TALLINN UNIVERSITY OF TECHNOLOGY

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EVALUATION OF MOBILITY AND RELAPSES WITH WIRELESS MOTION SENSORS ON MULTIPLE SCLEROSIS PATIENTS

Master’s Thesis

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SCLEROSIS MULTIPLEX'I DIAGNOOSIGA HAIGETE LIIKUVUSE HINDAMINE KODU-MONITOORINGU UURINGUS

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Author´s declaration of originality

I hereby certify that I am the sole author of this thesis and this thesis has not been presented for examination or submitted for defense anywhere else. All used materials, references to the literature and work of others have been cited.

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01.04.2019

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Abstract

Multiple Sclerosis (MS) is a neurological disease that may arise in any stages or years of adulthood, from early to middle ages. It involves either genetical or environmental factors and has a direct impact on movement and ability to function normally. The disease affects personal and healthcare system finances due increase of medical visits, and the costs for the patient associated to disability. To improve on waiting times for specialist visits and make it easier for both parties to monitor the disease, an innovative solution could be implemented. Health monitoring through sensors and other uses of new technologies and devices at home helps to capture changes in mobility and balance, and to evaluate remotely the progression of the disease.

This pilot study has been conducted to monitor patients with low EDSS score (0-3) and evaluate relapses in the patients with the disease. The patients were shown the tests needed to be conducted in order to monitor their results and were given the motion sensors to take home. Once the patients started to do the learned tests, doctors were able to see remotely all the data generated by the patient's tests from home.

As a result of the home tests, most of them had no signs of relapses and since they had minimal to no signs of disability, the need for additional consultation due to relapses seen in the data was not necessary. However, most of the patients had difficulties at the time of taking the tests. The addition to a new step in the daily routine of some patients was a burden which made them forget to do the tests. The overall absence of data for some days creates an issue with data consistency which makes it difficult for the doctor to determine accurately when a relapse is seen.

Annotatsioon

Multipleksskleroos (MS) on neuroloogiline haigus, mis võib ilmneda täiskasvanu ea algus- või kesketappis. Haigus tuleneb geneetilistest või keskonnalistest faktoritest ning mõjutab otseselt inimese võimet liikuda ning normaalselt funktsioneerida. Suurenenud meditsiiniliste külastuste arvu ning kulude tõttu, on haigusel suur mõju nii indiviididele kui ka riiklikele finantssüsteemidele. Võttes kasutusele innovaatiline lahendus, on võimalik parendada spetsialistide visiitide ooteaegu ning muuta haiguse jälgimine paremaks mõlemale osapoolele. Tervise kaugmonitoorimine sensorite ja teiste uute tehnoloogiate ning seadmete abil aitab talletada muutusi liikumises ning tasakaalus ja hinnata indiviidi haiguse kulgemist ning progressi.

See pilootuuring viidi läbi jälgides ning hinnates madala EDSSi tasemega (0-3) patsientide haigushoogude kordumist. Patsientidele anti vajalikud sensorid ning tutvustati vajalikke teste, mida oli vaja kodus läbi viia, et jälgida nende tulemusi. Kui patsiendid õppisid ära kuidas vajalikke teste kodus läbi viia, võimaldas see arstidel kõikide testide andmeid eemalt jälgida, mida patsiendid kodus läbi viisid.

Kodus läbi viidud testide tulemusena selgus, et enamus patsientidel ei esinenud korduvaid haigushoogusid. Kuigi patsientidel oli raskusi testide läbi viimisel, esines neil vähene või olematu halvatuse määr, mis tähendas, et kogutud andmete kohaselt ei olnud patsientidel vajadust lisa arsti konsultatsioonide jaoks. Igapäevane lisakohustus patsientide rutiinis osutus osadele patsientidele liialt koormavaks ning seetõttu unustati teste igapäevaselt läbi viia. Igapäevaste andmete puudumine tekitab arstidele raskusi korrektselt hinnata millal haigushood korduvad.

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1 Introduction

Multiple sclerosis (MS) is a chronic disease of young adults affecting over 2.3 million people worldwide. MS causes neurological disability affecting multiple systems. Patients with this disease frequently develop problems with walking, balance, muscle tone. During the course of the disease functional mobility may become affected influencing physical independence and the overall quality of life (17).

Chronic diseases have complex needs which frequently require services from different health care practitioners in multiple settings including frequent visits to doctors and other specialists. Technology offers the possibility for patients with chronic conditions and complex needs to be followed at home and maintain an acceptable quality of life (15).

Various technologies with sensors have been developed in later years to track movements. One of the options are wearable sensors that can utilize miniaturized accelerometers and/or gyroscopes. These provide direct measurement of the acceleration and angular velocity of body segments to which they are attached and can be used to evaluate movement patterns and speed (16). These small devices are unobtrusive and can provide precise insight into the patient's physical activity. With the frequent advances in technology there has been an increase in the development of objective methods to allow continuous monitoring of the daily physical activity of populations (18).

A few studies have examined the reliability of functional activity measured with an activity monitor at home in people with degenerative diseases while performing daily activities and analyzing movement by placing sensors in different parts of the body. Pedometers have also shown to be useful to track and evaluate patients with MS, however, some devices may need to be professionally supervised constantly or can only be controlled under laboratory conditions (18).

Having a walking impairment has been considered as the most visible sign of functional disability in patients with MS and it can decline in early stages of the disease which prompts recent researches to be targeted to understand the correlation between disability, accelerometer output, and walking impairments (18).

Internet and mobile health technologies can ease and promote the reporting of symptom and simplify patient-centered care by collecting regularly health related information with a low cost, which allows to change the patient role through new access to data and control. MS is a promising target for mobile health technologies because of the gradually progressive nature of the disease, the unpredictability of relapses, and the importance of continuous assessment (9).

2 Multiple Sclerosis (MS)

MS is a chronic inflammatory disease that affects young to middle aged adults (1). The inflammation is the product of the self-damaging action of the immune system (autoimmunity) on the white matter of the central nervous system (CNS), which first results in the destruction of myelin. The symptoms and signs of the disease are different and depend on the affected areas of the CNS. MS can cause some symptoms loss of balance, muscular weakness, visual problems, bladder dysfunction and some general symptoms like fatigue, cognitive problems and other impairments that influence the patient's autonomy and quality of life (4).

There is no one factor that causes MS. The current data suggests that certain environmental factors in genetically susceptible background predisposes an individual to MS. Studies that include families and assess the risk in relatives suggest that first-degree relatives are 10–25 times at greater risk of developing MS than the general population but it is a general agreement that MS is not a genetic disease (1).

2.1 Symptoms

The symptoms of MS are dependent on CSN damage and are multiple. The hallmark of the disease is the relapsing-remitting course. Relapsing -remitting course means that new neurological symptoms occur and remit spontaneously in the beginning of the disease. Relapsing-remitting course is typical at onset of MS in about 90% the patients with MS. However, in about 10% of all MS patients the course is progressive since onset. Unfortunately, even in relapsing remitting MS in nearly 25-30% the disease starts to progress with or without superimposed relapses. Symptoms, which depend on the location and extent of the lesion and destruction of the tissue, can range from mild to severe depending on the extent of CNS tissue destruction.

Common symptoms of worsening of the disease (relapse or attack) can include numbness, tingling, weakness of hands and/or legs, problems or loss of balance, blurred vision, double vision, lightheadedness, and bladder or bowel dysfunction. Facial weakness, hearing loss, and speech impediments are not very common (19).

2.2 Diagnosis

The diagnostic standard for the disease has evolved over time. New disease diagnostic standards and criteria were established in 2001 and revised in 2005 and later again in the year 2010 and most recently in 2017 (published in 2018).

These new diagnostic criteria allows to make a diagnose significantly earlier which is very important since the drugs that can modify the disease are most effective when treatment is initiated early in the course of the disease. Not to mention that a delay in the treatment and drug administration may result in irreversible neurologic deficit.

The diagnosis needs at least one episode of neurologic dysfunction with inflammation and demyelination that happens without fever or infection and lasts for at least 24 hours along with objective evidence of lesions. This can be proven clinically by performing a magnetic resonance imaging (MRI) and cerebrospinal fluid testing (19).

2.3 Progression

Although the course of MS is impossible to predict in an individual patient, usually females that are at a younger age with little to no disability after five years symptoms appeared are generally favorable prognostic signs.

In contrast to that, males at an older age that experience frequent attacks early in the course of the disease, with a short interval between the first 2 attacks, do not recover completely from the first attack, experience disability rapidly, and progressive disease from onset are associated with worse outcomes (19).

Some patients may present a very mild form of MS with almost no disability for at least 10 years and even 20 years after disease onset is referred sometimes as a benign form of the disease. However, many patients will still develop disability over time and enter the secondary-progressive phase of the disease within 20 years or later. There is no reliable way to predict which patients will continue to have a mild form of the disease. There is a consensus that early treatment and monitoring the efficacy of the treatment plays a crucial role in determining the prognosis (19).

In addition, in order to prevent the progressive course of MS, it is also required to monitor early and timely evaluate and treat relapses in order to reduce or delay the possibility of loss of function that is often developed during the advanced stages of the disease (7).

2.4 Home Based Monitoring and the importance in Multiple Sclerosis

Home monitoring of chronic diseases looks to be a promising patient's management approach. This produces scientific data, as well as empower the patients and influence their attitudes, behaviors, and could improve their medical condition (11). If these technologies and nowadays easy access to devices can make it easier and further recruit participants for the collection of data, it can contribute greatly to the further advancement of studies of preventive strategies and treatment for the population based on collected evidence (12).

Multiple sclerosis (MS) is an example of a lifelong disease that responds well to continuous and coordinated care with the health providers (5).

Health care that is focused in patient care has helped the patients and practitioners to find common ground, and the use of monitoring symptoms electronically can improve overall quality of life (8).

When a patient-centered approach is used the patients go for health care services less often, which in correlation, reduces the cost associated to the frequent visits. For these reasons, both aspects are part of an agreed and desired vision for the future of the care of MS.

2.5 Disease Monitoring and Self-Management

In clinical practice, as mentioned earlier, disease activity monitoring means frequent visits to clinics. According to Estonian MS treatment guidelines the frequency of visits to treating physician have to be performed every three months (21). Due to recent advances in treatment more than 75% of patients are free of permanent disability even after 20 years. Therefore, it is clear that many patients with MS have to visit clinics three-monthly during 20 years without clear medical need.

Many tools have been developed to help monitor the disease and help with self-management. One of the major challenges that physicians and patients with MS face is how to organize, integrate, and interpret medical data to track development of MS relapses and the progression of the disease, to personalize the treatment without over-burdening the medical care (10). On the other hand, health care that is focused in patient care has focused on the use of monitoring symptoms electronically to improve overall quality of life of MS patients. This will help to decrease the burden of frequent (often unnecessary) medical appointments (8).

When the patient-centered approach in technology is used, there is less use and need of health care services by patients, and it results in correlation with the reduction of the costs associated to the frequent visits. For these reasons, both aspects are part of an agreed and desired vision for the future of the care of MS.

Internet and mobile health technologies can ease and promote the timely reporting of new symptoms and simplify patient-centered care by collecting regularly health related information with a low cost. This approach allows to change the patient role as well through access to data and control. MS is a very promising target for mobile health technologies because of the spontaneous, unpredictable and unforeseen relapses and for many patients, also, to evaluate gradual progression nature of the disease (9).

Over 80% of patients with MS use and have access to the internet weekly and 90% can navigate an electronic health record, making internet-based interventions technically feasible in MS (10).

The ability to provide feedback and monitor the patient's health wirelessly as they make exercises, practice skills, walk and fitness while the physician is in their office may be an efficient and effective alternative strategy for the delivery of the care needed (14). Technology such as the internet, smartphones, computers, sensors, and home-based monitoring devices can be used to support data collection also during large-scale clinical studies. This type of access to technology is also being used increasingly by middle age and older adults since it provides them opportunities to be included in the research. If these technologies and nowadays easy access to devices can make it easier and further recruit participants for the collection of data, it can contribute greatly to the further advancement a study of preventive strategies and treatment for the population based on collected evidence (12).

Home monitoring of chronic diseases looks to be a promising patient's management approach that could produce scientific data, as well as empower the patients and influence their attitudes and behaviors and could possibly improve their medical condition (11).

2.6 Telerehabilitation

Telerehabilitation has been developing quickly during the last 10 years and is now moving from one-person cases or small sample researches to controlled trials with larger patient study groups. The financial effectiveness of telerehabilitation is still being discussed. Although the number of studies that evaluate interventions of telerehabilitation are arising, reports on using the technology with MS are limited (13).

Physicians who treat chronic diseases frequently face the following problems: measuring gains and losses of daily motor function over time, assessment of the timing and dose effects of a medication on target symptoms related to motor function, being able to order enough physical therapy to maintain or improve normal daily activities, assessing if the patient is following the instructions for exercise and skills practice, providing enough feedback about performance of that practice, and being able to update instructions more frequently than only once per clinic visit (14).

The ability of a patient to follow with the mandatory practice and exercise can be estimated daily and the information of interest can be immediately available to a therapist or physician. Feedback about performance from data that sensors collect over weeks or months or years can be provided by graphs and text over a smartphone or computer.

Remote monitoring of daily activity may serve as a physiological measure of wellness or decline in health (14).

3 Motion sensors for Multiple Sclerosis patients

3.1 Aim of the Study

The aim of the pilot study was to test if sensor measurements of critically important neurological symptoms typical of MS are feasible at home. Specifically, tests of balance (Romberg test), leg speed, jumping and sensorless hand strength tests were chosen as the same measurements are part of everyday clinical practice.

The aim was to evaluate MS patients with little or no disability as the main target group for personalized treatment decisions. the EDSS score in this group was from one to three, which indicates minimal to no disability.

3.2 Description of the study group

The pilot study conducted for this project was carried out by the author with the help of Dr. Katrin Gross-Paju, Merje Siiro MsC and Kadri Taafeld MsC at the Astra Clinic at Kotka Health Center (Kotka Tervisemaja). The approval from Ethics Committe was previously obtained for the study and all patients signed a written informed consent prior to testing.

Study group was established following the criteria:

- Patients with diagnosed Multiple Sclerosis
- No relapses within last 3 months
- EDSS score is between 0-3 indicating patients with minimal to no disability (22).

All patients were selected after completing the Romberg test (for balance), leg speed test (for leg strength), 1 leg jump test (leg strength) and the Nine-Hole Peg Test (indicating hand function) The performance of the test battery takes less than 10 minutes.

21 persons with MS participated in tests performing different clinic-based assessments and 9 patients (8 females and 1 male) took part in this pilot study (Table 1).

One of them was excluded due to unwillingness to continue with the study.

	Sex	Age	Disease duration (years)	EDSS score	BMI (body mass index)
User 11	F	35	3	3	27,8
User 14	F	32	9	2	24,4
User 15	F	44	4	2,5	35,7
User 16	M	28	13	2,5	23,4
User 17	F	40	21	3	24,3
User 18	F	35	7	3	25
User 19	F	51	14	1	22
User 20	F	21	4	1	17,3
User 21	F	29	13	2	20,7

Table 1. Data of all patients (Users) that participated in the pilot study.

3.3 Methods

All patients were shown the tests and were trained at the Astra Clinic to perform the tests at home. The app that recorded the measurements was attached to the sensor was only working in Android devices. Patients who had their own Android smartphones were able to configure the app and take the tests at home right away. Patients who did not had an Android smartphone were provided with one from the clinic.

Patients were asked to perform the tests for 7 consecutive days in a week at first, and after that only repeat the tests once a week. This allowed patients to assess their condition at home. Collected data from the sensors was received at the specialist's office through the app. The data were transferred to a website, where the information was seen and analyzed by professionals.

After the first 7 consecutive days of incoming data from the patient's test, the calculation of individual mean values and standard deviation was calculated. This was done all in Microsoft Excel. The individual data for later comparisons served as a standard value for future measurements.

The formula for evaluation individual normal limits was developed during previous studies.

The formula used to obtain the comparison number was the mean +/- (2 times the standard deviation) (mean +/- (2*SD)). Depending on the tests, the mean and the 2SD was either added or subtracted. The balance test was added (mean + (2*SD)) as higher number indicates worse result. The leg strength test and the one leg jump test were subtracted (mean - (2*SD)) as higher numbers indicate worse results. Only worsening as clinically meaningful change was significant for the current study and evaluating fluctuations towards improvement were not clinically relevant.

These calculations were not used with the Nine-Hole Peg Test.

After the comparison values (individual baseline values) were calculated, all values out of individual range were detected for each patient. For the balance test numbers that were bigger (balance was worse) than the comparison number were marked in red, suggesting an health issue or a relapse (worsening of condition), while for leg strength test and one leg jump test numbers that were lower (diminished strength) than the comparison number suggested worsening of condition. Values measured by the patient that did not satisfy mentioned criteria, were considered normal and demonstrated patients' neurological stability.

All measurements, data and values obtained from this study were analyzed for each patient individually.

The individual mean values and 2SD were calculated after the first 6 consecutive days of tests done at home.

Also, feedback given by the patients was collected and analyzed separately. Patients were asked to provide feedback on a series of questions:

1. Has your vision been good for 3 days?
2. Do you have new sensation problems?
3. How are you feeling?
4. Additional comments

3.4 Description of the device used

The main component of the device is a micro-mechanical movement sensor connected to a phone app that worked on Android devices only. The app allowed the patient to see the test that was required at the time. Then the patient completed the test and other the next test until all tests were completed.

The app along with the device measured line acceleration (m/s2), angular speed (deg/s) and average time (s) of the movement. Movement sensor is specific 5x5 mm micro scheme, also known as Inertial Measurement Unit (IMU) or Micro Electro-Mechanical Systems (MEMS). The sensor was built by the company Eliko.

All data collected with the sensor, is read by a microprocessor and transferred by Bluetooth to the patient's mobile phone. During this pilot study only one sensor was used at a time for each test. The battery of the sensor is charged by USB cable and working time with one charging is approximately a week. The device was easy to use for patients and did not need any special technology in addition.

3.5 Description of the tests

EDSS evaluation

One of the tools frequently used for disability monitoring is the Expanded Disability Status Scale (EDSS) (22).

Expanded Disability Status Scale (EDSS) is an indicator of disability. It is a functional system scale that includes motor, sensory, visual, mental and other indicators. The EDSS scale ranges from 0 (no disability) to 10 (death due to MS). Patients who score at or less than 5.5 are able to walk at least 100 m without aid or rest. Patients with score between 6.0 and 8.0 are ambulatory with limitations. Patients with EDSS score more than 8.0 considered to be totally dependent. Patients' disease severity and clinical symptoms were assessed using EDSS by a neurologist (18).

