Enhanced Feedback in Balance Rehabilitation using the Nintendo Wii Balance Board

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***Abstract*—Balance retraining is a critical part of rehabilitation for many individuals following neuro-trauma such as stroke. The *WeHab* system described in this paper is a low-cost rehabilitation instrument suite centered around the Nintendo Wii Balance Board that has the potential to enhance rehabilitation for patients with balance disorders. Using the *WeHab* system, therapists can lead patients through normal rehabilitation exercises with the added benefit of visual biofeedback based on center of pressure location. Patient improvement can be tracked by the *WeHab* system through objective analysis of trends both within a single session and from one session to the next. Pilot data from several patients receiving inpatient therapy using the *WeHab* system at the Wound Care center at Memorial Hospital in South Bend, IN, indicate the potential benefit that the system could bring to balance rehabilitation. Specifically, the details of and results from sit-to-stand, weight-shifting, and stepping activities are presented for pilot subjects. Further expansion of the *WeHab* system is planned, including incorporation of auditory feedback. Future work also includes more structured studies of the effects of the *WeHab* system on balance recovery.**

***Index Terms*—Patient rehabilitation, Human computer interaction, Clinical diagnosis, Public healthcare**

I. Introduction

STROKE is a significant cause of disability, with approximately 6.4 million stroke survivors living outside of long-term care institutions in the United States [1]. Balance disorders are often a serious problem following stroke and other neuro-trauma that become an important focus of rehabilitation efforts. In large part, the restoration of a sense of balance represents a key return to normalcy that can make the critical difference between returning home and entering long-term care [2]. Balance rehabilitation activities often involve weight shifting, reaching, and transfers such as from sitting to standing. Evaluation criteria like the FIM (Functional Independence Measure) Instrument [3] used by Medicare and the BBS (Berg Balance Scale) [4] are employed to provide measurements of the efficacy of the rehabilitation for balance and other stroke-related disorders. These measures are subjective in nature with the test results being reliant on the perceptions and knowledge of the therapists who administer them.

Visual feedback based on objective data is one option to improve the efficacy of balance rehabilitation in stroke patients, and the use of visual center of pressure (COP) feedback as measured with a force plate has been a topic of balance retraining research since the mid-1980’s [5]. A number of studies have demonstrated that providing visual feedback yields improvements in postural sway [5, 6], symmetry [7-9], dynamic balance [10], and functional abilities [11-13], while other studies have demonstrated no improvements at all relative to therapy without visual feedback [14-17].

One method for collecting data which can be used to provide feedback is through the use of gaming peripherals. Since these devices are produced for the mass market, their cost is significantly less than that of laboratory-grade force platforms while their accuracy is still competitive [18]. The Nintendo Wii Balance Board in particular can be employed to directly measure a subject’s COP, which can be used in providing visual feedback. In other work, the Wii system has been shown to be a low-cost tool that is effective in therapy for cerebral palsy [19]. Similarly, standard Wii Fit games have been used for stroke rehabilitation through utilization of weight-shift and balance activities [20].

In this paper, the Balance Board is used as part of what is termed the “*WeHab*” system to provide visual feedback for balance rehabilitation of stroke patients. Figure 1 shows two stroke rehabilitation therapists demonstrating the *Wehab* software with the therapist on the left playing the role of the patient. The name “*WeHab*” highlights the more collaborative type of therapist-patient interaction that can result with the system’s use and alludes to both its low cost and central hardware component (“we” rhyming with both “wee” to indicate small cost and “Wii” to indicate the Wii Balance Board). Unlike the off-the-shelf software used in prior studies, the “*Wehab*” software used in this work has been custom developed, allowing greater flexibility in terms of activity difficulty level, data collection and processing, and program controls. Another novelty is that this work focuses on acute patients within three weeks post-stroke, whereas most previous research has been with stroke patients who have stabilized after their strokes. This approach has the potential to dramatically improve rehabilitation when the patients are at their most dynamic in terms of recovery. The low cost of the system also has the potential to enable more widespread adoption by rehabilitation clinics.

Fig. 1. Two therapists demonstrating the *WeHab* system. The program is run on a laptop while the main view is shown on a separate monitor. Using a Wii remote, the therapist is able to control the program.

The remainder of the paper is organized as follows. Section II reviews the approach by which the Balance Board is incorporated into rehabilitation. Section III describes the specific activities developed for the system. Section IV presents representative results from implementing these activities with acute stroke patients, and Section V provides conclusions and identifies areas of future work.

