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Evaluation of user experience of a computer vision-based stabilometry system in Multiple Sclerosis

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Abstract

Computarized posturography is a set of methods and techniques intended to provide objective measures of the balance function of a subject with postural control system alterations, in order to support diagnostic and therapeutic procedures. Modern computerized posturography systems yield accurate and reliable representations of the patient performance, such as force platform-based stabilograms (an account of the center of pressure trajectory along a balance test). However, such tests are quite expensive and usually imply uncomfortable displacements and procedures, such as marker placement protocols. As an alternative, recent developments on video-based stabilometry systems offer portable, low-cost computerized posturography solutions. This work presents an exploratory study on the user experience of the application of such systems in balance function assessment tests for both patients with diagnosis of Multiple Sclerosis and clinical personnel. The reception reported by the survey is highly positive, yet it points out that some improvements in the preparation of clinical staff to interpret stabilometry results are required, and summarized balance function descriptors could be necessary.

1 Introduction

Balance is the ability of a subject to preserve the center-of-gravity (COG) of his or her body directly above the base of support (BOS), by means of coordinated voluntary muscular actions. This function is controlled by different components such as visual, vestibular and somatosensory inputs of the human body [4]. Balance function is required to hold the posture against the influence of gravity, and allows people to perform daily living actions by themselves [3], such as walking, eating, bathing, dressing, among others [9]. Thus, the balance function assessment is a topic of interest in medical community since it is a key predictor to determine the state of the postural control system (PCS) of a subject [1], involving its evolution, recovery and intervention through physical therapy when balance disorders are present.

Despite the utility that functional balance tests have brought to physical rehabilitation evaluation and tracking, they still have several drawbacks, such as the lack of reproducibility associated to the inherent subjectivity of an ordinal scale, evaluated by an expert using direct observation of the subject performance. However, recent advances in computerized posturography (CP) technology, allow physicians to overcome these disadvantages by providing accurate quantitative data related of the postural control state. Indeed, traditional and emergent acquisition systems for CP evaluation, such as force platforms (FO), motion capture systems and electromyography, have converged into the implementation of motion analysis laboratories

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(MAL) [8], offering objective measures related to postural control such as COG, ground-reaction forces, range of motion, etc. in a non-invasive way.

The potential of computer applications to support rehabilitation of patients as well as diagnosis from physicians has been evidenced in variety of works and articles in academic publications [5]. However, most of those approaches address only one type of population at the same time, i.e. patients or physicians. For patients, some works describe the implementation of compact and portable virtual reality tools that might be used at clinic or home improving the impact of therapy but usually lacking of objective measures. In contrast, different approaches have been presented to provide accurate measures for physicians by using measuring systems e.g., FP and MAL, beside standard physical tests. However, such tests do not usually look attractive to patients because they imply large displacements (from home to laboratory) and extenuating therapy sessions.

Even though MAL systems [8] became the standard choice for balance assessment (among other uses), their implementation is rather expensive because of the high cost of their measurement equipment and their space requirements, related to work space and accuracy. On the other hand, new low-cost motion capture systems, e.g. Kinect devices [6], have been developed for human-computer interaction (HCI) and video gaming, using real time human body segmentation and skeleton tracking. Despite the motion detection in Kinect-based applications is coarse, since such software is not intended to estimate dynamic measures like COG, the kinematic data that they provide is being used in physical therapy with remarkable results for postural control assessment and rehabilitation process support.

In this context, a low-cost portable posturography system based on the Kinect sensor [2] was developed at the Universidad Central (Bogotá, Colombia) within the MSc thesis of Sosa [7], in order to provide reliable stabilograms to patients of Multiple Sclerosis (MS) with access barriers to this kind of health services. This paper presents the results of an exploratory study on the reception of such a system according to its technical and clinical features.