All participants were tested by a neurologist (Ulvi Thomson) who performed complete EDSS examination previously to the start of this work. Only patients demonstrating EDSS score from 0 to 3 were included in the study.

All patients participating in this study were tested and taught to work with wireless sensors. Balance, leg strength and leg jump were evaluated during test conditions with sensors.

The Romberg Test (Balance test)

This test designed to screen for problems with balance, particularly to determine disorders of orientation in space and possible disorders in the vestibular apparatus (2).

The ability to maintain balance depends of an individual's vision, the person's ability to sense movement and orientation in space, and the proper functioning of the vestibular apparatus of the inner ear. Analyzing these three factors is the basis for the Romberg test (2). For this test the patient stands with their feet together, arms either folded across the chest or down at their side, and their eyes opened for 30 seconds and later they stand in the same position with their eyes closed for 30 seconds. The patients placed the sensor on their chest and fixated it with the help of an elastic belt or, in the case of women, it could be hold in the underwear, between the breasts.

A little swinging from side to side may be seen and is considered normal. For a positive test the patient needs to be unable to maintain balance or need to move their feet for stability.

Leg Strength test (Range of Motion of lower extremities)

This test (presented in degrees) allowed to measure leg's flexibility with sequential exercises with both legs, left and right in a sitting position with the sensor attached to the thigh.

The Nine-Hole Peg Test (Hand strength)

The NHPT required patients to repeatedly place and then remove as quickly as possible nine pegs into nine holes, one at a time. Roughly, 53% of the variance in the NHPT score is explained by muscle strength, tactile sensitivity of the thumb, and presence of intention tremor (3).

One Leg Jump Test

This test (presented in seconds) allowed the doctor to assess if the patient can jump off the floor and how much time is spent "in the air" while jumping. The patient had to keep one leg folded back while jumping with the other leg. The sensor was attached to one of the subject's jumping ankle, and they jumped to assess balance and control.

4 Results from the pilot study

4.1 Results from Romberg test (balance)

The measurements from the balance test with open and closed eyes varied from 9 to 228.

Since each patient is different, as mentioned in the methodology, we will address the results for each patient individually. During home-based monitoring 8 patients demonstrated balance measurements (Romberg test, eyes opened, eyes closed) within 2SD deviations and were considered stable.

Patients did the test daily for the first week and calculated a baseline number that was compared with further testing.

In total for all 8 patients there were 252 stable measurements collected for the balance test and 17 unstable measurements collected.

Example of unstable patient for balance test: User 11

The patient demonstrated some stability issues when measuring for balance, which in the graph can be seen that there were some out of normal values. The patient was sick in January 21 and 28 for two weeks with a strong cough. The results showed that on a few days the balance was worse than the baseline. This shows how sensitive the sensor is to the slight change, and a change in behavior or feeling will change the test results.

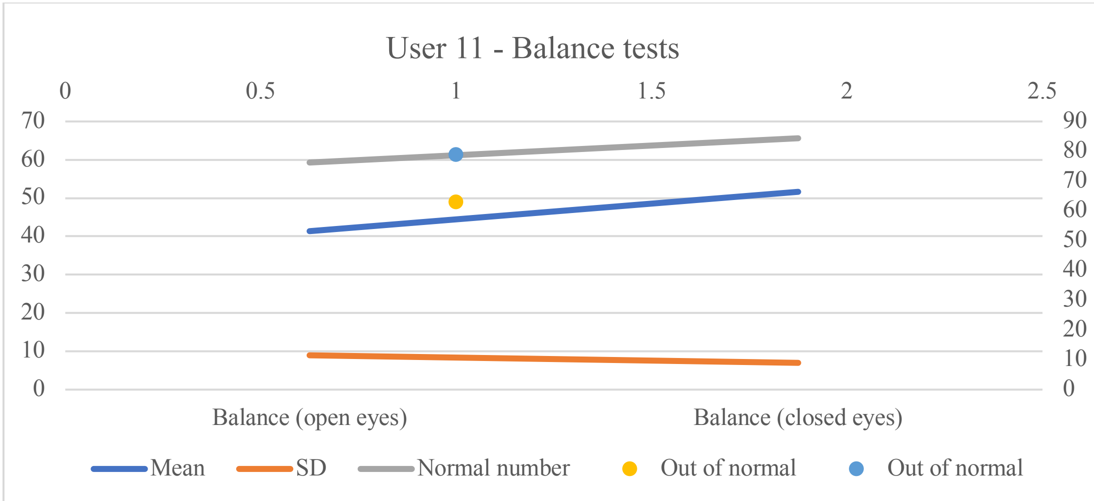


Figure 2. Balance test results for User 11 showing two values out of normal range when done with open eyes

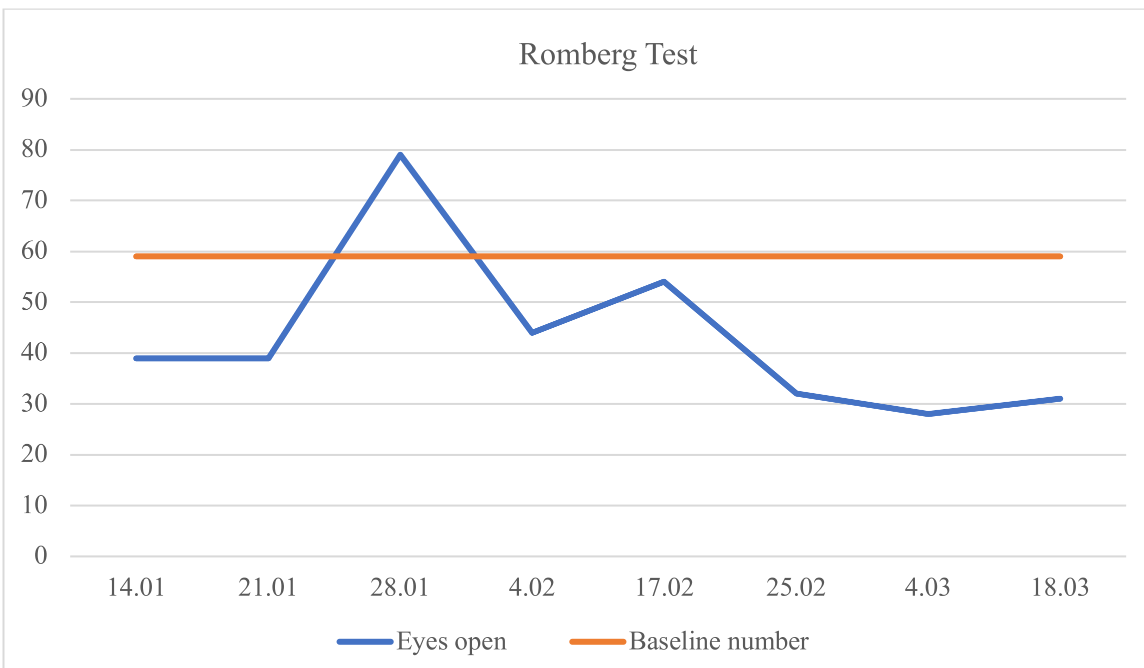


Figure 3. Comparison of the Baseline number vs. the rest of the measurements

Example of stable patient for balance test: User 21

The first example of the user 21 demonstrated excellent stability of all balance measurements (smaller numbers are better). No out of normal values were seen for this test for this User. This patient reported to be feeling good throughout the duration of the tests.

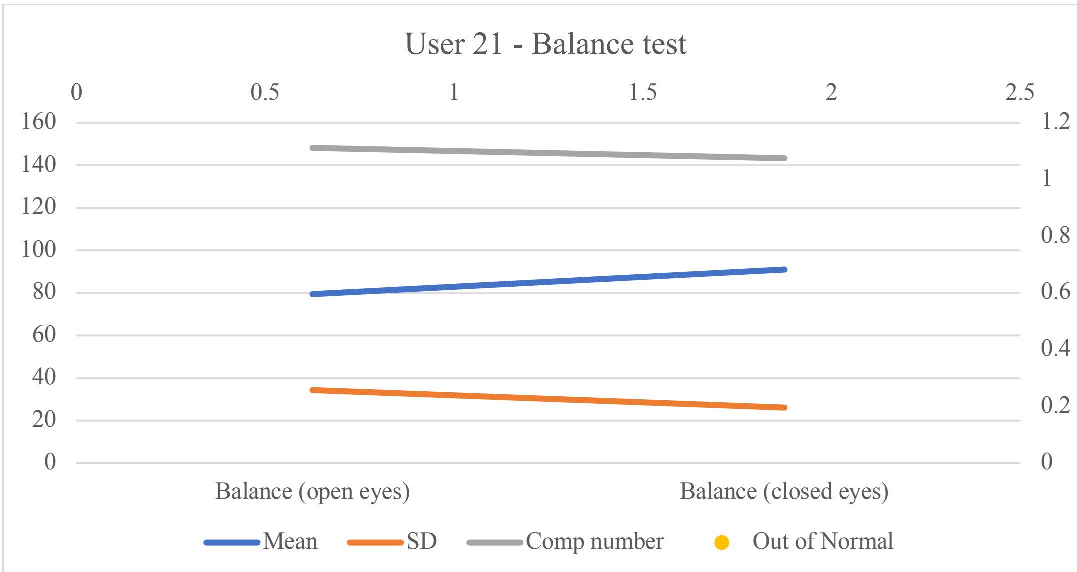


Figure 1. Balance test results for User 21 with dates of measurements. There are no out of normal values for this patient

4.2 Results from leg strength test

During home-based monitoring 8 patients demonstrated leg strength measurements (range of motion - left leg flex, right leg flex) within 2SD deviations and were considered stable.

Patients did the test daily for the first week and calculated a baseline number that was compared with further testing.

In total for all 8 patients there were 605 stable measurements collected for the balance test and 16 unstable measurements collected.

Example of unstable patient: User 15

The patient had only one value out of normal range for the angular speed test in the left leg. For the best flex range, user 15 had in total 3 values out of normal range, two for the left leg and one for the right leg. On 18 and 20th of December the patient reported that felt tired and on January 15th the patient reported that it was painful to do tests with legs. This can be seen in the graphs where the dates of late December and January demonstrate out of normal values. On March 23rd the patient was feeling bad and had a relapse.

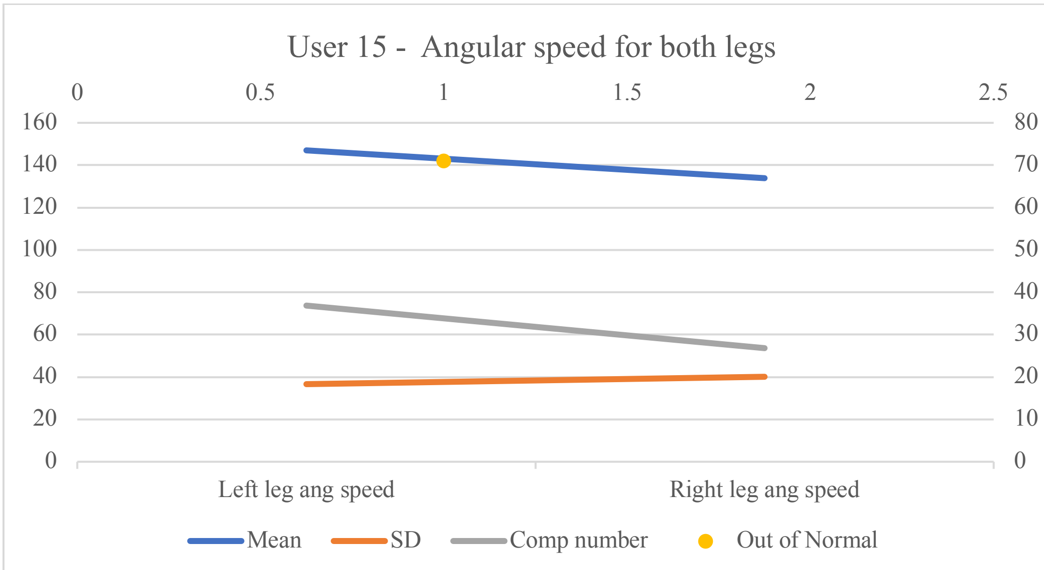


Figure 4. Angular speed results for User 15 on both legs, one out of normal values was present.

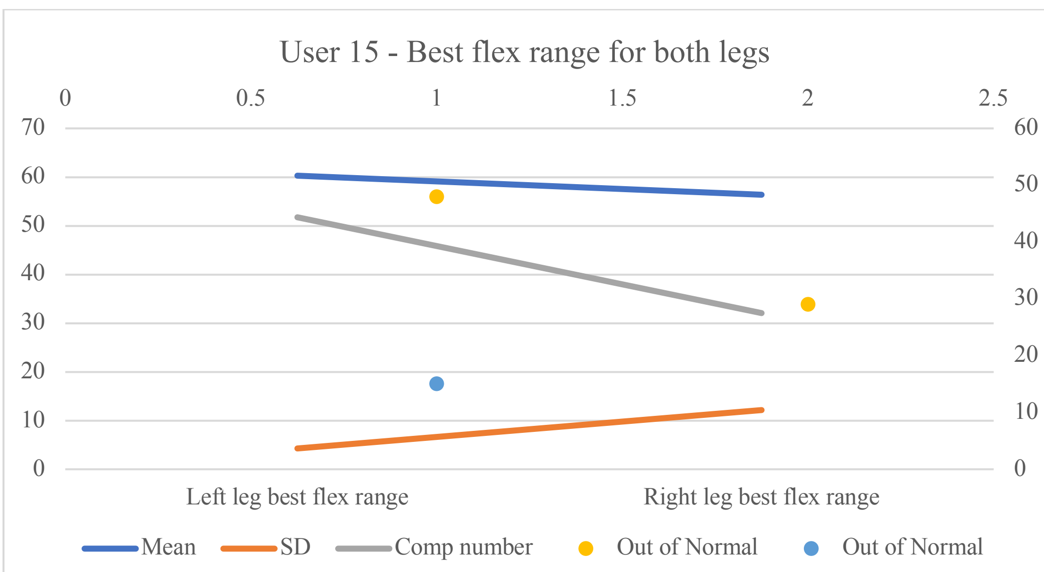


Figure 5. Best flex range test results for User 15 on both legs, three out of normal values were present.

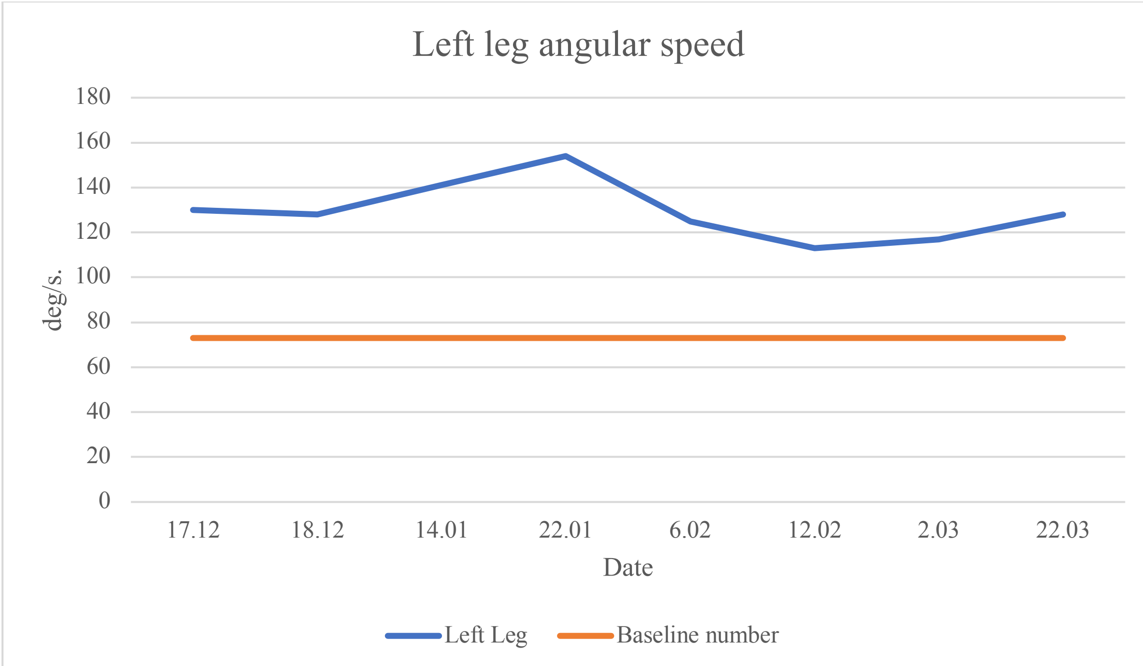


Figure 6. Comparison of the baseline number vs. Measurements by date of angular speed for left leg

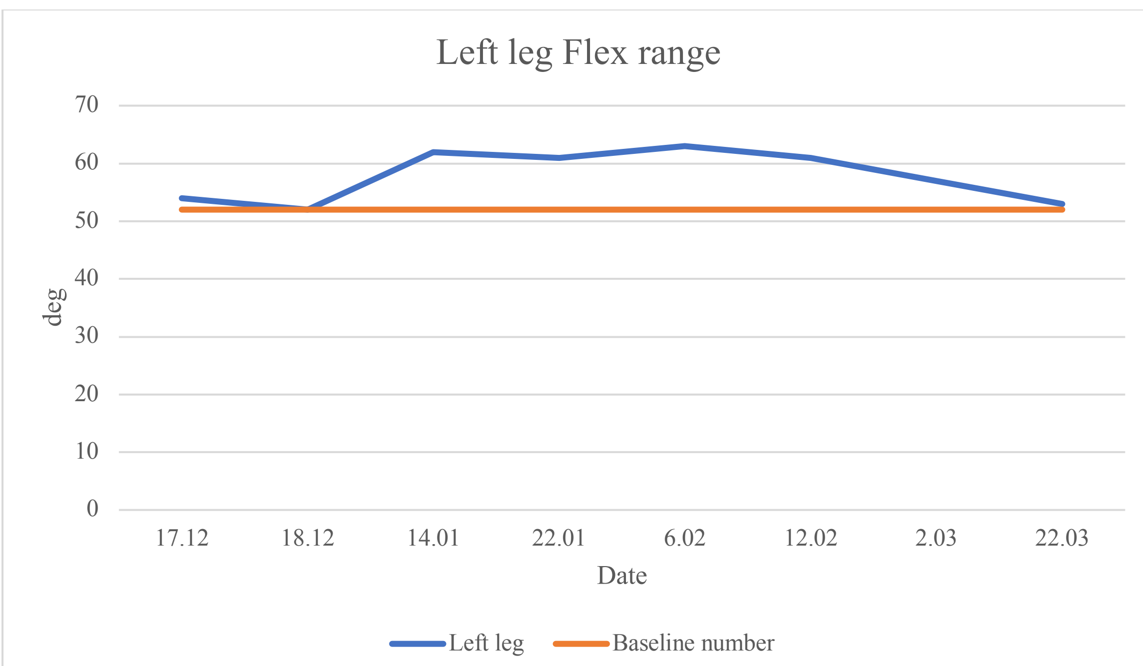


Figure 7. Comparison of the baseline number vs. Measurements by date for flex range of left leg