II. *WeHab* Software

The software suite used in this paper builds upon Striegel's earlier work (WiiLAB) that developed MATLAB interfaces for the Wii remote control (Wiimote) for an introductory engineering programming course [21]. The Balance Board and Wiimote interfaces are paired via Bluetooth with a normal Windows desktop or notebook allowing for a full suite of application development on the Windows platform. Once paired with the PC, events or updates from the Wiimote are pushed out asynchronously to the application via the open-source WiimoteLib [22] on which WiiLab and its successors were constructed [23]. This allows the *WeHab* software to receive data from and transmit data to the Balance Board and Wiimote, enabling their use for rehabilitation activities. Along with the Wii gaming peripherals, the *WeHab* system consists of a computer equipped with Bluetooth, a large LCD screen for displaying visual feedback, and webcams for recording audio and video data.

A. *WeHab Capabilities*

The *WeHab* system can monitor the center of pressure of a subject standing on the Balance Board, providing visual feedback as to how his/her weight is distributed. The weight load placed on the board is also measured, which proves especially important if the subject is also using a walker for support as it indicates what percentage of the subject's weight is supported with his/her legs. A trace of the subject's center of pressure can also be displayed, providing an indication of the smoothness of the subject's weight shifts. Multiple display types can be used for visual feedback. The *WeHab* system primarily uses a board display to directly indicate the subject's center of pressure and a bar display to indicate the right-left distribution of the patient's weight (both shown in Section III, Fig. 2).

Use of the *WeHab* system allows several applications that are not possible through off-the-shelf games previously used in rehabilitation.

-- Customization of activities and difficulty are possible. Commercial games used for balance rehabilitation are often at the upper limits or beyond the capabilities of the average stroke patient. By allowing a range of adjustable difficulties as well as designing activities specifically for rehabilitation needs, the *WeHab* system can more effectively help in stroke rehabilitation.

-- Multiple Balance Boards can be utilized together. This allows physical separation of left-right weight distribution (as seen in Figure 1), as well as a wider base of support for less steady subjects.

-- Webcams can capture video footage during balance rehabilitation sessions and be synced to the collected balance data. This allows the recording of more detailed information about the subject's kinematics during balance activities.

B. *Feedback and Balance Assessment*

The *WeHab* system provides feedback to both the therapist and the patient during the course of rehabilitation, objectively displaying the patient's performance. By supplying the therapist with this information, a more accurate assessment of the patient's performance may be obtained. Likewise, stroke patients, who often experience cognitive difficulties due to their strokes, may be more easily led through activities by their therapists with the use of visual cues.

Another important advantage of the *WeHab* system is its ability to improve rehabilitation balance assessment. Traditional balance assessment involves a subjective process through use of a balance metric such as the FIM or BBS. These assessments are non-therapeutic in nature; therefore they are performed as infrequently as possible in order to maximize therapy time.

During rehabilitation activities, the *WeHab* system records quantitative information about the subject's balance. The *WeHab* system provides the capability for balance assessment using purely objective measures such as the COP mean velocity (displacement amplitude over time) and the standard deviation of COP displacement [24]. These measures can also be calculated from data collected during therapy activities, improving awareness of a patient's progress without reducing therapy time. This provides therapists with more information in setting patient goals and planning therapeutic activities. Additionally, patients may also be motivated more easily to improve their quantitative balance performance score than by a therapist's qualitative performance assessment alone.

In practice, the *WeHab* system received positive reviews from both patients and therapists. The therapists appreciated receiving additional information about their patients' balance and the ability to easily lead patients through therapy activities. The patients enjoyed the visual aspect of their sessions as well as being able to see better their progress from session to session.

III. Balance *WeHab* Activities

The *WeHab* system was designed over the course of several months with direct feedback from stroke rehabilitation therapists and patients at Memorial Hospital in South Bend, IN. Therapists incorporated the evolving *WeHab* system into their normal rehabilitation activities with many stroke patients, providing their opinions about desired features and activities. Using this feedback loop, the *WeHab* system was designed specifically to serve as a tool which can be used for activities used by therapists during normal rehabilitation. The three most common activities performed using the *WeHab* system are as follows.