2 Materials and Methods

TThis work is a first approach to the evaluation of user experience reported by final users (both physiotherapists and Multiple Sclerosis patients) of the computer vision-based stabilometry system developed by our group [7], intended to support diagnostic and therapeutic intervention processes. This evaluation is carried out by surveying two focal groups: a group of patients with diagnosis of MS and a group of physiotherapists, in order to explore their reception of the proposed method and its related technological tools.

A balance test, consisting of 5 tasks from the Berg Balance scale, was performed by the patients, in order to explore the usability of the system, its potential clinical contribution in Multiple Sclerosis and the value of including stabilometry results to assess the patient evolution along the therapeutic intervention. Clinical staff (physiotherapists) were asked to grade the contribution of the balance assessment provided by the resulting stabilograms, as well as the software implementation. In parallel, patients with a neurodegenerative disease evaluated the benefits of using real time visualization tools during the execution of balance tests. For this study, the evaluation was focused on patients with Multiple Sclerosis from Fundación Colombiana para la Esclerosis Múltiple (FUNDEM) and a group of physiotherapists from Universidad Manuela Beltrán (Bogotá, Colombia). Both institutions were selected since they have a collaborative agreement with Universidad Central about the use of technological tools to support physical rehabilitation processes. The surveys for patients and physiotherapists are independent, with different evaluation criteria as described below.

2.1 Balance test and stabilogram acquisition

2.1.1 Subjects

For the selection of clinical personnel, undergraduate physiotherapy students from Universidad Manuela

Beltrán were invited to participate in the proposed study to evaluate the use of a computational balance assessment tool in physical disability. Participation of physiotherapists was voluntary and required their attendance to two different sessions: a training course to perform balance data acquisition using the postural acquisition software used for model fitting, and the evaluation of the estimated COG trajectories from patients in terms of balance function assessment.

On the other hand, the patients must be able to perform a similar balance test as the one performed for model fitting process. Thus, patients should meet the following requirements for a proper balance test execution.
Inclusion criteria: Adult people with a Multiple Sclerosis condition with less than 20 years after onset, able to perform at least 3 exercises included in the proposed balance test without assistance. 20 years or less is recommendable since Multiple Sclerosis has not reached a severe condition.
Exclusion criteria: People unable to hold upright position without assistance, or with a cognitive limitation that might interfere with a proper understanding of the balance test execution.

2.1.2 Balance test description and protocol

Patients must be able to perform the balance test without overexerting while following the instructions given by the specialist. In accordance to the PCS deterioration caused by MS, the functional reach test exercises were excluded, so that the balance tests consisted of five static equilibrium tasks with an execution time, based on the Berg Balance Scale: (1) standing unsupported during 1 minute with wide supporting base, (2) standing unsupported during 1 minute with feet together, (3) standing unsupported during 10 seconds with closed eyes, (4) standing unsupported during 30 seconds with one foot in front, a.k.a Tandem position, (5) standing unsupported on one foot during 10 seconds or more.

Balance test for Multiple Sclerosis patients:

1. For each test, an informed consent should be given to the subject informing theobjective of the test, some recommendations and involved risks, e.g. falling.
2. Check the subject meets the established inclusion and exclusion criteria.
3. The subject is positioned onto the platform in frontal view respect to the Kinect.
4. The first exercise is explained to the subject informing its correct execution andduration.
5. Subject is asked about if is able to perform the task without assistance. In caseof negative answer, proceed to explain next exercise.
6. If subject can perform the task, its execution starts at the same time as Kinectacquisition.
7. After the task is finished, the acquisition is stopped and exported to a file, thesubject can rest in standing position onto the platform.
8. Subject is asked if requires more time for resting or even stop the test.
9. If subject can continue, repeat steps 4 to 8 for each of the exercises in the test.
10. End the balance test for that subject. Next one must be ready to perform thesame acquisition protocol.

During test execution, platform measures are not required since the model was already fitted at this stage. However, the acquisition space was set to provide similar conditions, in terms of patient location and Kinect device orientation, in order to obtain reliable COG estimations by means of the fitted model. To supervise patient physical effort, the execution protocol must follow the steps described in Protocol 2.1.2.