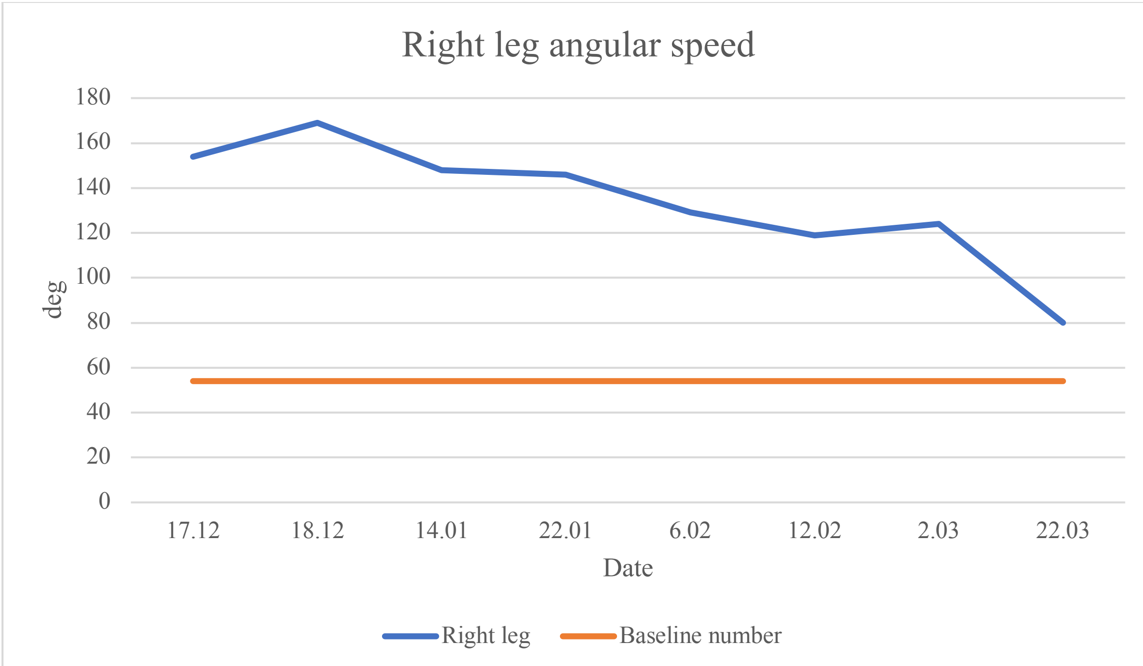


Figure 8. Comparison of the baseline number vs. measurements by date of angular speed for right leg

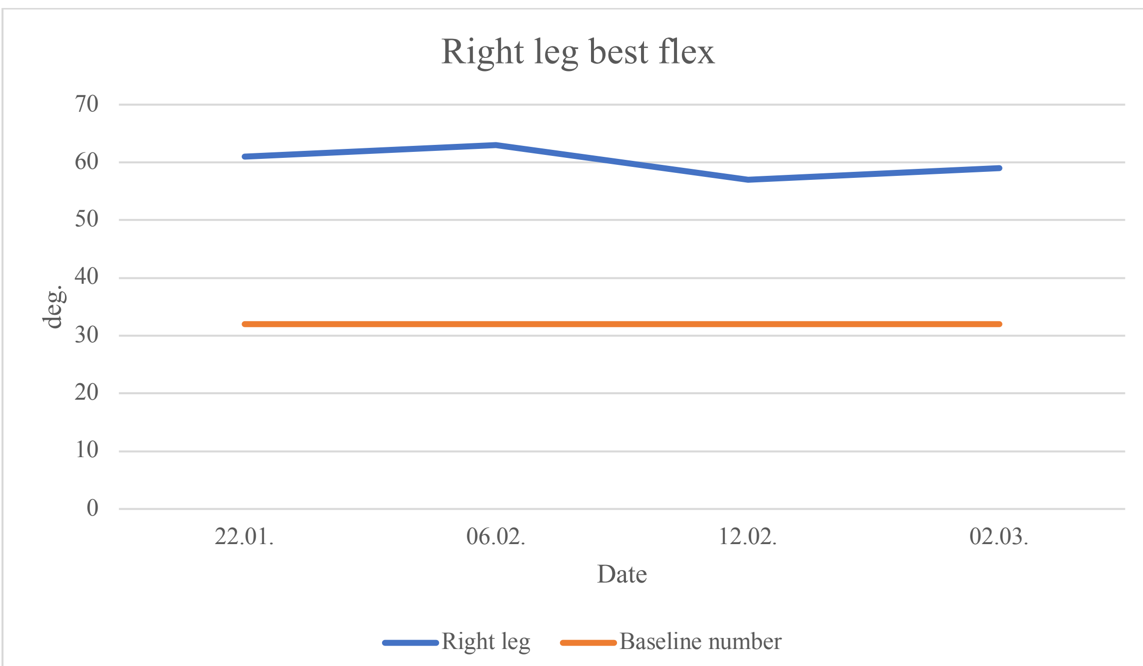


Figure 9. Comparison of the baseline number vs. Measurements by date for flex range of right leg

Example of a stable patient for leg strength test: User 18

User 18 did not have any out of normal values for both tests, angular speed and best flex range.

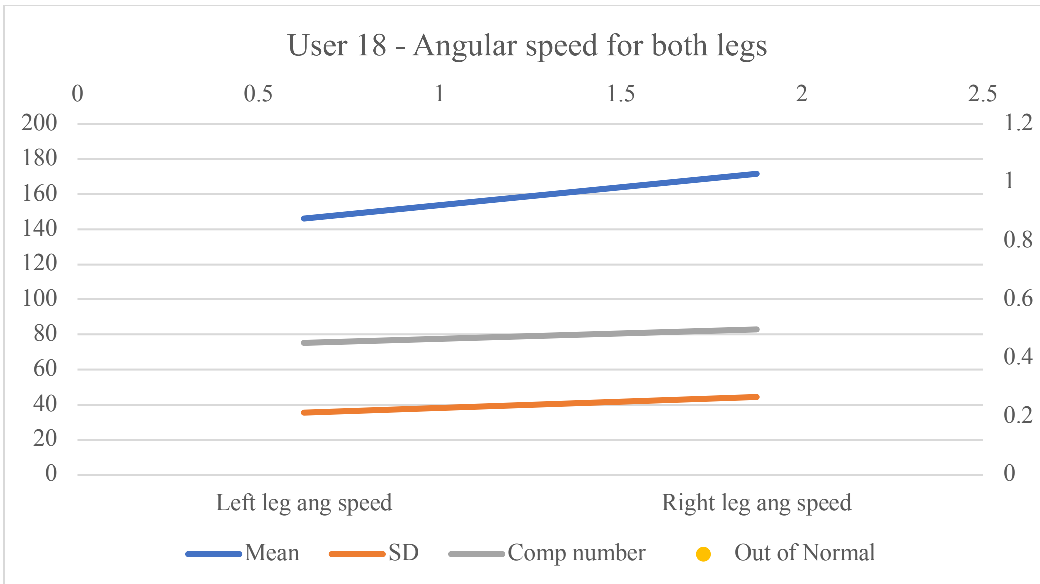


Figure 10. Angular speed test results for User 18 on both legs, no out of normal values were present.

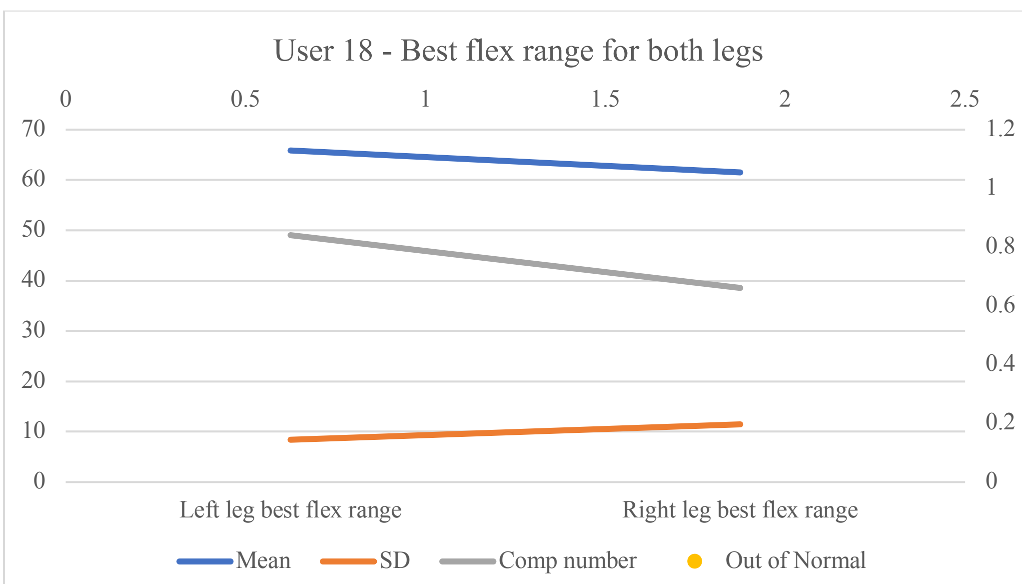


Figure 11. Best flex range test results for User 18 on both legs, no out of normal values were

4.3 Results from one leg jump test

During home-based monitoring 8 patients demonstrated balance measurements (jump with left leg, jump with right leg) within 2SD deviations and were considered stable.

Patients did the test daily for the first week and calculated a baseline number that was compared with further testing.

In total for all 8 patients there were 499 stable measurements collected for the balance test and 29 unstable measurements collected.

Example of unstable patient for one leg jump test: User 15

This patient had several out of normal range values for both legs in different test measured. For the left leg, user 15 had 6 out of normal values when measured for average time and no out of normal values when measured for longest flight time. For the right leg, there were 6 equal out of normal values on the longest flight time measurement, there were no out of normal values found in average time. The patient commented that on 18 and 20th of December felt tired. The patient also commented that on January 15th it was painful to do the right leg jump test, around the ankle. From the beginning of March, he felt worse and on March 23 the patient had a relapse. This relapse can be seen on the days around March 23rd, where the measurements show out of normal.

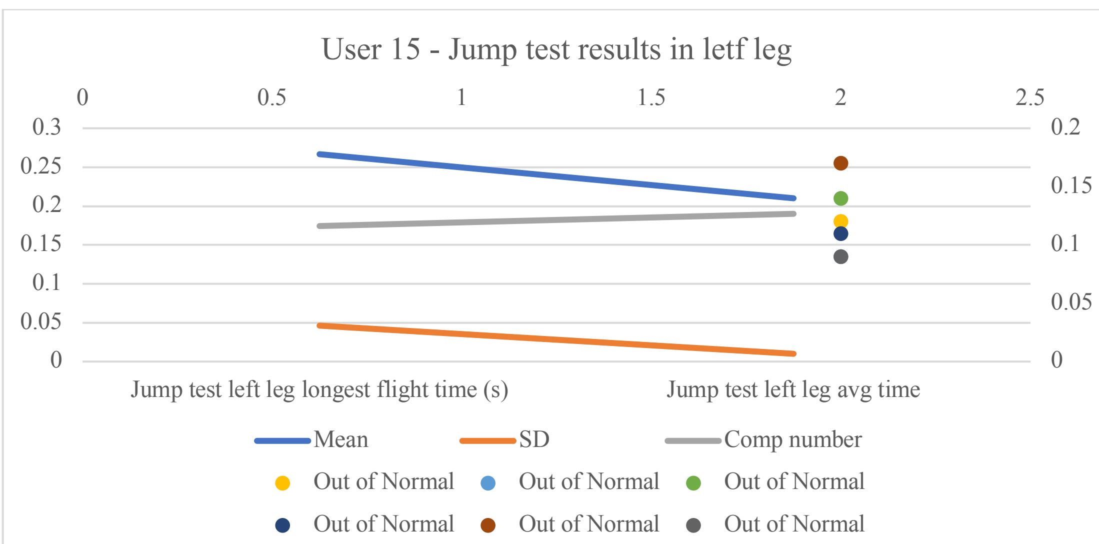


Figure 12. Jump test result for User 15 on the left leg. Six out of normal results were found.

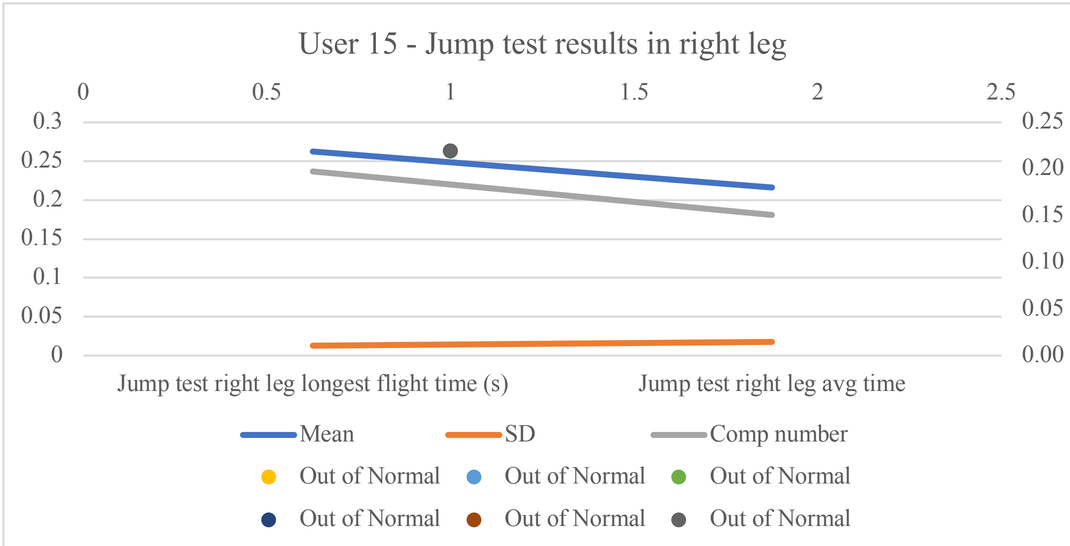


Figure 13. Jump test result for User 15 on the right leg. Six equal out of normal results were found.

Figure 14. Comparison of the baseline number vs. measurements by date of left leg jump

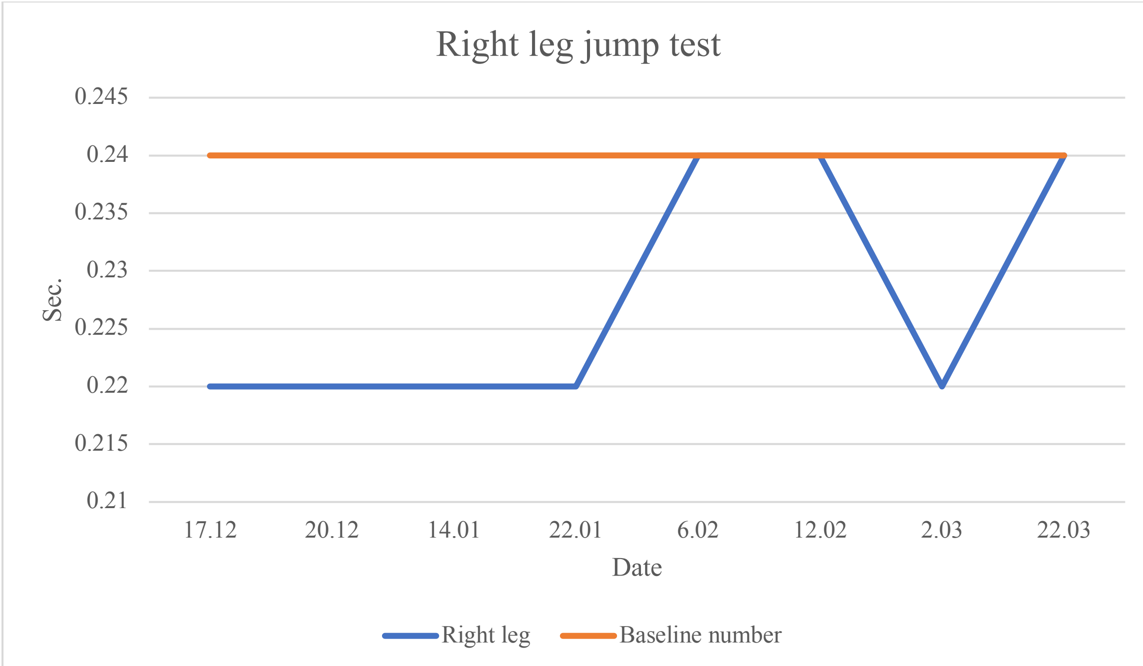


Figure 15. Comparison of the baseline number vs. measurements by date of right leg jump

Example of a stable patient for one leg jump test: User 20

User 20 did not have any out of normal values that was found in both legs for both type of measurements taken.

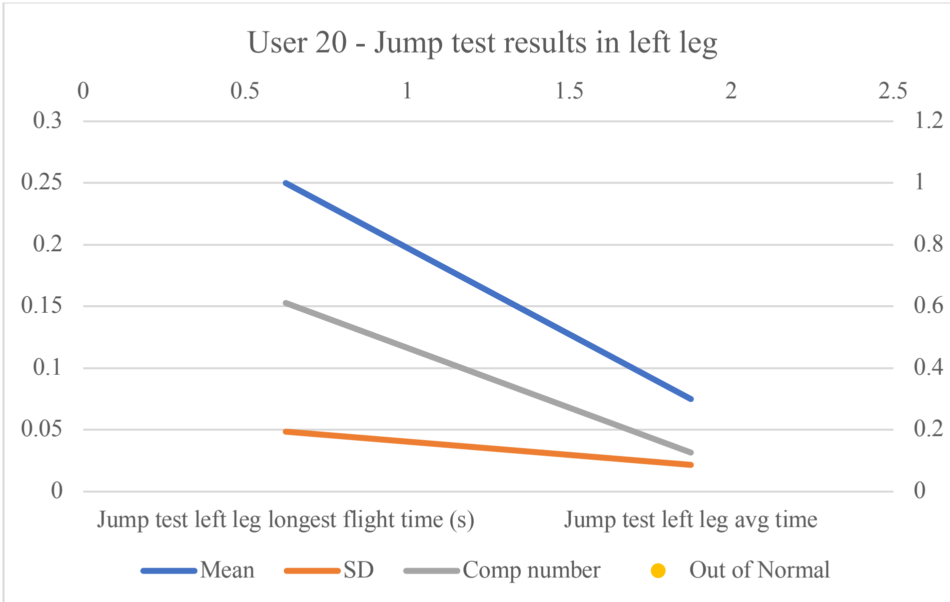


Figure 16. Jump test result for User 20 on the right leg. No out of normal results were found.