A. Activity 1: Sit-to-Stand Transition

After a stroke, patients frequently experience weakness on one side of their bodies, often requiring therapists to lead patients through rehabilitation activities to help them recover their strength on the affected side. When such a patient stands up from a seated position, there is a tendency to rely mostly on the unaffected limb when pushing up with the legs. During this activity, the *WeHab* system's visual feedback enables the patient to observe his/her reliance on the stronger side and allows the therapist to encourage him/her to put more conscious effort into using the affected side. The therapist can assist the patient in this activity by elevating the initial height of sitting, placing a walker in front for the patient to grasp, or simply providing hands-on lifting aid, depending on the patient's physical strength. The sit-to-stand activity is a basic task and frequently performed by patients who are at the lower end of functional ability.

Figure 2 shows the *WeHab* interface during a sit-to-stand activity. In this instance, the subject is shifting his/her weight to the left side while standing. This indicates a preference for placing weight on his/her left leg. The desired result of a sit-to-stand transition is a trace that is more centered around the vertical axis. In the bottom-right corner, the bar display is visible, indicating the subject's instantaneous left-right weight distribution, which is even at the final standing position in this instance.

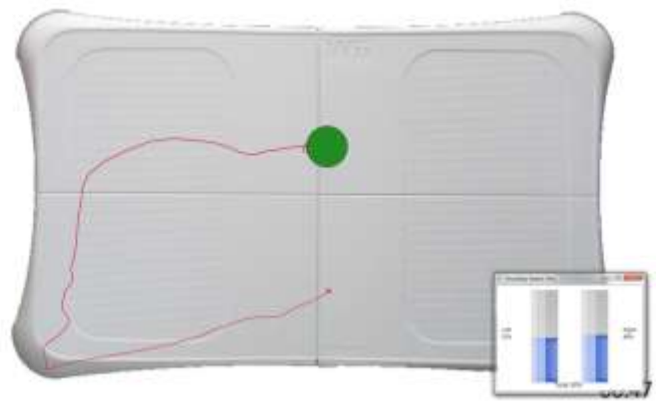

Fig. 2. The *WeHab* main display during a sit-to-stand transition.

B. Activity 2: Weight Shifting

In order to improve balance, therapists are interested in making their patients shift their weight to different positions. Lateral shifting is generally more important for balance stability, although anterior-posterior shifting is frequently incorporated once a patient is able to do basic lateral shifts. Weight shifting activities are used to give patients practice with maintaining off-center COP postures, thereby increasing their thresholds of stability. Additional support is sometimes provided by allowing the patient to place one or both hands on a walker or by the therapist's direct physical support. With the *WeHab* system, these weight shifting activities involve having patients shift their weight to a target COP range, frequently represented as a light-colored circle. Generally, the patients are required to hold at each position before moving back to a central target location or to a new off-center target. Weight-shifting activities generally require more patient stamina than sit-to-stand transitions.

Figure 3 shows the *WeHab* display during a weight shift activity. In this instance, the subject starts with his/her weight centered and is asked to shift his/her COP to a target region that is located forward and to the right. The subject's center of pressure is indicated by the small green circle and the target location is indicated by the larger light blue circle. The subject's trace is displayed to show his/her path toward the

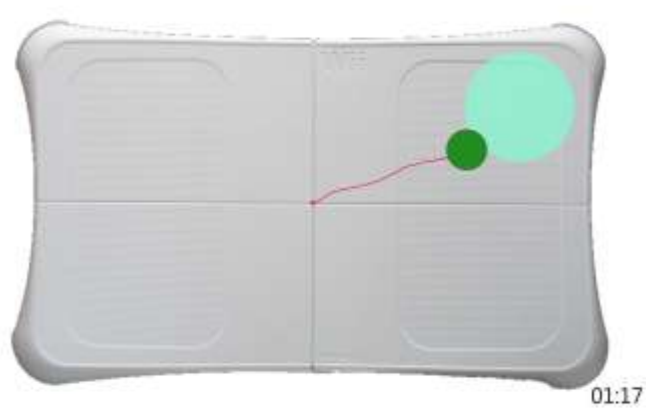

Fig. 3. The *WeHab* main display during weight shifting.

target. Once the subject has maintained his/her COP within the target region for a sufficient time (usually 5 seconds), the next target is displayed.

C. *Activity 3: Stepping*

Dynamic balance stability during walking is an important goal for stroke patients after rehabilitation. In order to improve stability and strength in walking, therapists often use stepping activities. These involve a number of activities including stepping up and down using a step, tapping a step with alternate feet, and walking up and down stairs. Stepping activities require a considerable amount of patient stamina and balance. Depending on the activity, stepping can be used to help improve motor control and muscle strength.

In one common activity used primarily for development of motor control, the patient is required to tap the Balance Board with his/her weak foot, placing no more than a maximum amount of weight in the tap (e.g. 20% or less of total body weight). This activity helps the patient improve coordination by practicing more fine-control over motion of his/her leg.