2.2 Evaluation of acceptance

This qualitative evaluation consists of two independent surveys given to patients and physiotherapists separately, each divided in two different parts. The first section evaluates the use of a technological tool for balance information acquisition. Subsequently, the second section examines the comprehension and relevance of the COG estimations given by the proposed regression model in terms of balance assessment. Each of the surveys are further described below.

2.2.1 Survey for patients

EThe patient-oriented survey includes 6 questions, 3 of them to be answered after balance test execution and the remaining 3 after discussing the test results (estimated stabilograms). So, the first 3 questions evaluate the acceptance of the Kinect and the data acquisition software during the balance test execution in terms of comfortability, and potential benefits in comparison to traditional balance assessment sessions. On the other hand, last questions evaluate their understanding about the COG trajectories explained by an expert and the contribution of objective balance measures to make physical rehabilitation procedures more attractive. The survey instrument was designed an applied as follows:

1. Answer after balance test execution
   (a) The test execution does require additional effort (physical or mental) in comparison to traditional assessment
   (b) The use of technological tools makes balance test execution moreattractive
   (c) Which are the principal contributions about the use of technologicaltools for balance assessment

2. Answer after results presentation
   (a) The presented results are understandable and can be associated withactual balance function state
   (b) The visualization of objective measures makes the diagnosis from anexpert more understandable
   (c) Assuming the permanent availability of these kind of tools in differentscenarios. Which of the following actions would you be willing to perform in terms of physical rehabilitation?

2.2.2 Survey for physicians

The instrument given to physiotherapists also has 6 questions, 3 to be answered after a balance test data acquisition, and 3 after a visual examination of the stabilograms (COG trajectories) yielded by the model, in terms of balance and postural control assessment. First 3 questions assess the software usability to perform postural data acquisition and explore their opinion on the sufficiency of the acquired data to estimate balance measures. Last questions examine the comprehension of the obtained results after visual inspection and their potential contribution for balance function assessment in comparison to standard functional balance test such as Berg Balance Scale. In those last questions, clinical staff are also asked about the inclusion of new measures, or visualization elements, able to be constructed from postural data, as expert hints for further development. The corresponding questions are:

1. Answer after balance test execution
   (a) Could you use the acquisition tool without significant interference in comparison to regular assessment procedures?
   (b) Do you understand the nature and the relevance of the acquired measures?
   (c) Do you consider that acquired measures are representative of the patient balance function?

2. Answer after results visual examination
   (a) Do you consider the presented results useful and comprehensible?
   (b) Do you think that presented results provide additional information to the balance function assessment in comparison to traditional balance test such as Berg Balance Scale?
   (c) Would you add, modify or remove elements regarding to the presented results?

3 Results

A group of six patients with Multiple Sclerosis from FUNDEM were enrolled in the study (Table 1), which were assessed by two physiotherapists from Universidad Manuela Beltrán operating the same Kinect-based acquisition tool, without the need of a force platform (due to the model is already fitted). After acquisition, the data was processed by the neural network model implemented in the server machine used for experimentation, then, the estimated COG trajectories are presented to physiotherapists for their visual examination and PCS state description.
In terms of the subjects included in the study, the information presented in Table 1 show a predominance of women, with a time after onset no greater than 20 years, in accordance to the prevalence and symptomatology described for Multiple Sclerosis in the literature review. Respecting to the physiotherapists present in the study, one is an undergraduate student and the other is a teacher with an important clinical experience.

3.1 COG trajectories for patients

One important component in the study is the generation of postural measures, i.e. stabilograms, with a low-cost acquisition tool, such as Kinect, able to support the objective assessment of balance function in people with a physical impairment. In that context, all the MS patients performed a set of 5 static balance exercises while being recorded by the Kinect sensor in presence of at least one physiotherapist.