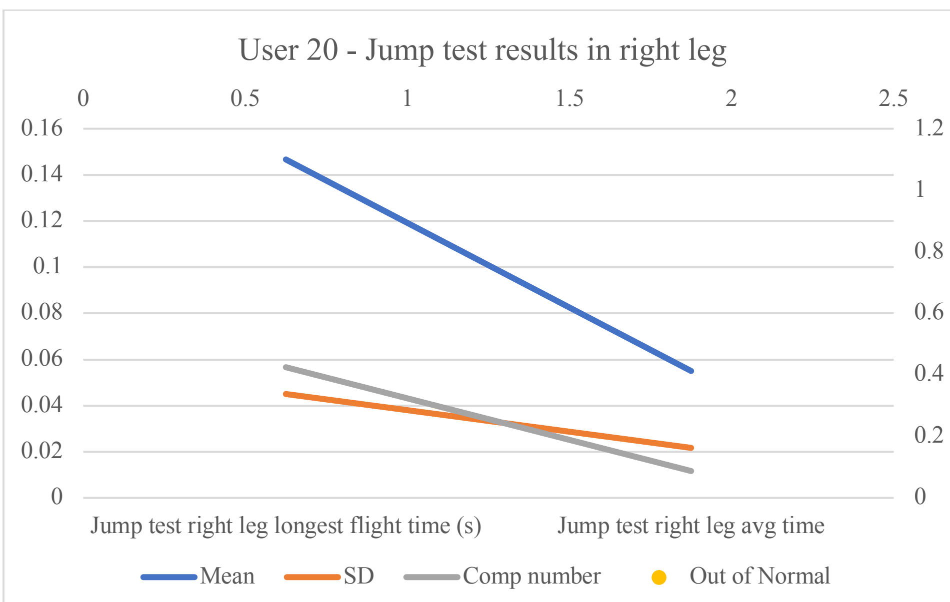


Figure 17. Jump test result for User 20 on the right leg. No out of normal results were found.

4.4 Qualitative results – Patients' feedback

The feedback provided by the patients (Users) was an indication of what was happening in a specific date, if they were sick, if they had technical issues with the app and taking the results, etc.

Here are some comments from the patients:

- User 11: The user's own comments were that in January 21 and 28 were two weeks sick with a strong cough and the jumping test was painful to do in the ankle area. The patient also missed some days to take the measurements because the tests program did not work well. The phone was checked at the clinic and sent back to the patient.

- User 14: In December and January, the patient had a constant 37.2 fever, head drowsiness and a was feeling bad. In February, the patient was in in the hospital and could not do the tests. In march 24 she had a slight headache. She also changed phones and could not go to the clinic to install the application on her phone again, which made her miss some dates to do the tests.

- User 15: The patient said that on 18 and 20 of December felt tired. On January 15th, it was painful to do the right leg jump test, around the ankle. From the beginning of March, he felt worse, March 23 was also feeling bad and had a relapse. Also, the balance tests indicate that the patient tried to do many repetitions before the test gave a result. The patient also complained that the tests take too much time.

- User 16: The patient was very motivated to do the tests if they were to be done on a daily basis. If the tests were to be done on a once a week basis, then there were a few weeks of no tests done. The patient also mentioned that he was on vacation and did not take the sensors with him. The main reason was that the patient forgot about it.

- User17: In January 25 felt tired, but before that the patient was feeling good. In February and March, the patient was feeling good as well.

- User18: On 4th of March the patient had issues with the sensor and the phone. She didn't know that the phone was not recording the data. The patient wanted to exit the study as well because she could not find the time to do it at home. There was also a limitation that the patient did not tell her children about the disease and the tests made her think about the disease, which lowered her mood.

- User19: The patient could not get the sensor and the phone to work. Then she asked to be excluded from the study.

- User 20 and 21 said they were feeling good throughout the three months period.

5 Discussion

Multiple Sclerosis is an example of a disease that is unpredictable. It may cause disability, but also patients with this disease live without having their quality of life affected or loss of motor function for a long period of time.

The patients in general did not have strong signs of relapses, however, some of the patients missed some days to do the tests due to sickness, forgetting to do them, issues with the phone or app, and one patient was unable to continue with the study as intended.

A few patients experienced issues with the app while taking the measurements, indicating that the tests are not being captured correctly. In general, there were more normal values than negative values that indicate a worsening of their condition.

Patients also mentioned that they did not want to do the test while they were travelling or in vacation. It was pointed out that the tests are cumbersome because the sensor needs to be tested before charging. That it would much more user-friendly if they were just using the phone.

Some patients also had problems with the app, sometimes no responses could be seen after doing the tests. There were meetings with the developer and the patients, however, the problem was not solved.

The sensors were very sensitive to the state of the patient, when the patient was not feeling well or was sick, the sensor showed that the values were not normal. Getting the feedback of the patient directly into the app also helped to understand what was happening on the day that the out of normal value was taken. According to this pilot study, if the patient does not have relapses, the measurements received are stable and the patient does not need to visit a doctor, because their condition is stable.

This shows that taking measurements at home with wireless sensors is feasible and provides value for the future of monitoring patients with MS, allowing the doctor to know when to call the patient for a visit at the doctor's office, which will happen only when needed.

This pilot study adds value to the way the future of healthcare could be monitored, it offers a better way to lower the long waiting times for specialist consultation because then the doctor will know when the patient is actually needed to be seen and provide with the necessary medication and assistance.

5.1. Limitations

While the excitement of enrolling into the program was noticeable for the first week, later on taking the tests once a week seemed to be not exciting anymore, which suggest the novelty of monitoring the disease at home doesn't last long and soon becomes more of an inconvenience than it is a monitoring tool created for the benefit of the patients.

This may suggest that longer study times may not be suitable since people need to incorporate this new routine into their daily lives or in a weekly basis and it may be forgotten.

Could be recommended that to get patient adherence to use home monitoring tools and get used to them, the test should be performed once a day for a short period of time. Could be one to three months, that way more test measurements can be collected but it won't be over a significant amount of time. Doing daily measurements will allow patients to try to familiarize themselves with the tool better and make it a habit.

We must consider as well that the sensors used for this pilot study have been used multiple times before and therefore are not brand new, which may incur in slow and not accurate measurements.

It is necessary to further develop the mobile phone software in connection with the Android upgrades and porting the software to the iOS platform. As a result of the development, the introduction of internal sensors, which makes testing much easier.

5.2. Future research

It can be suggested to keep studying an optimal way to make the patients adhere to making the tests at home. Making a study that involves a shorter period but increases the times per day and per week that the tests are done may make the patient aware that they need to monitor their health, instead of making it once a week as this study was done.

5.3. Conclusions

These studies are valuable to understand what kind of disease monitoring can be offered at home for patients. Studies that have negative results are also valuable to understand what kind of monitoring system works for the average amount of patients with this disease in particular.

In this pilot study, it was proven that the sensor measurements at home are a feasible method to understand the current condition of the patient with critically important neurological symptoms typical of MS. The doctor can evaluate remotely when the patient is stable and the amount of time that the patient has been stable before a relapse (if there is any). The doctor can also review if the patient needs to visit the clinic or if the medication dose should be increased.

Annex

Expanded Disability Status Scale (EDSS) (22)

Score	Description
1.0	No disability, minimal signs in one Functional System (FS)
1.5	No disability, minimal signs in more than one FS
2.0	Minimal disability in one FS
2.5	Mild disability in one FS or minimal disability in two FS
3.0	Moderate disability in one FS, or mild disability in three or four FS. No impairment to walking
3.5	Moderate disability in one FS and more than minimal disability in several others. No impairment to walking
4.0	Significant disability but self-sufficient and up and about some 12 hours a day. Able to walk without aid or rest for 500m
4.5	Significant disability but up and about much of the day, able to work a full day, may otherwise have some limitation of full activity or require minimal assistance. Able to walk without aid or rest for 300m
5.0	Disability severe enough to impair full daily activities and ability to work a full day without special provisions. Able to walk without aid or rest for 200m

Score	Description
5.5	Disability severe enough to preclude full daily activities. Able to walk without aid or rest for 100m
6.0	Requires a walking aid – cane, crutch, etc. – to walk about 100m with or without resting
6.5	Requires two walking aids – pair of canes, crutches, etc. – to walk about 20m without resting
7.0	Unable to walk beyond approximately 5m even with aid. Essentially restricted to wheelchair; though wheels self in standard wheelchair and transfers alone. Up and about in wheelchair some 12 hours a day
7.5	Unable to take more than a few steps. Restricted to wheelchair and may need aid in transfering. Can wheel self but cannot carry on in standard wheelchair for a full day and may require a motorised wheelchair
8.0	Essentially restricted to bed or chair or pushed in wheelchair. May be out of bed itself much of the day. Retains many self-care functions. Generally has effective use of arms
8.5	Essentially restricted to bed much of day. Has some effective use of arms retains some self-care functions
9.0	Confined to bed. Can still communicate and eat
9.5	Confined to bed and totally dependent. Unable to communicate effectively or eat/swallow

Score	Description
10.0	Death due to MS

Graphs for all patients for three tests performed: Balance, leg strength, and jumping test.

User 11

User 11 is a female with EDSS score of 3, is 35 years old and was diagnosed with the disease 3 years ago.

This patient completed 13 days of tests at home, for which a mean, a standard deviation (SD) and a comparison number was calculated after the first 6 consecutive days of tests done at home. The comparison number allows to know if the data received from the sensor is indicating relapses or normal values. Relapses for balance test were known as the numbers that are above the comparison number.

For the open eyes' balance test only 2 values came as outside the normal number. The balance test with closed eyes did not have any values outside of normal range.

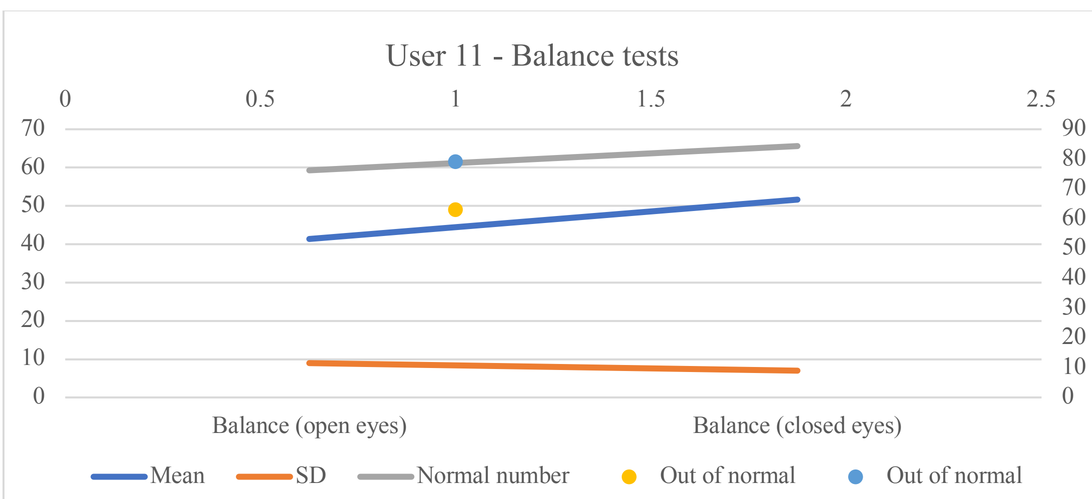


Figure 1. Balance test results for User 11 showing 2 values out of normal range when done with open eyes

User 14

User 14 is a female patient with an EDSS score of 2, is 32 years old and was diagnosed 9 years ago.

This patient completed 20 days of measurements and the mean, SD and comparison number was calculated after 5 days of consecutive days of tests completed at home.

For the balance test with eyes open there were 4 values outside the normal, while no values were found outside the normal for the test with the eyes closed.

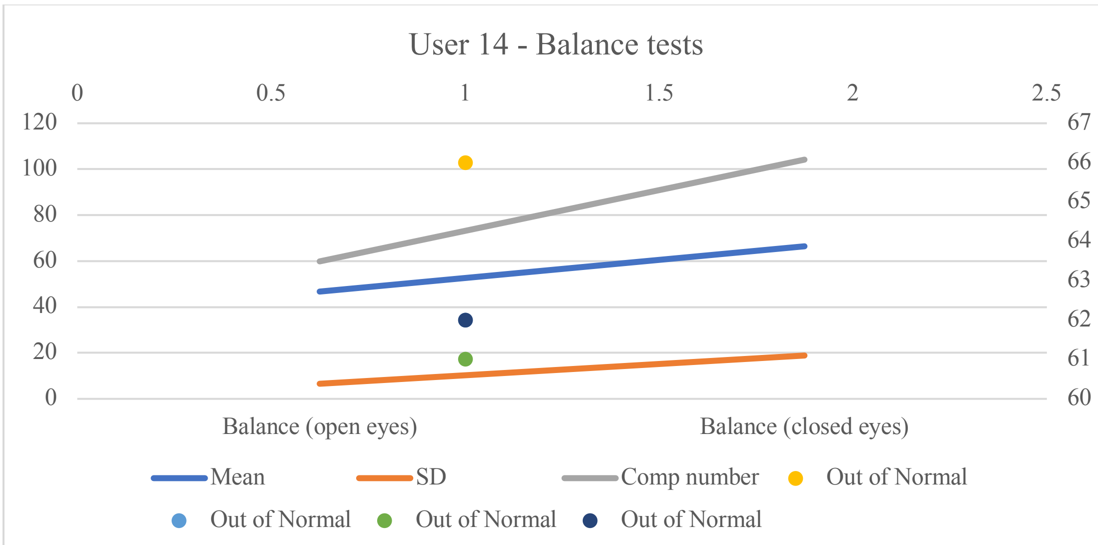


Figure 2. Balance test results for User 14 showing 4 values out of normal range when done with open eyes

User 15

User 15 is a female with an EDSS score of 2.5, is 44 years old and was diagnosed 4 years ago.

She completed 18 days of tests and the mean, SD and comparison number was calculated after 6 days of consecutive tests performed at home.

The patient had 3 numbers out of normal range for the balance test with eyes open and 3 values out of normal for the test with eyes closed.

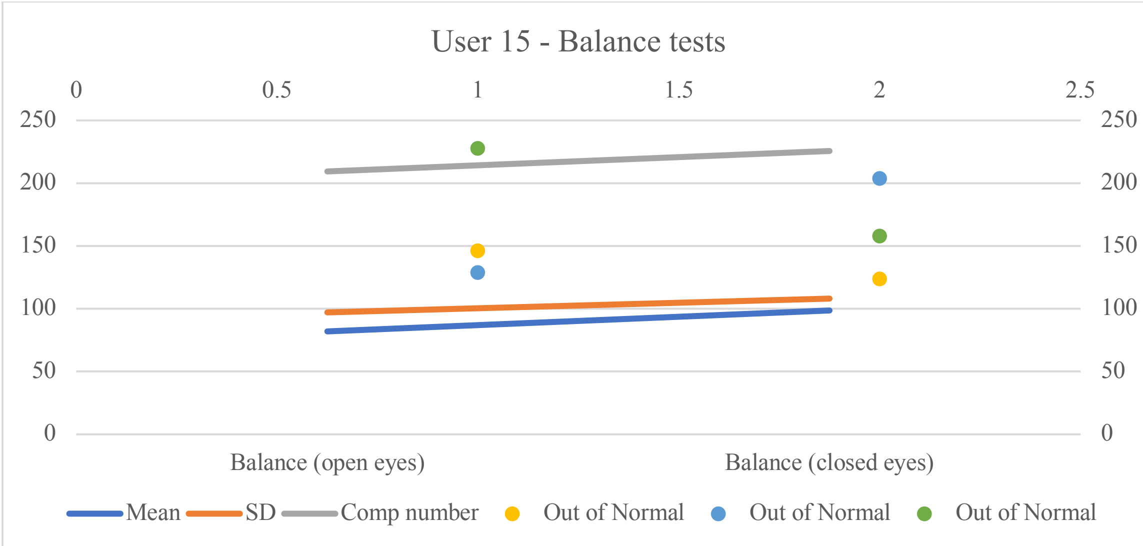


Figure 3. Balance test results for User 15 showing in total 6 values out of normal range, 3 when done with open eyes and 3 for eyes closed

User 16

User 16 is a male with an EDSS score of 2, is 28 years old and was diagnosed 13 years ago.

He completed 13 days of tests at home and the mean, SD and comparison number was calculated after 7 days of consecutive tests completed at home.

The patient had only one number out of normal for the balance tests with eyes open, no other number out of normal range for the test with eyes closed.

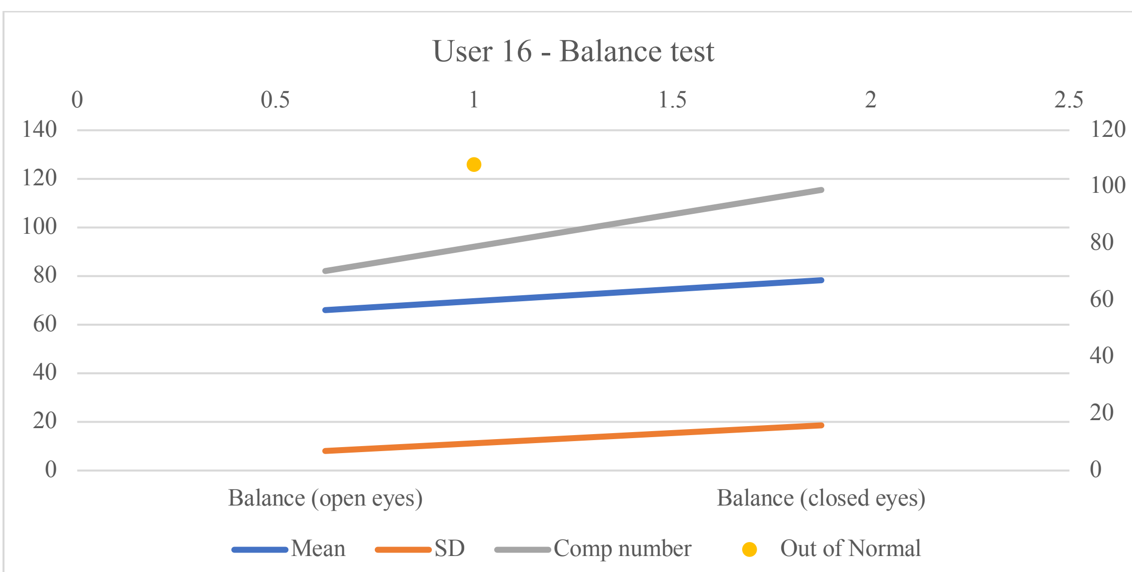


Figure 5. Balance test results for User 16 showing 1 value out of normal range for the test done with eyes open

User 17

User 17 is a female with EDSS score of 3, she is 35 years old and was diagnosed with the disease 21 years ago.