One muscle-strengthening activity involving stepping is demonstrated in Section IV. In this activity, the patient places the foot on his/her strong side onto a stool, bending the leg and raising the foot above that of the weaker side. This encourages the patient to place a greater amount of his/her weight onto the weaker leg, which can be measured by the Balance Board located under the weaker foot. Further strengthening can be achieved by having the patient bend his/her weaker knee and doing a series of shallow squats. This activity exercises the muscles of the weaker leg, helping improve patient stamina.

Figure 4 shows the *WeHab* interface during a stepping activity. In this instance, the subject has his/her left leg on the floor in front of the Balance Board and is tapping the board with his/her right foot. The maximum load placed on the board in this step is indicated to be 22% of the subject's total weight, while the subject's instantaneous load is 12%, as shown at the right side of the bars in the figure. The approximate percentage of the patient's total body weight placed on the board is shown visually in the horizontal bottom bar (10%), rounded to the nearest 5%.

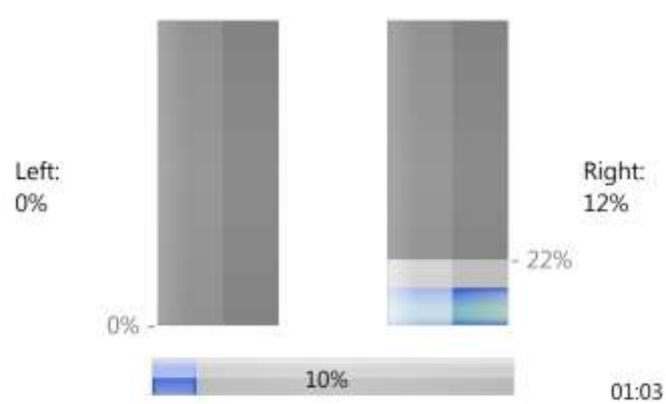

Fig. 4. The *WeHab* main display during stepping.

IV. Results

Over 20 patients have been involved in the pilot study and development stage of this work over the course of more than 40 rehabilitation sessions. Recently, five pilot subjects have gone through rehabilitation with their therapists and the *WeHab* program multiple times over the course of their hospital stay, while most of the earlier subjects only participated once or twice. These subjects included patients affected by stroke, head trauma and brain tumors, and ranged from patients who were barely able to stand to those with almost normal balance capabilities. Overall *WeHab* results were not made available to the patient or therapist at any point. Therapist and patient reactions have been positive. Therapists have especially appreciated the ability to receive quantitative data during rehabilitation sessions instead of relying on their own visual estimations of patient weight distribution.

A. *Representative Case: Sit-to-Stand*

Patient 1 participated in 6 sessions during which she performed sit-to-stand activities. This patient had experienced a stroke that affected the right half of her body, resulting in muscle weakness. When she first started, she had considerable difficulty using her right leg, and her therapist estimated that she needed about 75% assistance in tasks such as standing or transferring from a bed to a wheelchair. Her data over the course of her hospital stay are shown in Table I and presented graphically in Fig. 5.

Post-session data analysis reveals that this patient reduced the average standard deviation of the lateral component of her COP during sit-to-stand transitions over the first four therapy sessions using the *WeHab* program, indicating an improvement in performance. During the last two sessions, her average standard deviation then increased, indicating a decrease in performance. Over the course of her hospital stay, her total FIM score increased. The amount of assistance provided by the therapist during each session was not quantitatively known during the data collection period.

TABLE I
Sit-to-Stand Patient Data

Week	Date	Standard Deviation[a]	FIM Score[b]
1	8/26 [c]		5
	8/31		8
2	9/7	11	12
	9/9	10	
3	9/14	10	13
	9/16	7	
4	9/21	10	14
	9/23 [d]	15	16

[a]Indicates the average standard deviation of the patient's lateral COP position during a sit-to-stand transition. Lower values indicate better patient performance. COP positions range in value from -100 (all weight on left foot) to 100 (all weight on right foot).

[b]Indicates the total FIM score determined by the therapist. This was calculated upon patient admittance and discharge, as well as weekly during the patient's stay.