Table 1: Gender, age and time since MS onset for each of the patients included in the focal group:

Patient	Gender	Age (years)	Years after MS onset
1	female	43	5
2	female	55	17
3	female	50	15
4	female	46	8
5	male	35	10
6	male	63	18
	average	**48.67**	**11.3**

he data collected by Kinect was then processed by the regression model to produce a set of stabilograms (Figures 1 and 2) for patients 1 to 6 presented in Table 1; 28 stabilograms were obtained since two of the patients were not able to perform the last exercise (i.e. standing on one foot), due to the balance deterioration (these are labelled as "no data" in Figures 1 and 2). In all cases, stabilograms were plotted over a specific area of 8 × 8cm2 to visualize sway paths in detail, as well as to make direct comparison among the exercises for a singular subject or one exercise for different patients.

As expected, the COG trajectories obtained from patients exhibit wider sway paths in comparison to those previously obtained for healthy subjects. It can also be observed that some stabilograms lie out of the limits defined by an 8 × 8cm2 area corresponding to the presence of momentary strong posture compensations during exercise execution or the inability to hold the standing position for the required time.

3.2 User acceptance survey

3.2.1 Survey results for patients

Patients were also asked to fulfill the survey instrument, consisting of a set of three questions (Table 2) to examine their reception to the inclusion of technological tools during balance assessment sessions. Later, after a brief discussion with their physiotherapist on the stabilogram results, patients were requested to answer three further questions (Table 3) to know how the presented measures may contribute to the awareness of their own balance state.

Results in Table 2 reveal that, in most cases, the introduction of a technological tool does not imply less effort by the patients to perform balance test. In just one case, the patient felt that balance test execution was harder using the Kinect device. However, all patients agreed on the inclusion of technology makes the test execution more attractive and they pointed out some advantages such as the introduction of new technology (5 of 6 agreed), visual-feedback about their current performance (3 of 6 agreed), a playful atmosphere (2 of 6 agreed) and the portability of the system (1 of 6 agree).

Additionally, the results in Table 3 show that all the patients were able to fully understand their balance performance in function of the presented stabilograms and, in most of cases, such representation makes diagnosis easier to understand. Finally, the patients expressed some of the potential advantages of this technological approaches in the support of their therapeutic procedures, including: attendance to

Table 2: Survey results for patients after performing balance test

Question	Answer choices	Results
The test execution does require additional effort (physical or mental) in comparison to traditional assessment?	No, it was easier to perform	0
	No, it demands the same effort	5
	Yes, it can be performed with more effort	1
	Yes, it cannot be completed	0
The use of technological tools makes balance test execution more attractive?	Yes, completely agree	6
	Does not make any difference to me	0
	No, their use is troublesome	0
	No, their use can be dangerous	0
Which are the principal contributions about the use of technological tools for balance assessment?	Use of new technologies	5
	Visual feedback	3
	A playful atmosphere	2
	System portability	1
	High benefit-cost ratio	0
	Others	0

3.2.2 Survey results for clinical personnel

On the other hand, the physiotherapists who participated in this study were asked to answer some questions about the potential benefits of the proposed technology for objective balance function assessment. After the training session, intended to learn the manipulation of the Kinect-based acquisition system, they were asked about the usability of the software for postural data acquisition, as well as their comprehension regarding to the reported measures (Table 4). Upon visual inspection of the stabilograms yielded by the system, the remaining questions in the survey were performed to know the specialist point of view about the utility, understandability and completeness of the measures in the context of balance assessment.