She completed 14 days of tests and the mean, SD and comparison number was calculated after 4 days of consecutive tests taken at home. This patient had 2 numbers out of normal range for the test done with closed eyes, and there were no numbers out of normal range when it was done with open eyes.

User 17 completed 6 consecutive days from a previous week of tests, however the tests seemed to be done incorrectly at home and the sensor could not take enough data to calculate the mean and SD.

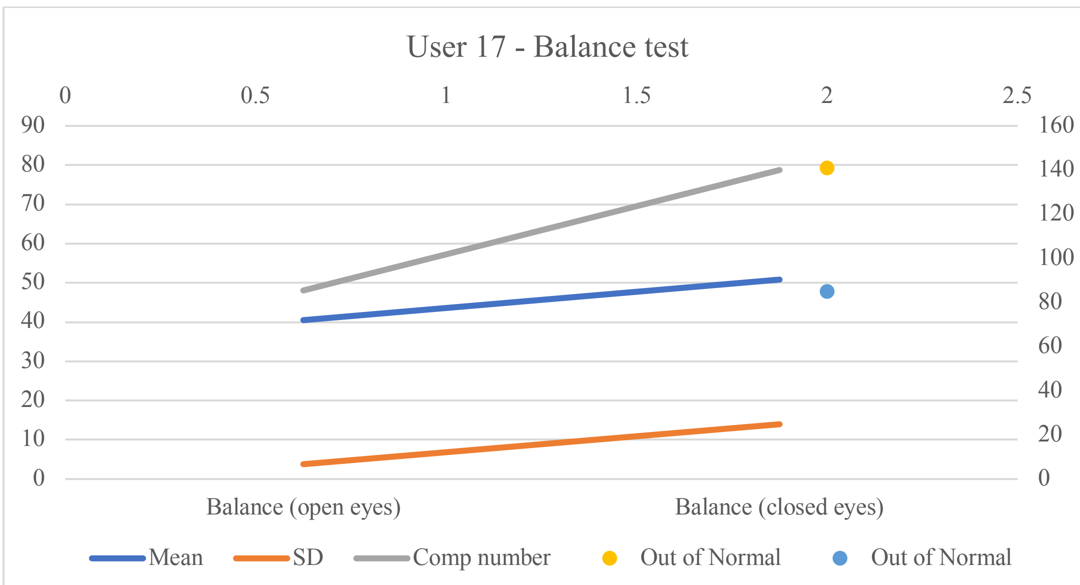


Figure 6. Balance test results for User 17 showing 2 values out of normal range for the test done with eyes closed

User 18

User 18 is a female with EDSS score of 3, is 40 years old and was diagnosed 7 years ago.

She completed 7 days of tests in total and the mean, SD and comparison number was calculated after 4 days of consecutive test taken at home.

The patient had 3 values out of normal range for balance test with eyes open and no out of range values for the test with closed eyes. Two of the three values were the same number.

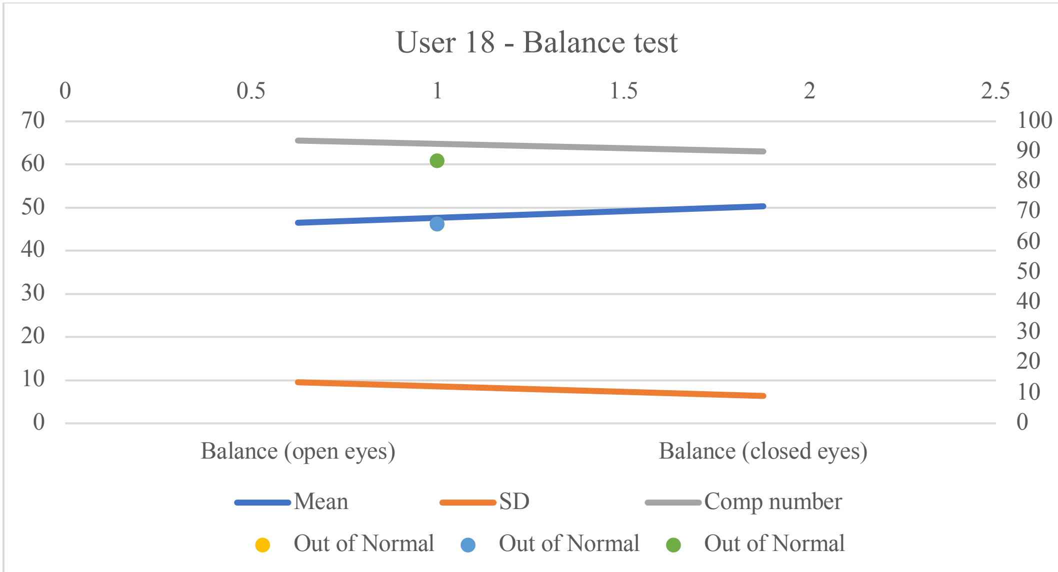


Figure 7. Balance test results for User 18 showing 3 values out of normal range for the test done with eyes open

User 20

User 20 is female with an EDSS score of 1.

The patient completed 12 days of testing and the statistical data was taken after 6 days of consecutive test completed at home.

She did not have any numbers out of normal range for this test.

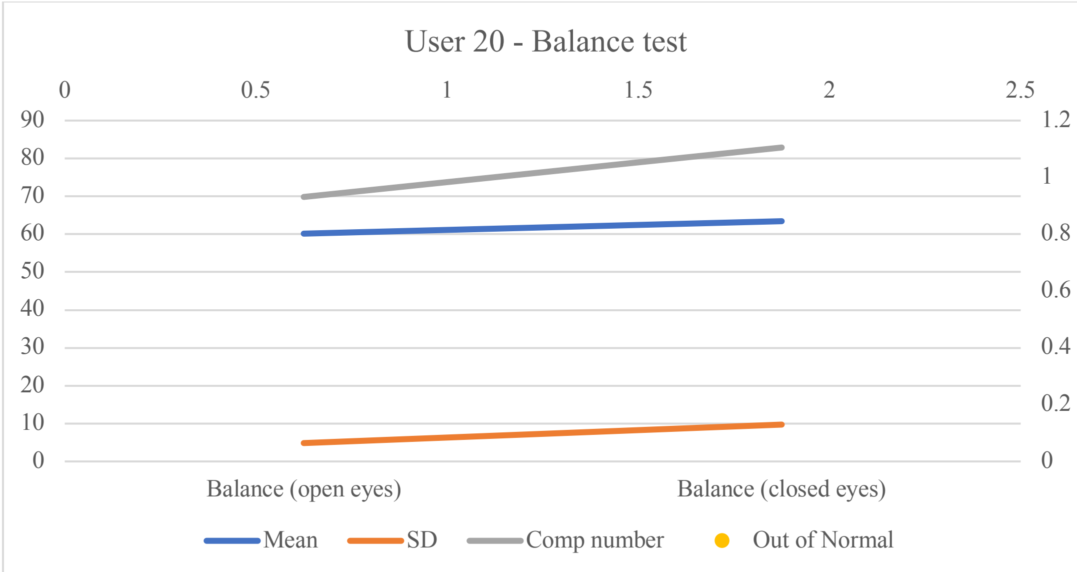


Figure 8. Balance test results for User 20. There are no out of normal values for this patient.

User 21

User 21 is a female, 29 years old and was diagnosed 15 years ago.

The patient completed 10 days of testing in total and the statistical data was calculated after 5 days of consecutive test done at home. There were no out of normal numbers for this test.

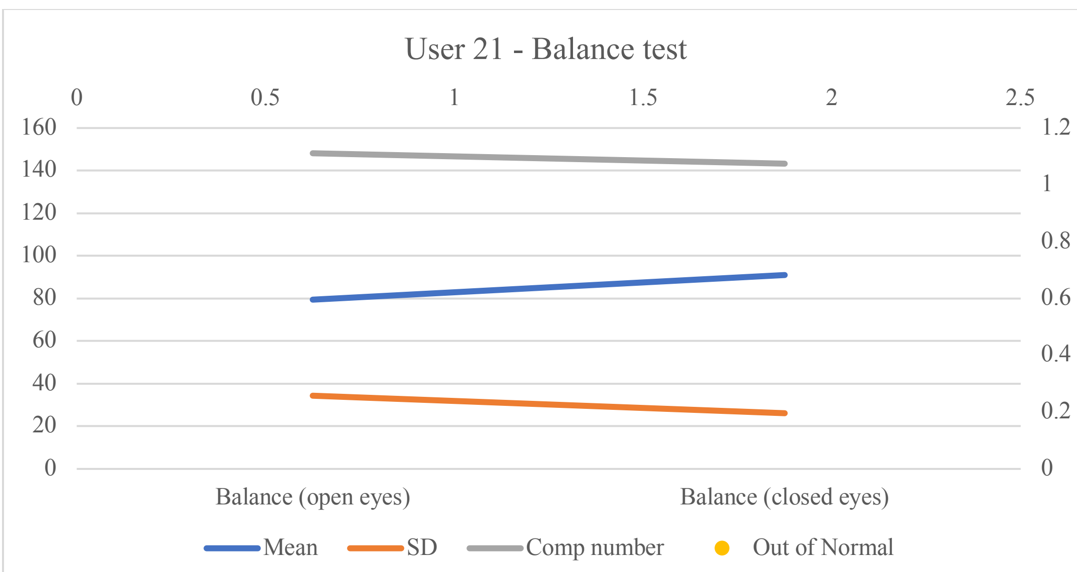


Figure 9. Balance test results for User 21. There are no out of normal values for this patient.

4.2 Results from the leg test

User 11

The measurements taken by the patient for the angular speed of both legs presented no values out of normal range, but the measurements taken by the patient for best flex range presented 2 values out of normal, one value for each leg.

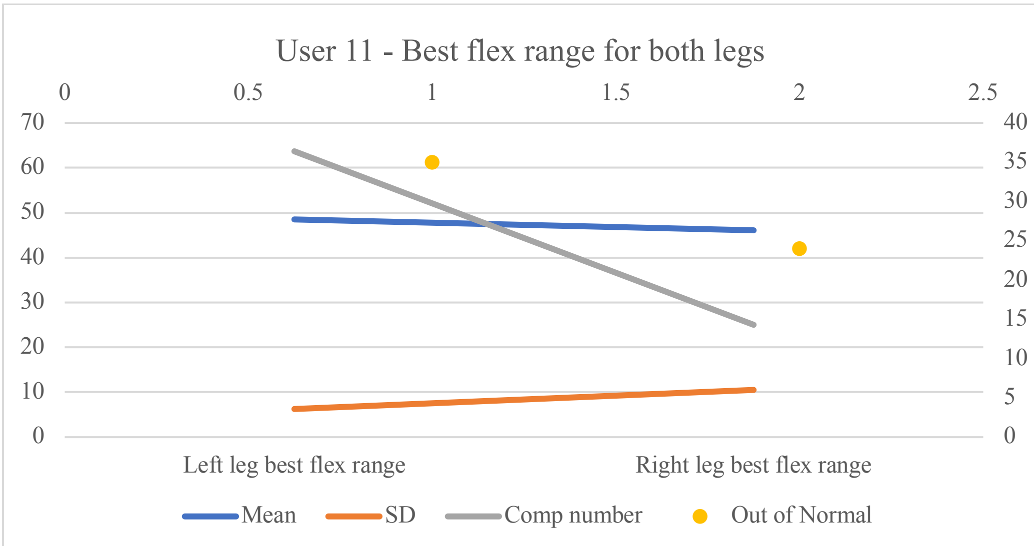


Figure 10. Best flex range leg test results for User 11. There were two out of normal values for the patient.

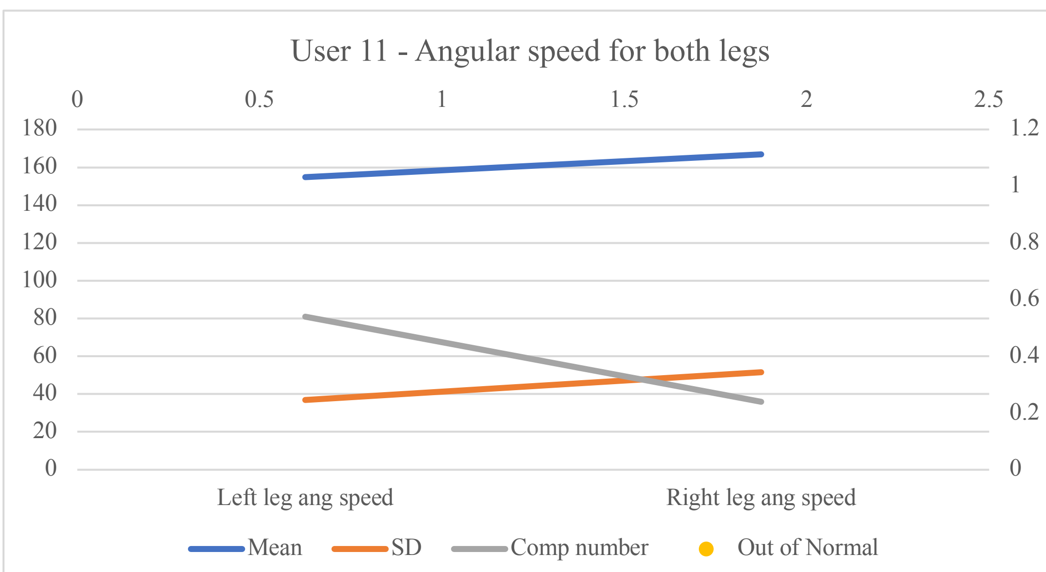


Figure 11. Angular speed leg test results for User 11. There were no out of normal values for

User 14

The measurements taken by user 14 presented only one value out of normal for the angular speed of the right leg. For the best flex range test, two out of normal values were present, one for each leg.

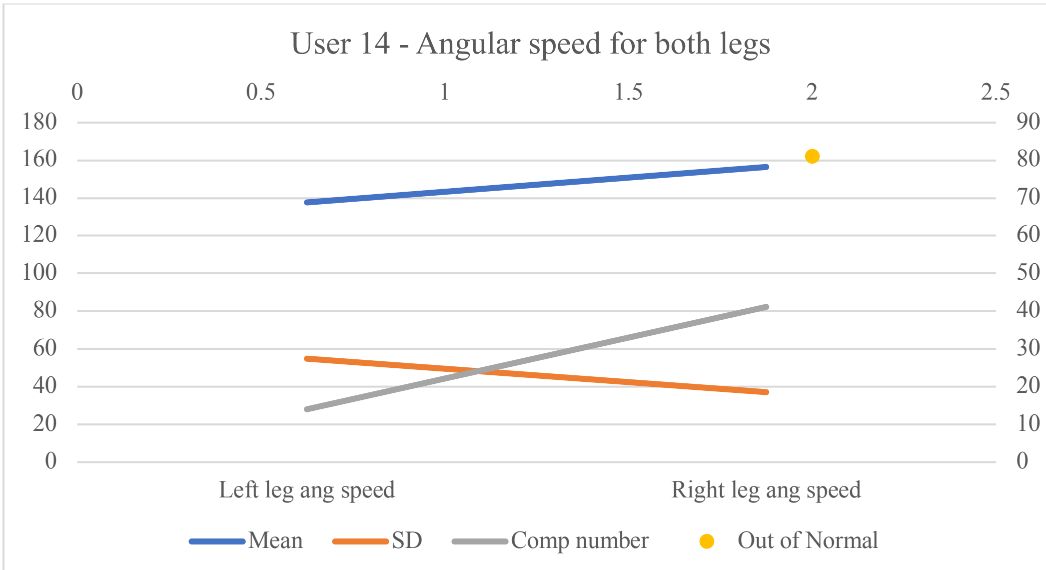


Figure 12. Angular speed leg test results for User 14 on both legs, one out of normal value for the right leg.

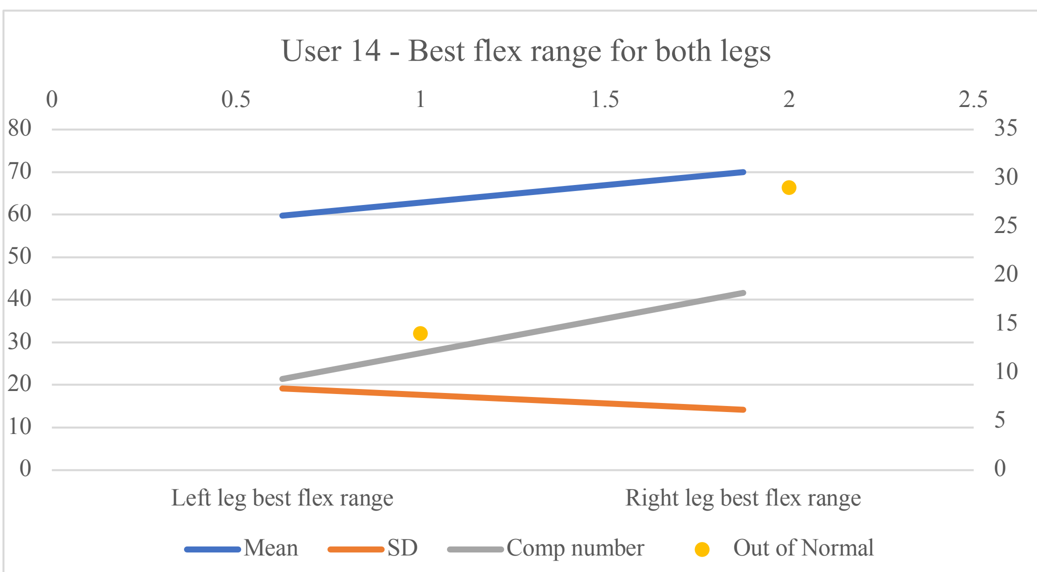


Figure 13. Best flex range test results for User 14 on both legs, two out of normal values were

User 15

The patient had only one value out of normal range for the angular speed test in the left leg. For the best flex range, user 15 had in total 3 values out of normal range, two for the left leg and one for the right leg.