[c]Date of patient admittance

[d]Date of patient discharge

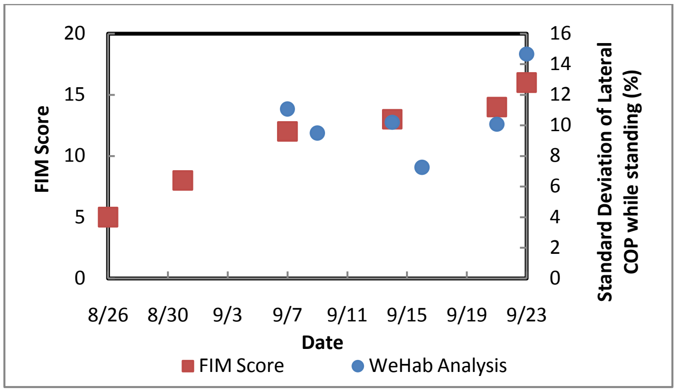

Fig. 5. Balance analysis for Patient 1 performing sit-to-stand activities using the *WeHab* system. Analysis from the *WeHab* system and traditionally-determined FIM scores are shown for the span of the patient's hospital stay. Higher FIM scores indicate better balance performance. Lower standard deviation values represent a better patient performance for sit-to-stand activities.

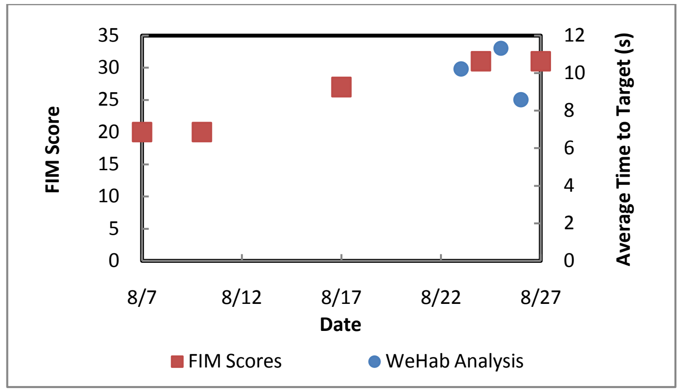

Fig. 6. Balance analysis for Patient 2 performing target sequence activities using the *WeHab* system. Analysis from the *WeHab* system and traditionally-determined FIM scores are displayed over the course of the patient's hospital stay. Higher FIM score values indicate better balance performance. Lower values for the average time to target represent a better patient performance for target sequence activities.

B. Representative Case: Weight-Shifting

Patient 2 participated in 3 sessions during which she performed weight-shifting activities. This patient had recently undergone surgery to remove a tumor from the left half of her brain and was experiencing weakness on the right side of her body. Along with balance issues, she was also experiencing double vision and wore an eye patch during rehabilitation sessions. Data from target sequence activities during her *WeHab* rehabilitation sessions are shown in Table II and presented graphically in Fig. 6.

WeHab data analysis reveals that this patient experienced an increase in average time in performing target sequences between her first and second *WeHab* therapy sessions, indicating a decrease in performance. Her last *WeHab* therapy session demonstrated a lower score than either of her previous sessions, indicating an overall increase in performance. Over the course of her hospital stay, her total FIM score increased. The amount of assistance provided by the therapist during each session was not quantitatively known during the data collection period.

TABLE II
WEIGHT SHIFTING PATIENT DATA

Week	Date	Average Time (s) [a]	FIM Score [b]
1	8/7 [c]		20
	8/10		20
2	8/17		27
	8/23	10.2	
3	8/24	11.3	31
	8/25	8.6	
4	8/26		
	8/27 [d]		31

[a]Indicates the average time required for the patient to move from one target COP position to the next. Lower values indicate better patient performance.
[b]Indicates the total FIM score determined by the therapist. This was calculated upon patient admittance and discharge, as well as weekly during the patient's stay.
[c]Date of patient admittance
[d]Date of patient discharge

C. Representative Case: Stepping

Patient 3 participated in 7 sessions, performing stepping activities during 5 of them. This patient had experienced an intracranial hemorrhage on her left side. As a result, she experienced temporary loss of use of her arm and leg on her right side. Stepping activities were used to help build up strength and control of her right leg. These activities involved having the patient elevate her left foot by placing it on a stool, while her right foot was positioned on the Balance Board. During this time, she was told to maintain at least 70% of her weight on her weaker right limb. Data from stepping activities during her *WeHab* rehabilitation sessions are shown in Table III and presented graphically in Fig. 7.