Table 3: Survey results for patients after seeing stabilogram results explained by an expert

Question	Answer choices	Results
The presented results are understandable and can be associated with actual balance function state?	Yes, results were completely understood	6
	Yes, results were generally understood	0
	No, results were hard to understood	0
	No, results were not understood at all	0
The visualization of objective measures makes the diagnosis from an expert more understandable?	Yes, completely agree	5
	Yes, partially	1
	No, visualization might be not necessary	0
	No, they are inconsistent with diagnosis	0
Which of the following actions would you be willing to perform in terms of physical rehabilitation?	More regular therapy sessions	6
	Spend more time in each therapy session	3
	Perform more demanding therapy sessions	3
	Perform physical exercise at home	3
	Perform therapy sessions with better attitude	5
	Recommend therapy supported by technology	3
	Others	0

Table 4: Survey results for clinical personnel after postural data acquisition training session

Question	Answer choices	Results
Could you use the acquisition tool without significant interference in comparison to regular assessment procedures?	Yes, the tool is easy to use	0
	Yes, it can be used efficiently after training	2
	It cannot be used properly	0
	No, it cannot be sued at all	0
Do you understand the nature and the relevance of the acquired measures?	Yes, I understand their nature and relevance	2
	I only understand the nature of measure	0
	I only understand the relevance for diagnosis	0
	No, measures cannot be understood	0
Do you consider that acquired measures are representative of the patient balance function?	Yes, measures are fully representative	1
	Yes, in conjunction with other measures	1
	No, they are insufficient to assess balance	0
	No, they do not provide any useful information	0

Results in Table 4 show that a training session was needed to manipulate the acquisition system efficiently without interfering a traditional assessment procedure. Yet, both physiotherapists were able to understand the nature and relevance of the obtained measures for balance assessment. However, just one of them consider postural data as a representative measure of balance, whereas the other one felt that measures are only representative of the balance function in conjunction with complementary measures.

Furthermore, concerning to stabilogram interpretation, the results in Table 5 indicates that both physiotherapists agree on the visualization of COG trajectories are useful and provide an enhancement of balance assessment, although in a moderate degree, since stabilograms are hard to be interpreted visually. Additionally, there one of the physiotherapist suggested a modification to the stabilogram visualization, consisting on the incorporation of additional guidelines to make spatial interpretation more clear.

4 Discussion and conclusion

This work reports a preliminary study to approach the potential contributions of the method associated to the system in a clinical scenario. In fact, the underlying motivation of this work is related to the development of tools and measures able to provide objective diagnosis and disease progression tracking support for people involved in physical rehabilitation processes, i.e. patients with physical disabilities and the clinical staff in charge of their treatment.

Table 5: Survey results for clinical personnel after visual inspection of estimated stabilograms

Question	Answer choices	Results
Do you consider the presented results useful and comprehensible?	Yes, they are useful and easy to understand	0
	They are useful but hard to understand	2
	They are comprehensible but not useful	0
	Results are incomprehensible and not useful	0
Do you think that presented results provide additional information to the balance function assessment in comparison to traditional balance test such as Berg Balance Scale?	Yes, they enhance assessment in high degree	0
	Yes, they enhance assessment moderately	2
	No, they provide the same information	0
	No, they do not provide relevant information	0
Would you add, modify or remove elements regarding to the presented results?	Yes, Which one?	1
	No	1

In this context, a subsequent stage of postural data acquisition and stabilogram generation was performed on six patients with diagnosis of Multiple Sclerosis from FUNDEM, assisted by two physiotherapists during the execution of a functional balance test. The corresponding evaluation was carried out by analyzing the COG trajectories estimated by the model beside the results of two independent surveys, fulfilled by both patients and physiotherapists.
For patients, the introduction of this type of technological systems does not represent a physical aid to improve balance ability, but a tool able to provide an attractive and entertaining environment that makes therapy sessions more bearable. This is an important result from the patient oriented survey, since the positive impact of physical rehabilitation as it contributes to palliate physical deterioration, highly depends on the consistency and regularity of diagnostic and therapeutic sessions. Furthermore, there are some additional features that can be provided by the Kinect-based technology such as the mirror-effect, which has shown to improve therapeutic effectiveness in physical rehabilitation processes. System portability also allows postural data analysis in a variety of scenarios outside specialized laboratories, such as home or consulting rooms.
Respect to the balance performance report, based on the analysis of COG trajectories, the patient feedback was quite positive. In summary, patients considered their corresponding stabilograms as a helpful visual aid to understand their own function balance state. This information could stimulate their performance in more rigorous therapy sessions with a better disposition, as it was declared by the patients in the survey.
On the other hand, for clinical staff involved in physical rehabilitation, the operation of the proposed system to perform postural data acquisition does not imply high skills to be used properly, though, it requires some previous training. Additionally, the survey suggested that estimated stabilograms as balance function assessment support were hard to interpret by direct visual inspection if used alone. This result was not completely unexpected given that stabilograms do not constitute a balance function biomarker by itself. Hence, it involves high levels of subjectivity that may be related to the way COG trajectories are visualized.