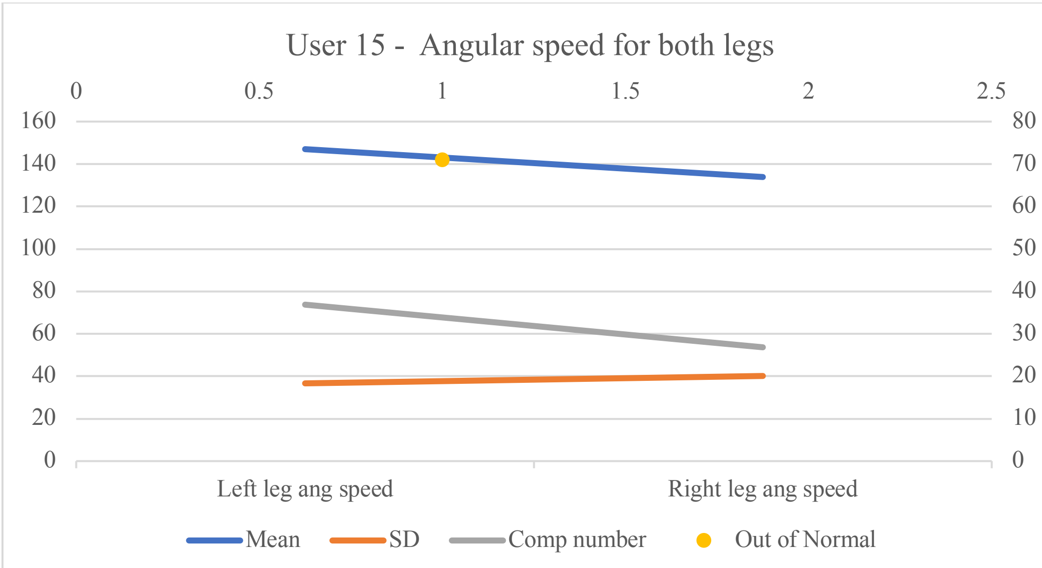


Figure 14. Angular speed results for User 15 on both legs, one out of normal values was present.

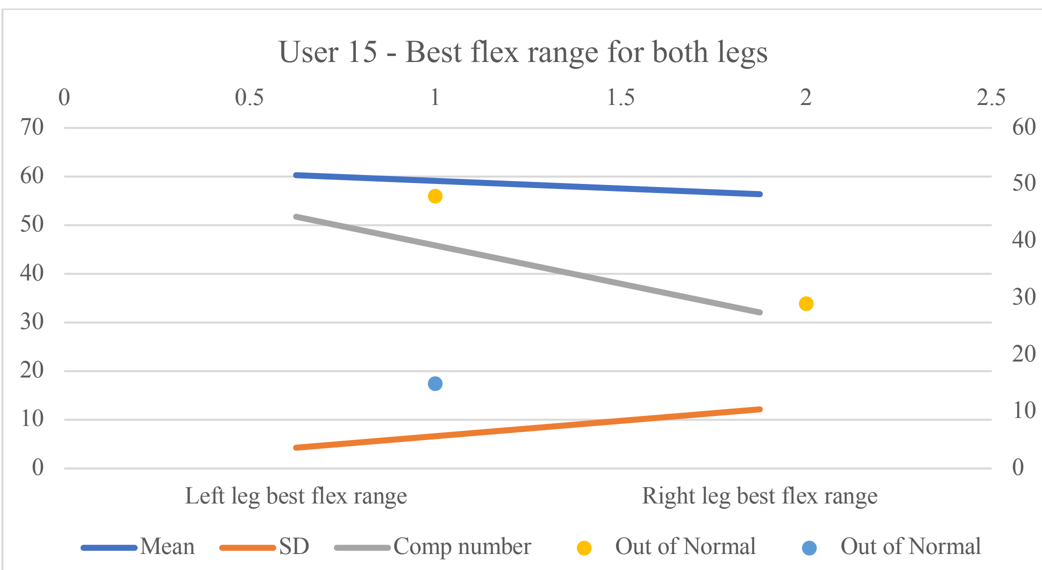


Figure 15. Best flex range test results for User 15 on both legs, three out of normal values were present.

User 16

User 16 presented only one out of normal value for the angular speed in the right leg, the rest of the values in angular speed and best flex range test were normal.

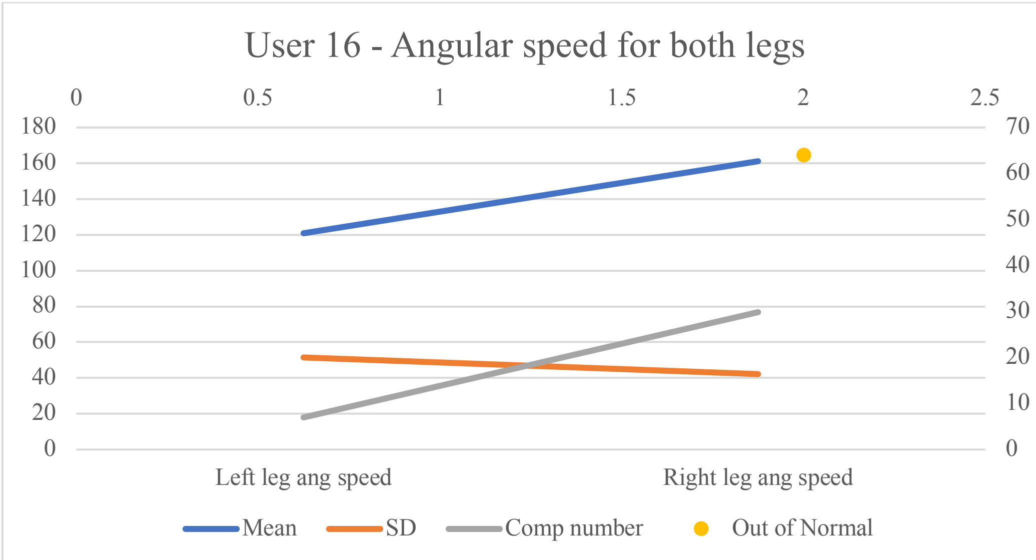


Figure 16. Angular speed results for User 16 on both legs, one out of normal values was present.

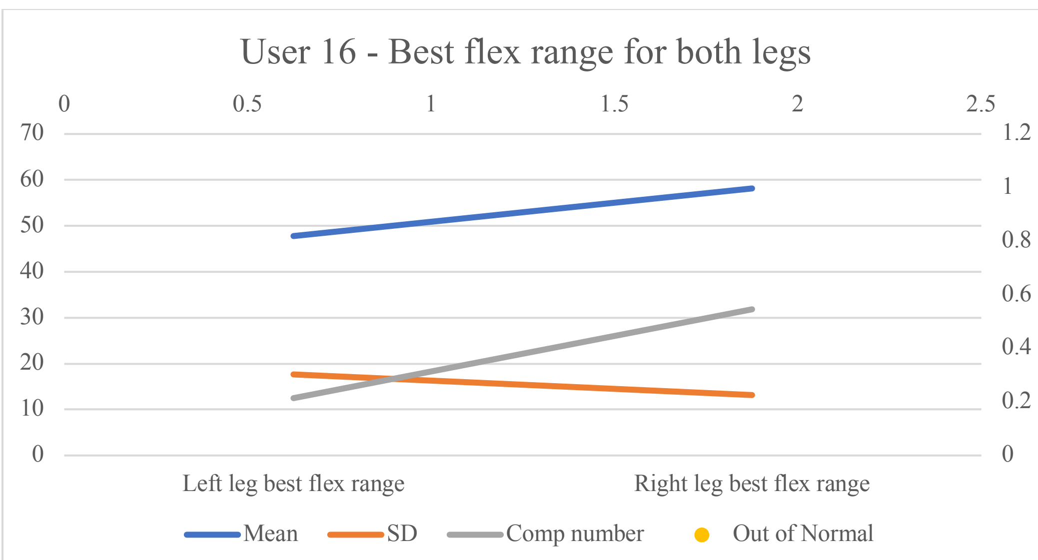


Figure 17. Best flex range test results for User 15 on both legs, no out of normal values were present.

User 17

User 17 had three values out of normal. One value was found for the right leg in the angular speed test and two other values were found out of normal, one for each leg in the best flex range test.

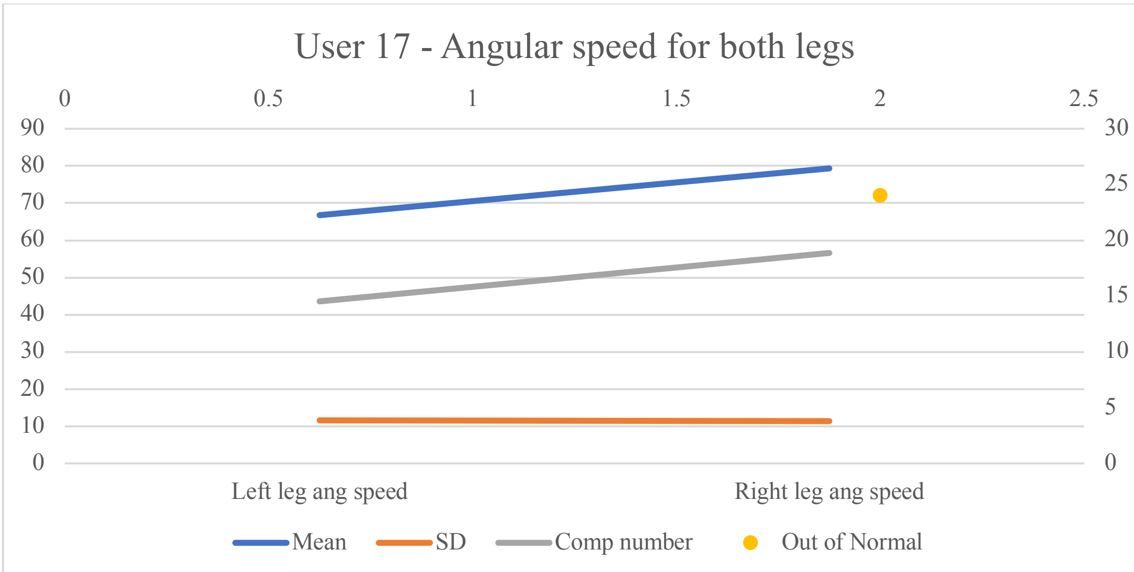


Figure 18. Angular speed results for User 17 on both legs, one out of normal values was found.

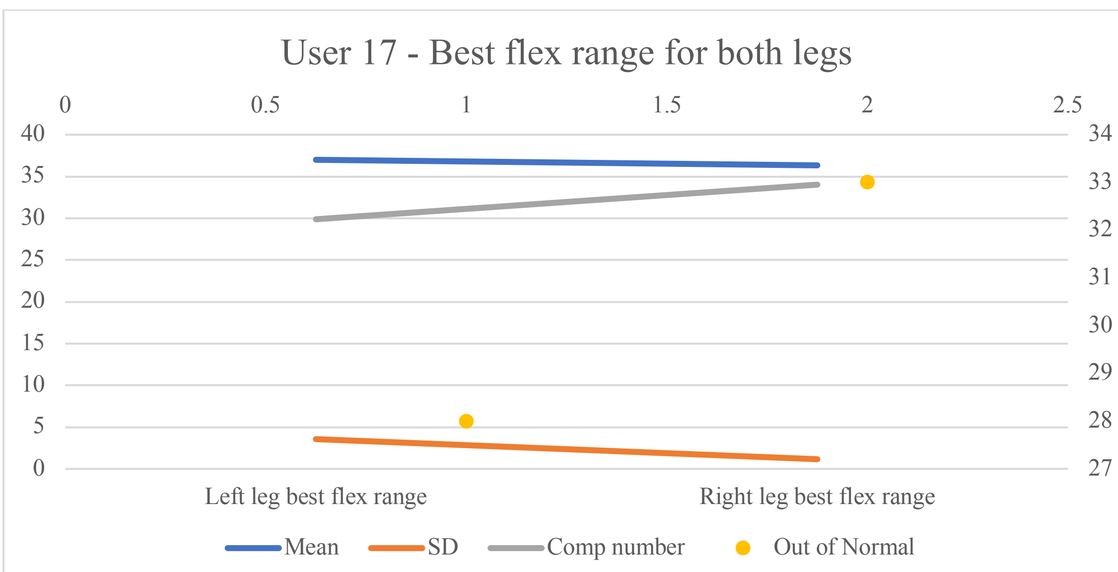


Figure 19. Best flex range test results for User 17 on both legs, two out of normal values were present.

User 18

User 18 did not have any out of normal values for both tests, angular speed and best flex range.

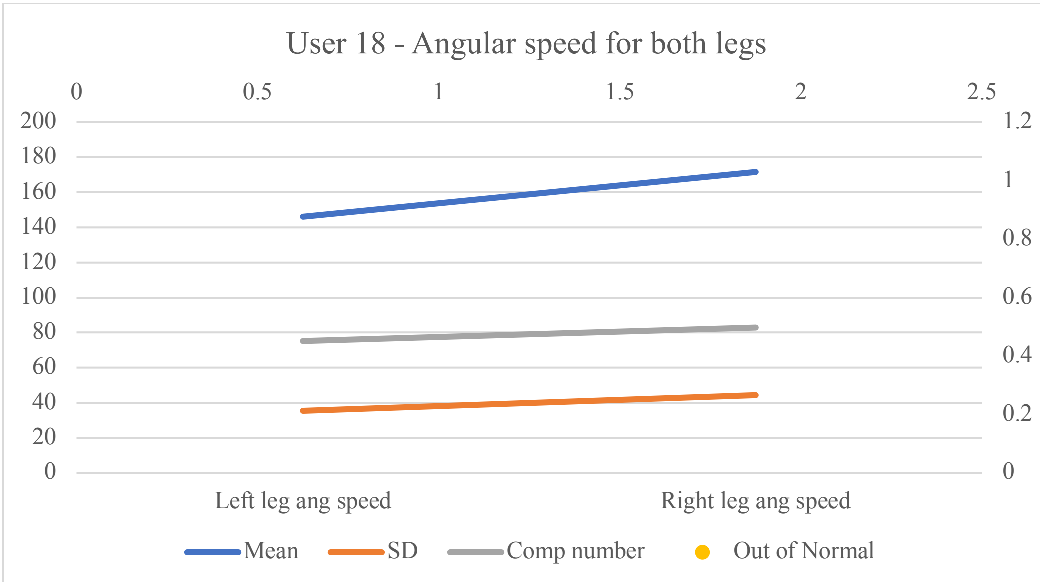


Figure 20. Angular speed test results for User 18 on both legs, no out of normal values were present.

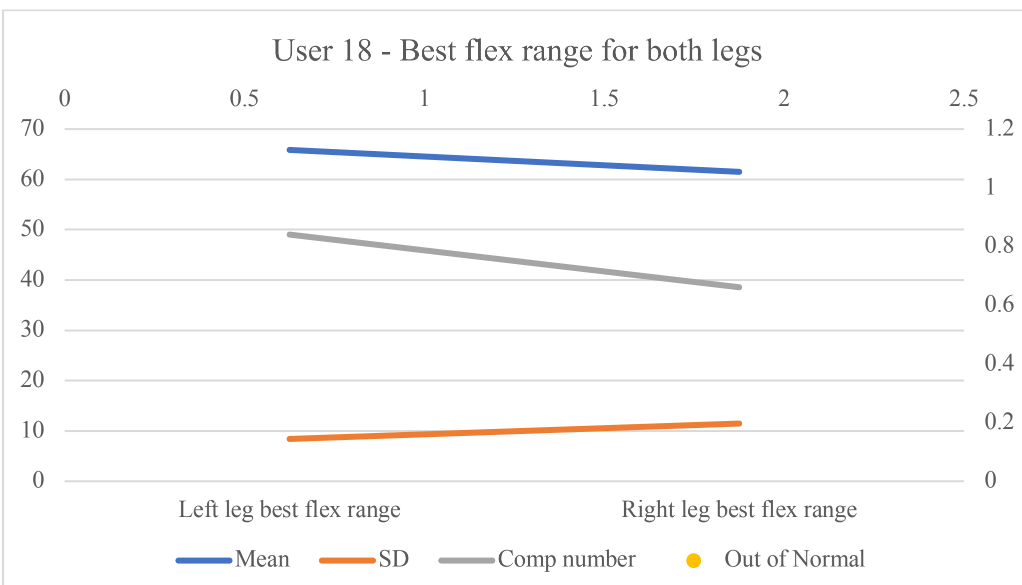


Figure 21. Best flex range test results for User 18 on both legs, no out of normal values were present.

User 20

User 20 had no out of normal values for the angular speed test in both legs, but it had one out of normal value for each leg, which makes it two in total for best flex range.

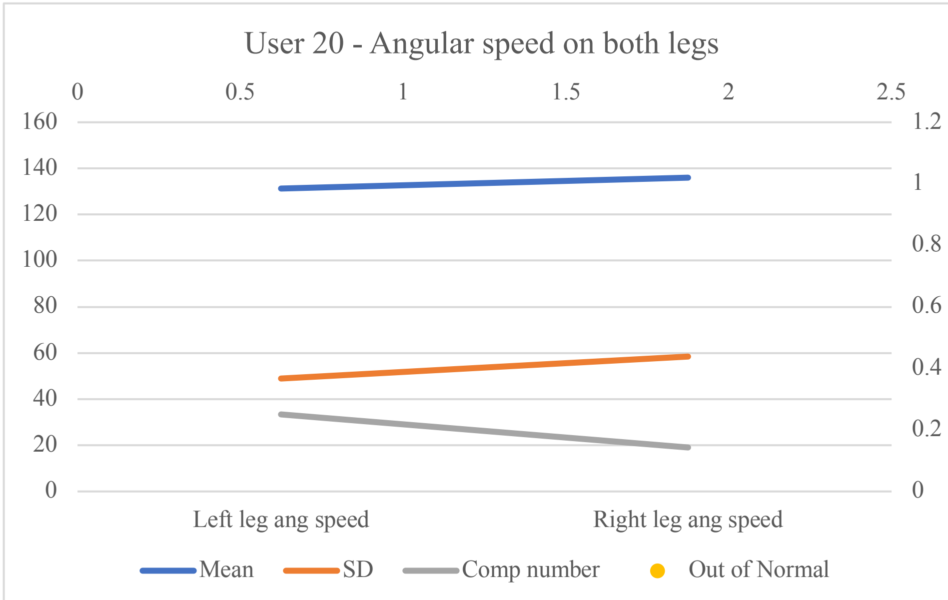


Figure 22. Angular speed test results for User 20 on both legs, no out of normal values were present.