WeHab data analysis reveals that this patient experienced a decrease in average weight placed on her right leg between her first and second *WeHab* stepping sessions, indicating a decrease in performance. Her subsequent *WeHab* therapy sessions demonstrated an increasing value and ended with a higher value than she achieved during her first stepping session, indicating an overall increase in performance. The total duration of her stepping activities increased overall

TABLE III
STEPPING PATIENT DATA

Week	Date	Avg. Weight (%) [a]	Duration (m:s) [b]	FIM Score [c]
1	11/12 [d]			7
	11/23			25
2	11/30			31
3	12/3	73	00:12.3	
	12/7	68	02:07.5	34
4	12/9	72	00:50.9	
	12/14	72	02:39.0	36
5	12/17 [e]	78	02:56.0	36

[a]Indicates the average amount of weight placed on the patient's right leg as a percentage of total body weight
[b]Indicates the time duration of the stepping activity.
[c]Indicates the total FIM score determined by the therapist. This was calculated upon patient admittance and discharge, as well as weekly during the patient's stay.
[d]Date of patient admittance
[e]Date of patient discharge

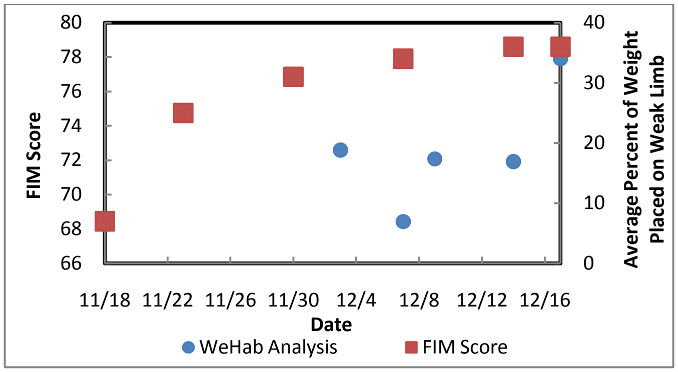

Fig. 7. Balance analysis for Patient 3 performing stepping activities using the *WeHab* system. Analysis from the *WeHab* system and traditionally-determined FIM scores are shown for the span of the patient's hospital stay. Higher FIM score values indicate better balance performance. Higher values for percentage of weight placed on the patient's weak limb represent a better patient performance for stepping activities.

throughout her sessions, although her third stepping session decreased in duration. Over the course of her hospital stay, her total FIM score increased. The patient's original stepping activities simply involved standing, while her later activities involved doing squats while standing with her left leg elevated.

D. Discussion

While the balance assessment scores determined by the *WeHab* system for each of the three subjects were not consistent with the trend in FIM scores, there are a number of factors which could influence these results.

First, as acute stroke and neuro-trauma patients are the focus of this work, there is an expected variation in patient balance performance due to the dynamic nature of recovery at the early stage. Additional studies with chronic neuro-trauma patients could provide a more stable population for evaluation of the *WeHab* system's performance.

Another factor was that the scheduling of *WeHab* sessions was completely controlled by the availability of the patients and varied in the time of day. This meant that the subjects often experienced different types and amounts of rehabilitation activities before starting the *WeHab* sessions. On one day, the *WeHab* session may have been early in the morning when the subject was better rested, while on the next the *WeHab* session may have occurred later in the afternoon when the subject was more fatigued from previous exertion. Further studies are planned using acute patients at another rehab facility which is more focused on research and willing to commit to more consistent scheduling of therapy sessions.

One more factor was that the *WeHab* balance assessment scores were calculated after all collected data had already been taken. Unlike the FIM scores, neither the patient nor the therapist were aware of the *WeHab* scores and were therefore less able to attempt to improve scores from one day to the next.

Finally, as FIM scores are required by Medicare to justify insurance expenses incurred by rehabilitation, therapists are more likely to push their patients to try hard during FIM evaluation and also are likely to experience some degree of interest in perceiving an increase or maintenance of patient performance despite any possible fatigue during evaluation. To account for this, an experienced therapist could be brought in from outside the clinic for FIM evaluations in order to provide more objective diagnoses.

V. Conclusions and Future Work

The *WeHab* system shows great promise in helping therapists improve balance rehabilitation sessions with their patients. Despite the inconclusive results obtained by evaluation of the pilot data collected during the *WeHab* sessions, positive reactions from both therapists and patients indicate that the *WeHab* system provides a perceived benefit to stroke rehabilitation. Several near-term additions are planned, including the incorporation of auditory feedback. As the *WeHab* system is refined, a more structured study of a sample of stroke patients will be initiated. A control group will undergo normal rehabilitation without any sort of feedback while the *WeHab* system collects data. Other groups will undergo rehabilitation while provided with visual feedback, auditory feedback, or a combination of the two.

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