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Annexe

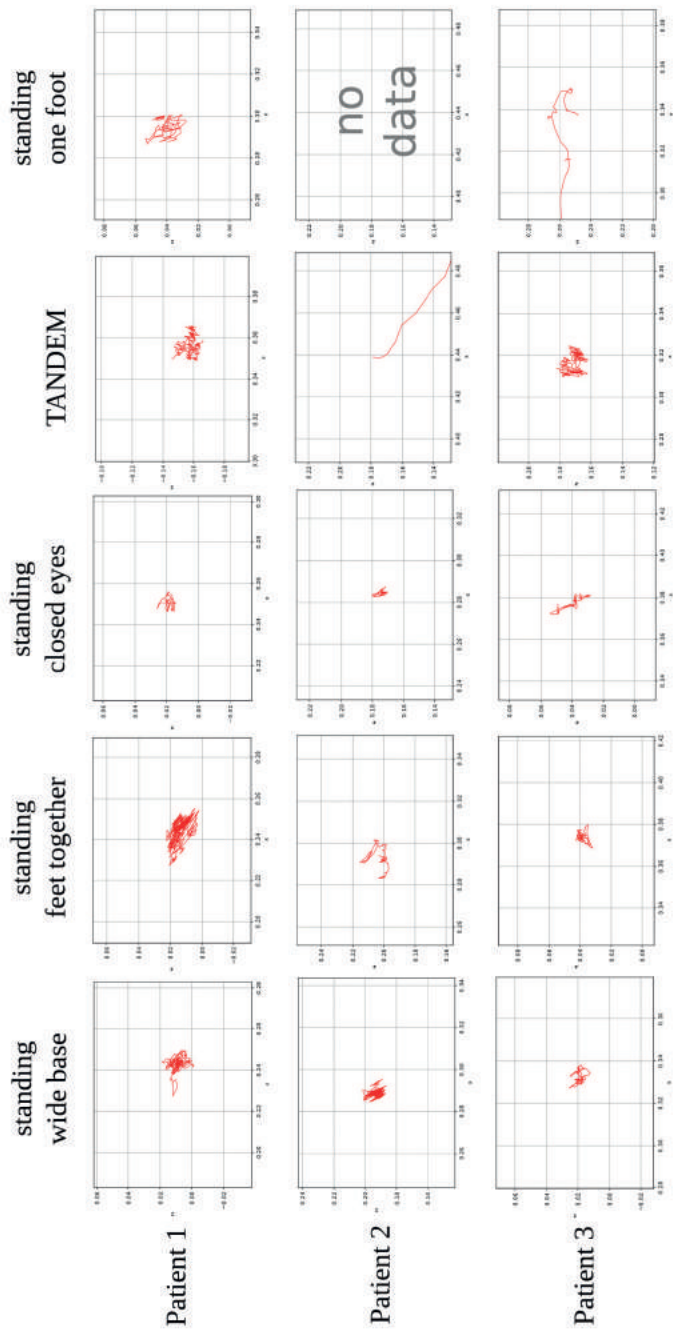