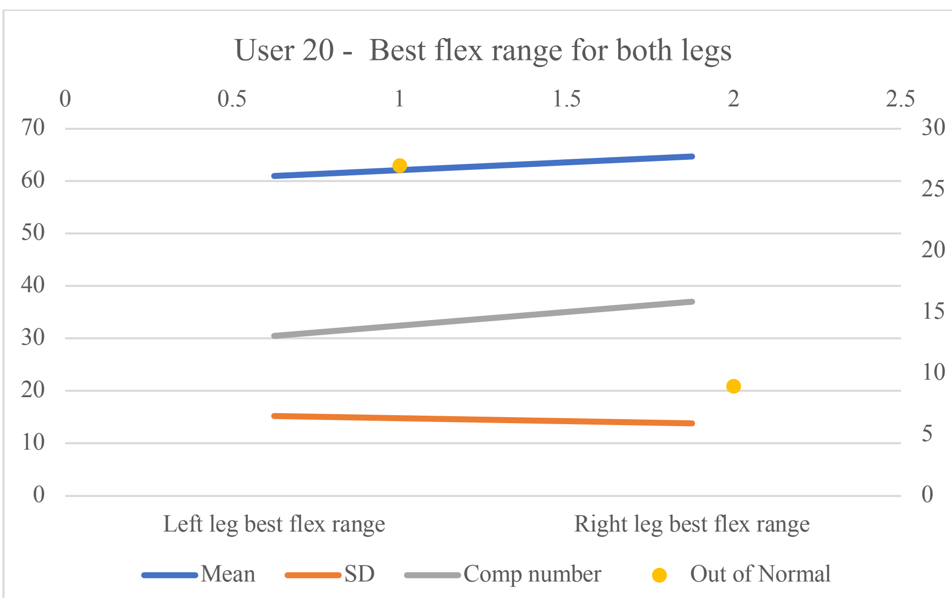


Figure 23. Best flex range test results for User 20 on both legs, two out of normal values were

User 21

This patient had no out of normal values in the angular speed test, while for the best flex range there were two out of normal values, one for each leg.

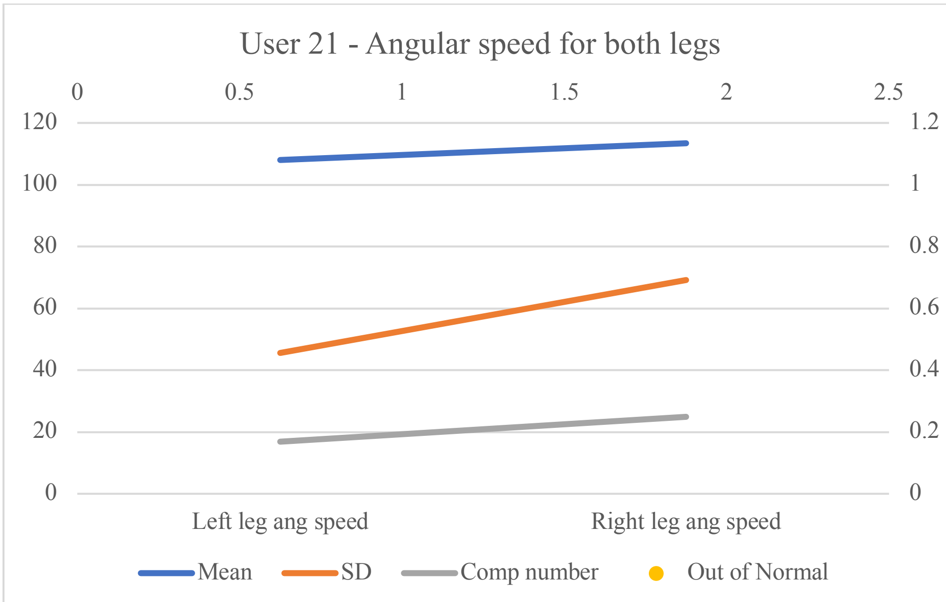


Figure 24. Angular speed test results for User 21 on both legs, no out of normal values were present.

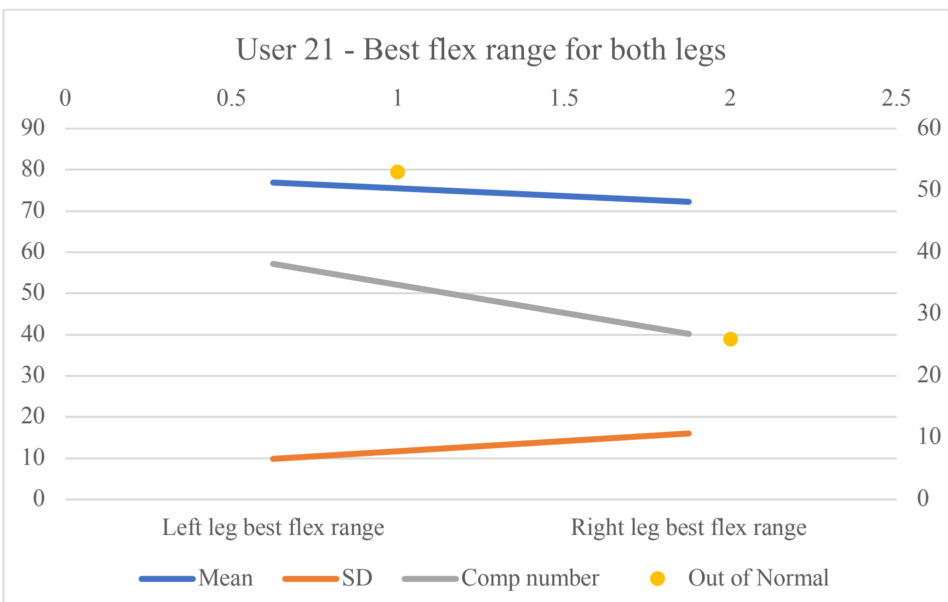


Figure 25. Best flex range test results for User 21 on both legs, two out of normal values were present.

4.3 Results from the jump test

User 11

The user 11 had one out of normal result for the jump test with the left leg in the longest flight time test. For the average time in left leg there were no values out of normal range.

The right leg had no values out of normal range in longest flight time or average time.

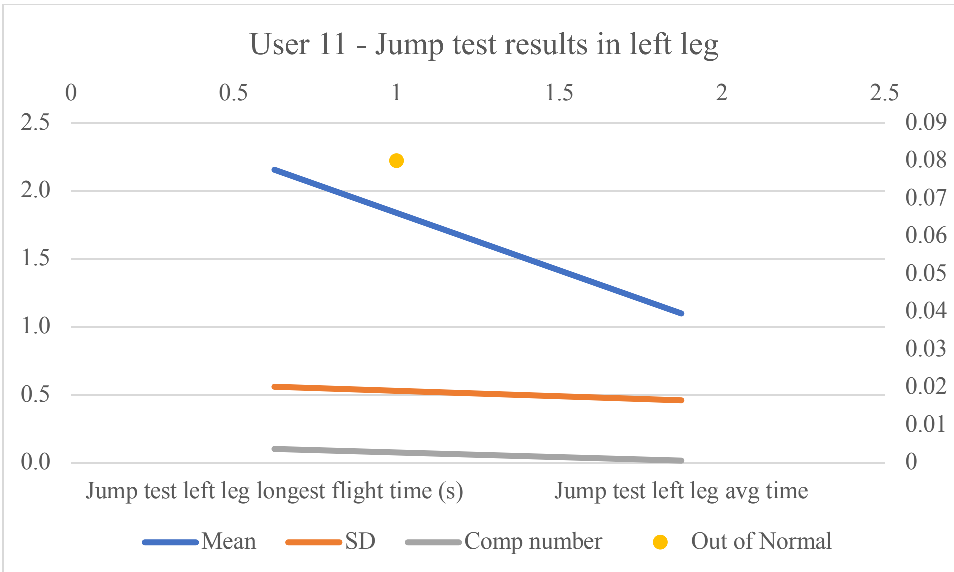


Figure 26. Jump test results shown for User 11 on the left leg, where one out of normal result was found.

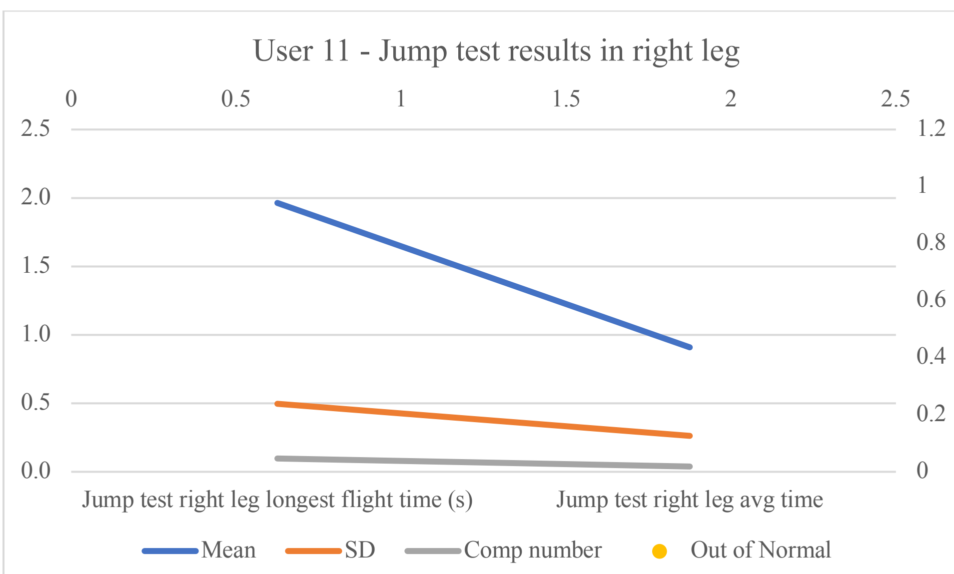


Figure 27. Jump test result for User 11 on the right leg. No out of normal results were found.

User 14

User 14 had 4 out of normal values for the tests performed with the left leg, two values for each measurement taken: longest flight time and average time, while for the right leg there were two equal values out of normal range which were found for average time measurement.

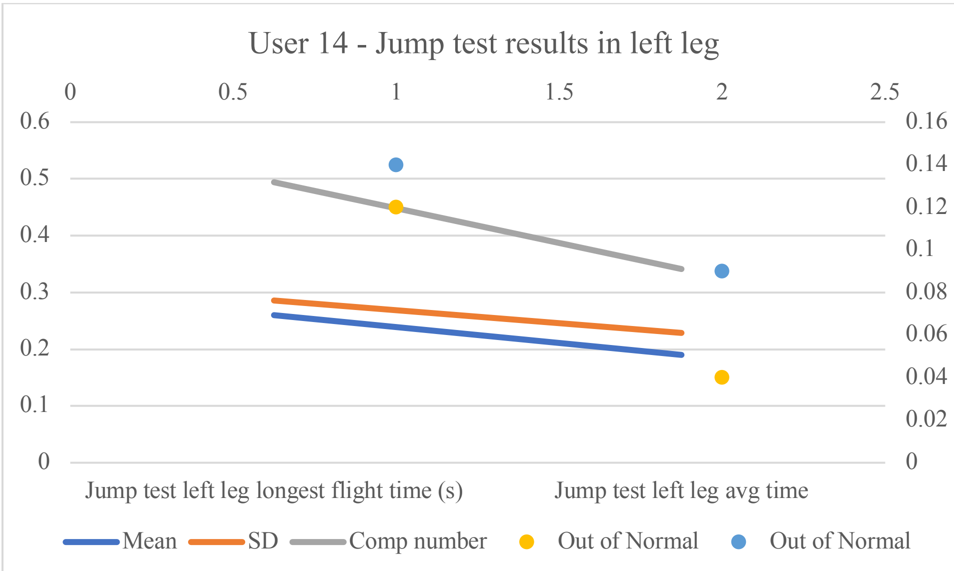


Figure 28. Jump test result for User 14 on the left leg. Four out of normal results were found.

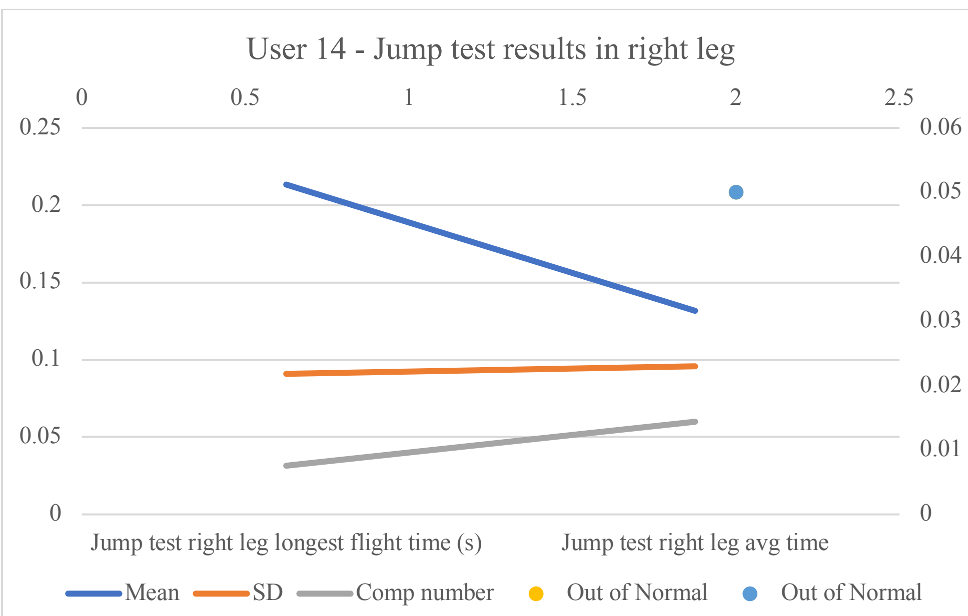


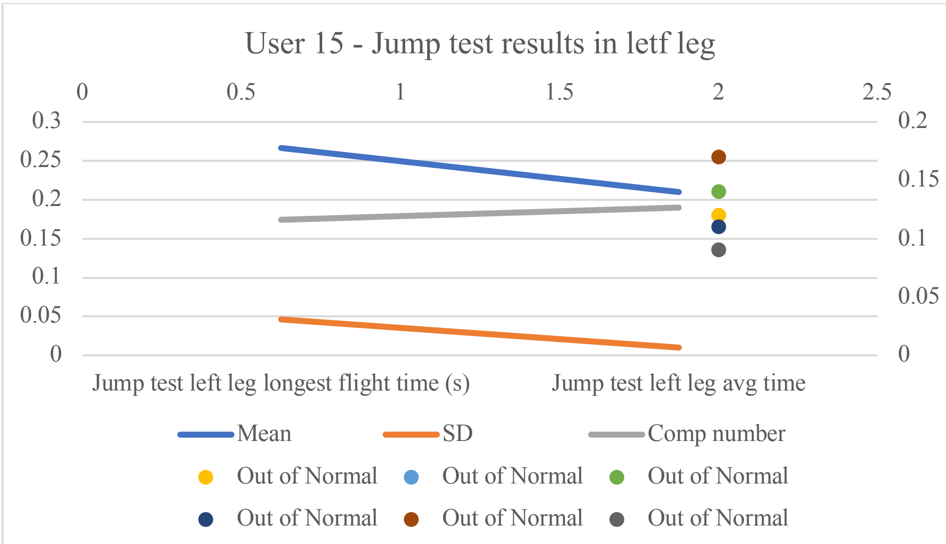
Figure 29. Jump test result for User 14 on the right leg. Two equal out of normal results were found.

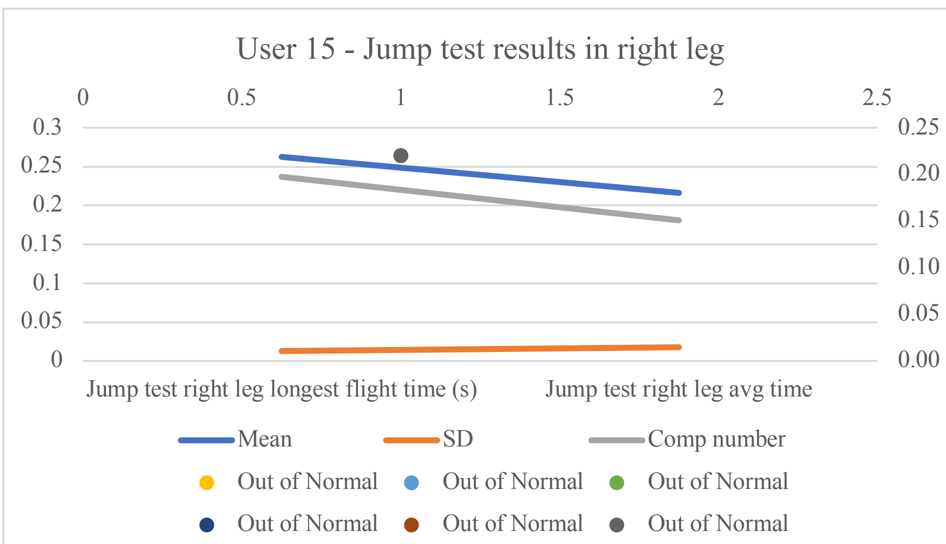
User 15

This patient had several out of normal range values for both legs in different test measured.

For the left leg, user 15 had 6 out of normal values when measured for average time and no out of normal values when measured for longest flight time.

For the right leg, there were 6 equal out of normal values on the longest flight time measurement, there were no out of normal values found in average time.





ere found.

Figure 31. Jump test result for User 15 on the right leg. Six equal out of normal results were found.

User 16

User 16 had no out of normal values for each leg and each measurement taken.

