervention evaluation, we measured other parameters such as falls, dizziness, and altered reality. We also measured other parameters such as the
following: body-mass index, number of drugs, calf diameter, visual/hearing impairment, education, occupation, rural/urban area, the evolution time of the illness, technical assistance in sessions (walking frame, parallel bars, English stick, chair), and hit rates in each session.

4. Results
The results obtained in both of the Guillain-Barré patients after the intervention showed improvements in different clinical tests. After the rehabilitation process, subject one was able to walk independently under the supervision of the therapist. He could go up and go down stairs as well as walk on the slope, with improvements in muscle mass and joint range in both shoulders. Nevertheless, there were motor coordination disorders in the upper limbs.

After the intervention, subject two achieved independent walking and did not need the aid of therapist. He could go up and go down stairs and walk on the slope, with improvements in muscle tone in the left ankle. However, he still had hypesthesia in fingers, soles, and the back of the feet.

The results obtained for the clinical test for dynamic balance were the following:

Berg Balance Berg Scale. The results obtained for subject one were 41 (T0), 49 (T1), and 53 (T2). The results obtained for subject two were 53 (T0), 56 (T1), and 56 (T2).

Time “up and go” test. The results of this test for subject one were 19 s (T0), 15 s (T1), and 13 s (T2), whereas the results for subject two were 10 s (T0), 10 s (T1), and 10 s (T2).

Timed 10-Meter Walking test. For subject one, the results were 23.5 (T0), 17.5 s (T1), and 14.5 s (T2). In contrast, the results for subject two were 9.2 s (T0), 8.82 s (T1), and 9.04 s (T2).

Tinetti test. For subject one, the results were 23 (T0), 26 (T1), and 26 (T2). The results for subject two were 27 (T0), 28 (T1), and 30 (T2).

30-second Sit-to-Stand test. For subject one, the results were 6 (T0), 8 (T1), and 10 (T2). The results for subject two were 7 (T0), 10 (T1), and 11 (T2).

The results obtained for the clinical test for static balance were the following:

Unipedal stance time. The results for subject one were 0.2 s (T0), 3 s (T1), and 3.5 s (T2). The results for subject two were 11.02 s (T0), 12.14 s (T1), and 15.37 s (T2), respectively.

Anterior reach test. The results for subject one were 18.6 cm (T0), 21 cm (T1), and 21.6 cm (T2). The results for subject two were 14.66 cm (T0), 15.33 cm (T1), and 23.33 cm (T2), respectively.

An overview of the clinical results is shown in Table 3.

Suitability Evaluation Questionnaire. The SEQ score for patient one was 49 (normalized score: 0.69) and for patient two was 56 (normalized score: 0.83). With regard to the specific items of the SEQ test, the results for both participants were: The results for both participants were: enjoyment-Q1 (both patients = 4), helpfulness-Q11 (patient one = 5, patient two = 4), and difficulty of the task-Q12 (both patients = 2).

5. Discussion
In this study, we have tested and analyzed a new system that is focused on the rehabilitation of Guillain-Barré patients. After an intensive training program using the ABAR system, we found improvements in both patients. In general, our results show less improvement for the dynamic clinical balance test than for the static clinical balance test.

The results for the dynamic clinical tests are explained below:

The BBS scale showed clear improvement over time for both subjects.

Our results confirm that, after the development of a specific treatment using VMR, the recovery of balance control is a reality.

The TUG test showed improvement in subject one for the three time periods (T0, T1, and T2); however, for subject two, the
results for the three periods showed no change. We think that this is due to the fact that this test mainly evaluates mobility, and the ABAR system is more focused on static clinical balance training.

In the 10 MT test, subject one showed a clear improvement over time, but subject two had no significant improvement in the follow-up period. We consider that this is due to the fact that our system does not specifically train gait disorders.

The Tinetti test showed significant improvement over time for both subjects for the intervention period (T0-T1); however, subject one no longer improved in the follow-up period. We think that this is due to the rating scale of this test; the Tinetti test evaluates balance and gait disorders, and our system specifically trains movements related to balance and postural control.

In the 30SST test, both subjects increased their recovery in all periods. This may be due to the potential of recovery in early stages from injury in relation to this specific movement, and also because the ABAR system has a specific game for training the sit-to-stand movement.

The static clinical balance tests showed significant improvements, due to the fact that the ABAR system trains tasks that are close to these tests. The results for the static clinical tests are explained below:

In the UST test, both subjects improved their recovery in all periods. We believe that this improvement is due to specific games of the ABAR system, where the patient performs weight transferences in the standing position.

In the ART test, both subjects obtained on appreciable improvement of approximately 3 cm for subject one and 8 cm for subject two. The reason for this is related to a specific game of the ABAR system, where the patient shifts his weight from foot to foot, forwards and backwards.

We consider that it would be advisable to use a long-term training program based on VMR systems such as ABAR to improve recovery in Guillain-Barré patients. Mhandy et al. [31] suggested a long-term rehabilitation treatment to improve recovery.

In the SEQ test, both subjects felt well during each session, indicating good results in important points related to VMR such as enjoyment, helpfulness, difficulty, and eye discomfort during the rest period. We consider that this is due to the fact that the ABAR system is designed specifically for retraining in the VMR process and the clarity of our questionnaire is specifically designed to test the usability in patients with motor disorders.

6. Conclusions

The goal of the present study was to test balance and postural control disorders in Guillain-Barré patients using the ABAR system. The use of VMR in patients with GBS is a novel contribution in traditional rehabilitation. The clinical and usability results demonstrate the suitability of this system for these patients. One of the main drawbacks of this study is the reduced sample, but the good results obtained encourage us to carry out a new study with a larger sample to reinforce our conclusions.

The virtual games of the ABAR system are designed to obtain improvements in static/dynamic rehabilitation. However, clinical specialists argue that it would be interesting to develop new modules to complete the dynamic rehabilitation process. For this purpose, we are developing new functionalities to cover this aspect, and we plan to integrate the new modules in a future study with more patients.

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Author contributions

S. Albiol-Pérez, J. A. Gil-Gómez, and M. Forcano-García contributed to the design of the ABAR system, the analysis of the results, and the draft of the paper. M. T. Muñoz-Tomás, P. Manzano-Hernández, and S. Solsona-Hernández contributed to the rehabilitation process and the clinical tests. Mohamed A. Mashat partially funded this contribution.

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