Figure 1: Patients 1 to 3

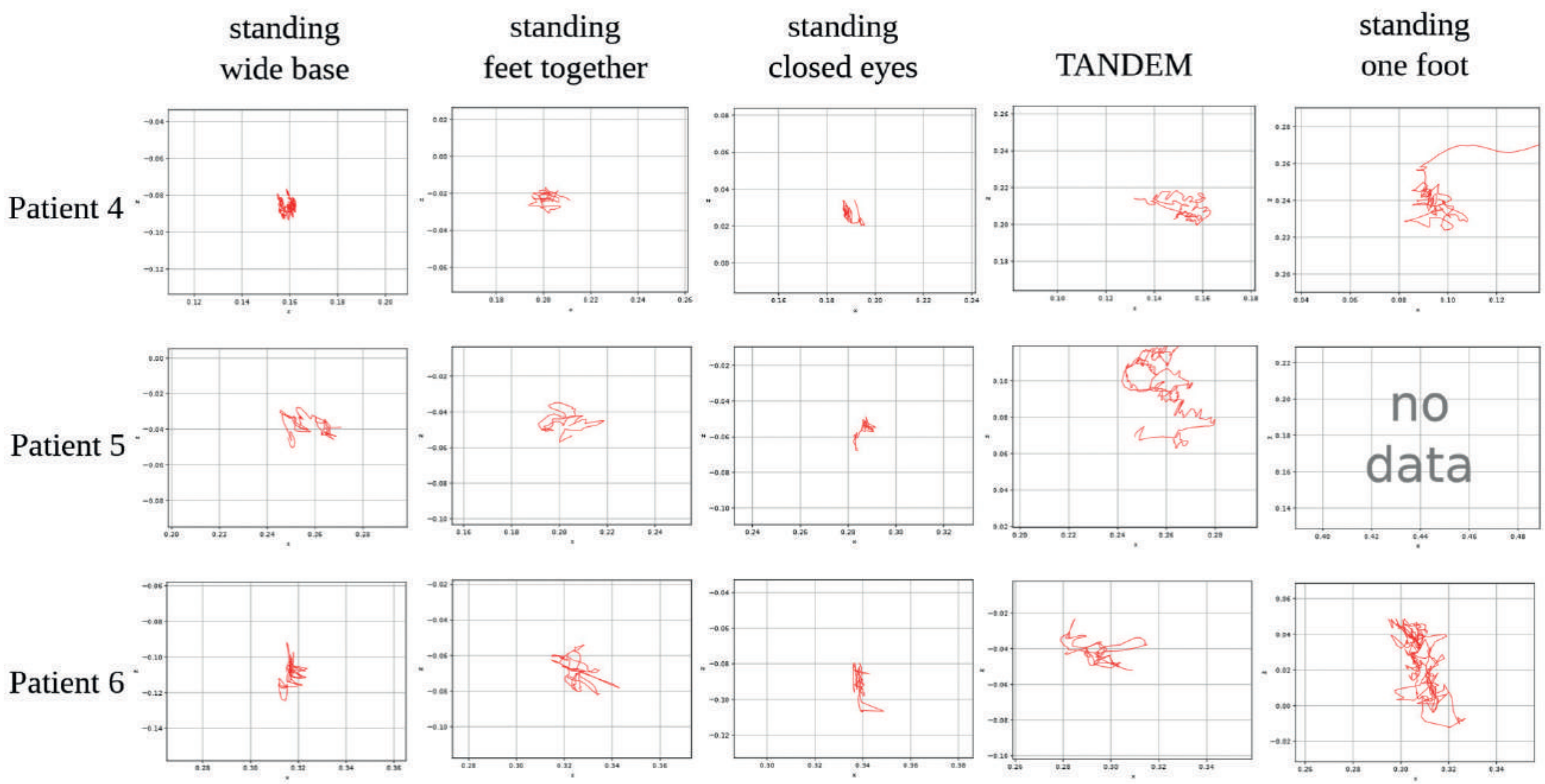

Figure 2: Patients 4 to 6