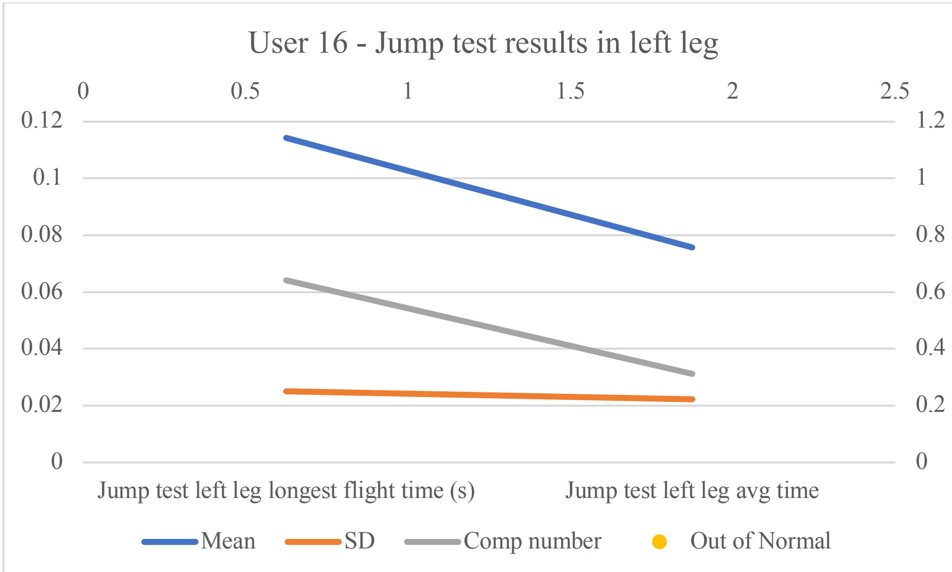


Figure 32. Jump test result for User 16 on the left leg. No out of normal results were found.

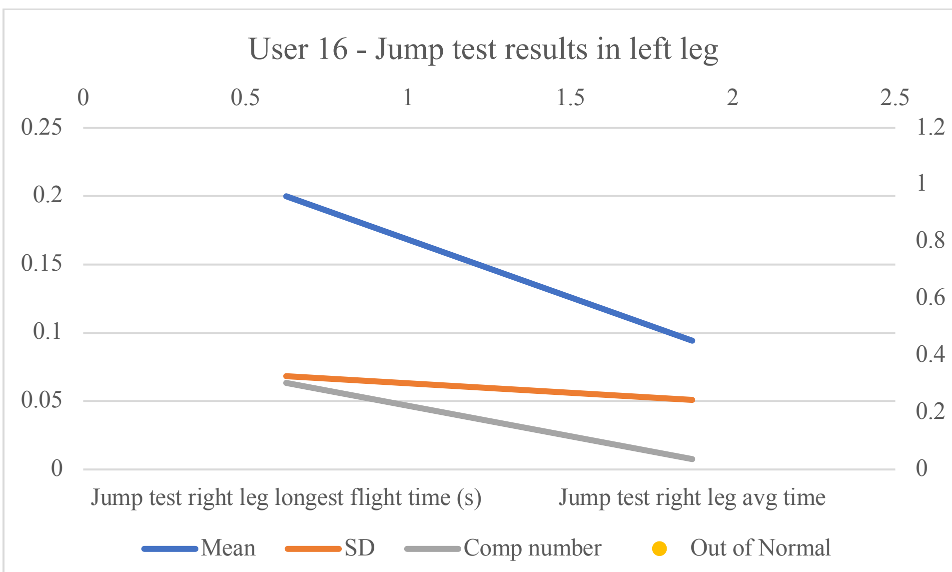


Figure 33. Jump test result for User 16 on the right leg. No out of normal results were found.

User 17

The measurements taken with the left leg displayed a few out of normal values, the measurements for longest flight time had one out of normal value while the average time had five out of normal values. The measurements taken with the right leg had no out of normal values.

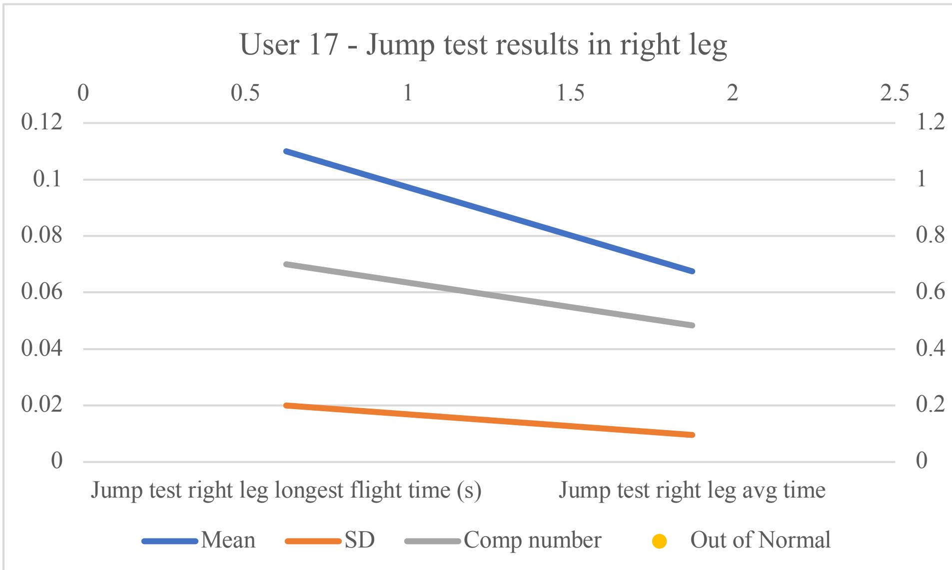


Figure 34. Jump test result for User 17 on the left leg. Six out of normal results in total were found.

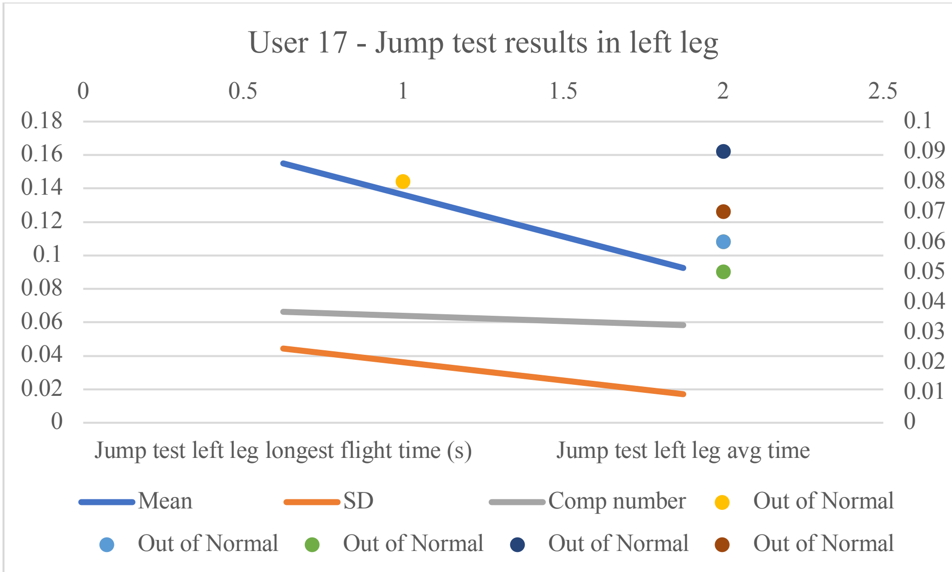


Figure 35. Jump test result for User 17 on the right leg. No out of normal results were found.

User 18

User 18 did not have any out of normal values that was found in both legs for both type of measurements taken.

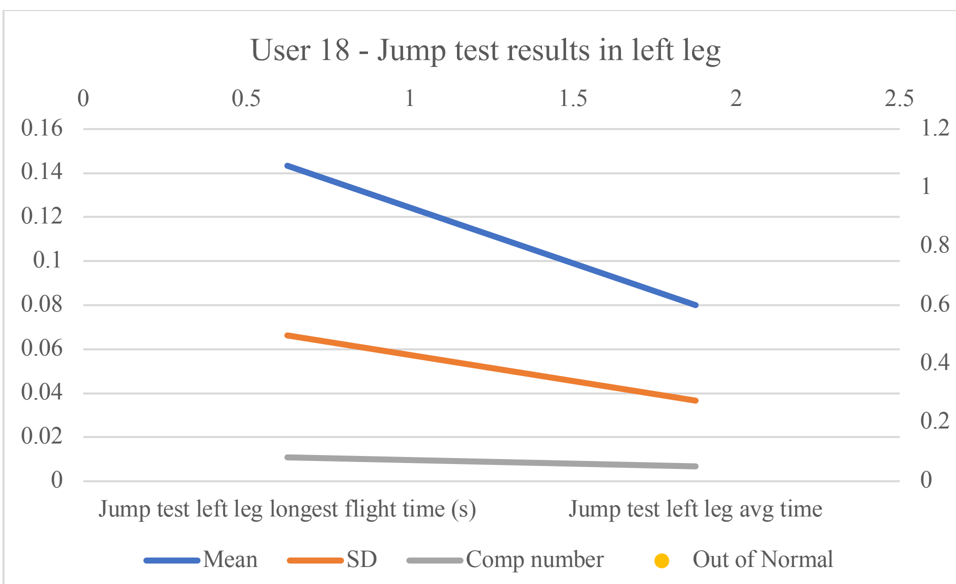


Figure 36. Jump test result for User 18 on the left leg. No out of normal results were found.

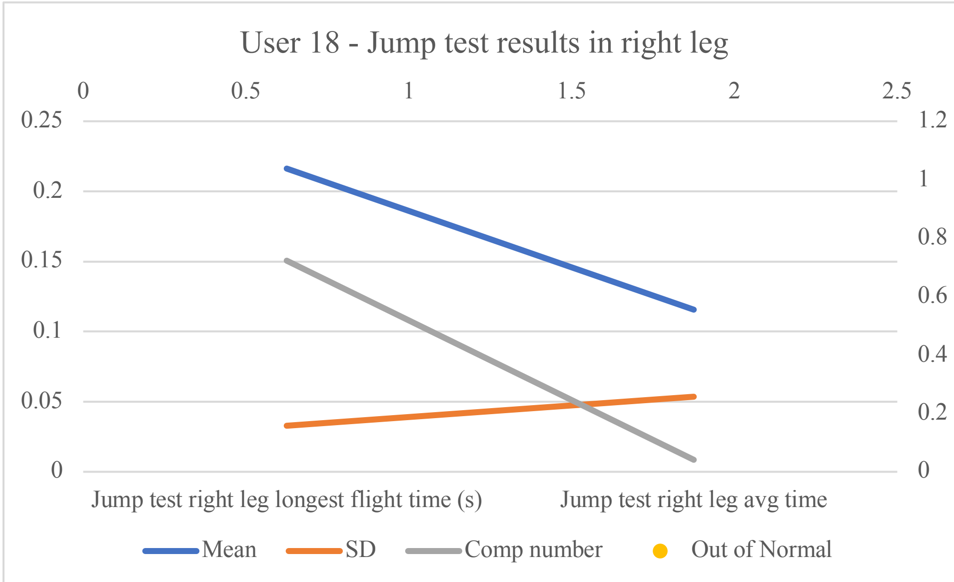


Figure 37. Jump test result for User 18 on the right leg. No out of normal results were found.

User 20

User 20 did not have any out of normal values that was found in both legs for both type of measurements taken.

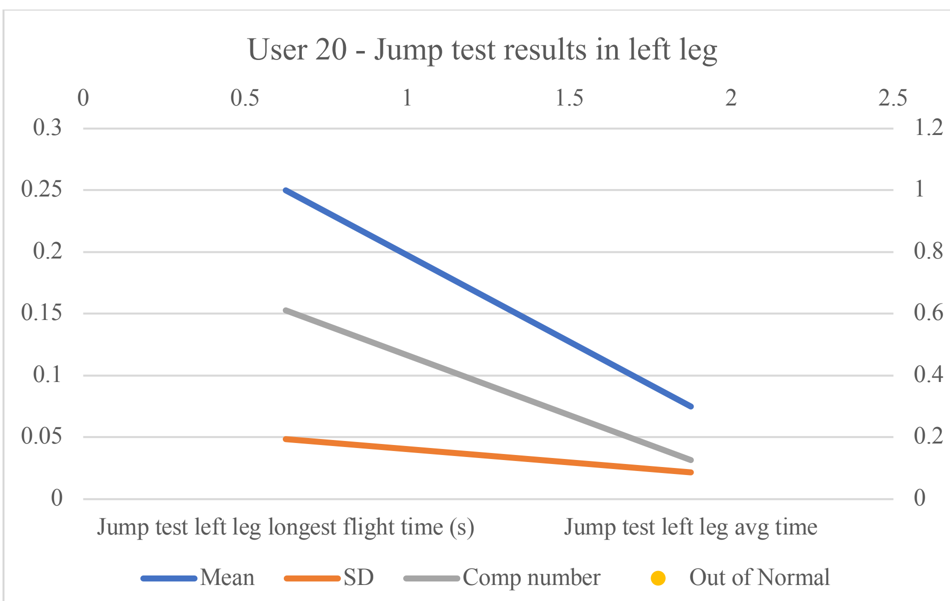


Figure 38. Jump test result for User 20 on the right leg. No out of normal results were found.

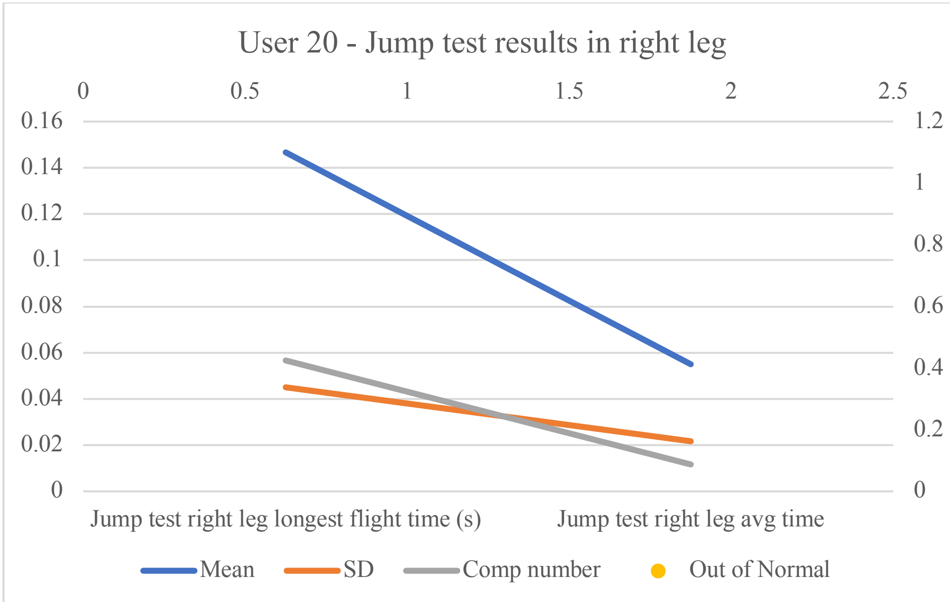


Figure 39. Jump test result for User 20 on the right leg. No out of normal results were found.

User 21

This user had only one out of normal value for the right leg with the longest flight time measurement. The other measurements taken came with no out of normal range values.

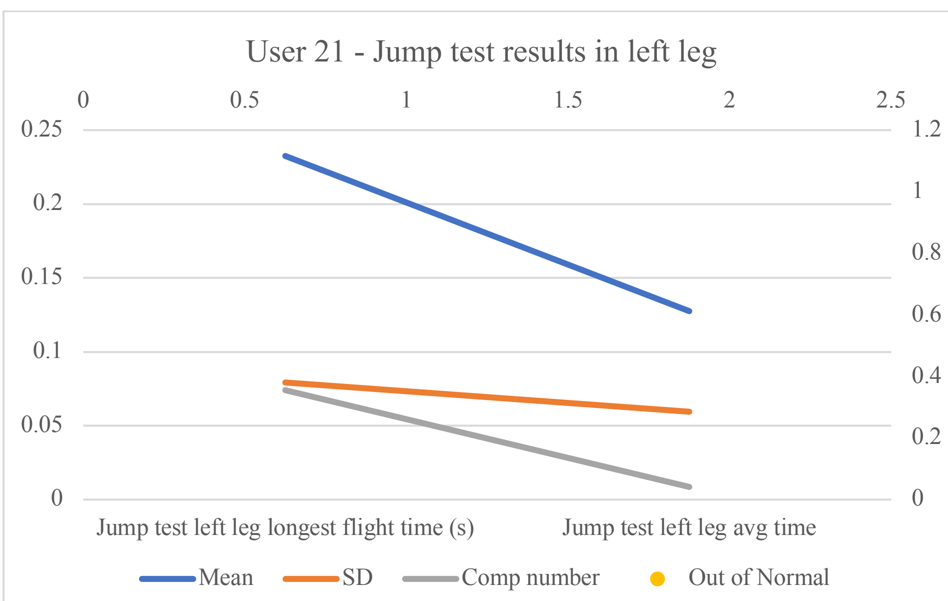


Figure 40. Jump test result for User 21 on the left leg. No out of normal results were found.

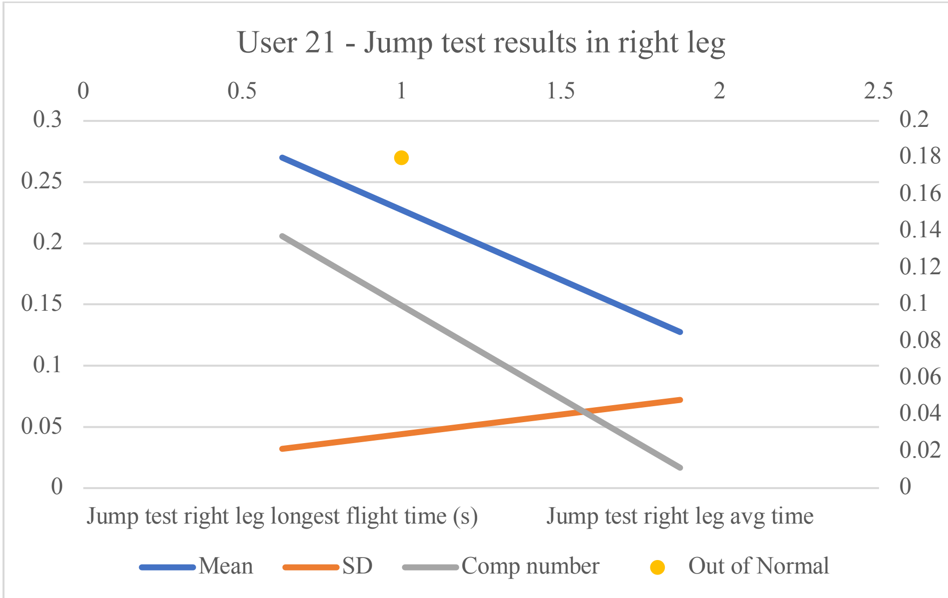


Figure 41. Jump test result for User 21 on the right leg. One out of normal results was found.

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