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Extended Abstract of Doctoral Dissertation

Analysis of biomechanical and bioelectric parameters for the needs of automation of diagnostics and rehabilitation of patients

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Introduction and motivation

Optimal results in rehabilitation and physical therapy are achieved when a thorough assessment is made of the patient who actively participates in and adheres to treatment recommendations, and his or her health and progress are continuously monitored. The success of conventional therapy depends largely on the therapist's experience, previous experience with similar cases, and ability to develop effective rehabilitation strategies.

These researches are motivated by current challenges in the healthcare system, especially in diagnosis and rehabilitation. Traditional methods often rely on the subjective assessments and expertise of rehabilitation physicians or physiotherapists, which can lead to variability in patient care. Additionally, the growing demand for rehabilitation in healthcare systems around the world calls for innovative approaches to reduce the burden on healthcare staff and resources.

Integrating advanced technologies such as machine learning and robotics into rehabilitation practices creates the opportunity to address these challenges by automating and optimizing certain processes. In the context of automation of the diagnostic and rehabilitation process, the goal is to reduce the dependence on human intervention, especially the knowledge of the physical therapist, throughout the entire stage of the therapeutic program. Therapy supported by expert systems using artificial intelligence enables automatic adjustment of each parameter to the patient's needs without the involvement of staff. Automation of diagnostic and therapeutic processes, and feedback loop mechanisms for rehabilitation applications are considered promising but under-researched areas. This dissertation is a significant step in the development of this research.

Thesis statements and scope

The scientific problem addressed in this thesis is the absence of conclusive evidence validating the effectiveness of the methodologies and treatment protocols employed in robotic-assisted diagnostics and therapeutic interventions. The central objective of the research conducted in this dissertation is to establish the methodological essentials for an automated expert platform designed to aid, enhance, and automate the diagnosis and rehabilitation process.

The research used calculations of biomechanical and bioelectric parameters, machine learning and robotics technologies to develop a feedback mechanism that integrates electromyography (EMG), torque and limb position data, thus enabling a more objective, effective and patient-tailored rehabilitation strategy. The research primarily investigated upper limb movements, with a particular emphasis on elbow flexion and extension actions involving the biceps and triceps muscles, during isokinetic muscle force assessments and tests for spasticity and muscle stiffness. Additionally, another study explored EMG biofeedback of pelvic floor muscles in the context of telerehabilitation, employing a remotely conducted evaluation protocol. Furthermore, there was research on EMG-triggered movement knee rehabilitation involving rectus femoris and biceps femoris muscles with using of a rehabilitation robot.

To address the scientific issue, the approach is to select established bioelectrical and biomechanical parameters and confirm their effectiveness and objectivity in diagnostic and therapeutic processes using robot-assisted methods.

Based on the motivation and the aim of this dissertation, the following hypotheses have been formulated:

I. **EMG signals complemented by torque and limb position, generated by patients during machine-assisted diagnostic procedures allow to objectively assess the patient's condition.**

II. **EMG, complemented by torque and position measurements, when applicable, provide a complete set of signals facilitating biofeedback-based effective rehabilitation, also in telemedicine solutions.**

Review of biomechanical and bioelectrical parameters and automatization in rehabilitation

A comprehensive literature review of existing knowledge on the analysis of biomechanical and bioelectric parameters for the automation of diagnostics and rehabilitation was performed. The latest developments in electromyography, torque measurement, and limb position assessment in rehabilitation are presented, as well as their integration into machine learning and robotics technologies to improve patient treatment.

Research on torque measurement and the parameters calculated from it in musculoskeletal assessment emphasize the key role of force, which is necessary to create body movements, support joint stability, and maintain posture. Position measurement allows you to set the limb's position in space, measure its speed and range of motion, and mark events according to the joint's range of motion. Electromyographic signals, after appropriate processing, provide valuable parameters allowing the assessment of muscle activity. Parameters presented include Moving Average (RMS), Zero Crossing (ZC), Onset, Offset, Mean Frequency (MNF), Median Frequency (MDF) and others.

Automation in diagnostics and rehabilitation was discussed, emphasizing the breakthrough importance of its introduction to these processes. By incorporating advanced technologies, the precision and speed of medical services have improved significantly, leading to better health outcomes and expanded access to medical care for patients. Clinical scales and protocols for assessing patients are presented, discussing the mechanisms, applications, and importance of these scales in the context of patient management.

Various scales, such as the Modified Ashworth Scale, Lovett Strength Scale, Brunnstrom Scale, Modified Rankin Scale, Fugl-Meyer Rating Scale, Barthel Index and others, were discussed, indicating their use in assessing various aspects of patients' health and functioning.

The current state of knowledge about rehabilitation robots, EMG biofeedback and gamification in rehabilitation, as well as artificial intelligence in rehabilitation was also presented, emphasizing the growing role of these technologies and methods in improving rehabilitation processes and in diagnosing and monitoring patients' progress.

System design and implementation

A system design and implementation framework developed for the analysis of biomechanical and bioelectrical parameters is presented, aiming to increase the automation of diagnostic and rehabilitation processes for patients. The integration of advanced measurement technologies (electromyograph, dynamometer, and goniometer), data analysis methods, and machine learning algorithms constitute the basis of this developed system, enabling precise monitoring and assessment of patient's condition.

The primary goal of this dissertation is to investigate and establish a basic methodology for an automated expert platform using biomechanical and bioelectrical parameters for the diagnosis and rehabilitation of patients. Using the power of machine learning and robotic systems, this study seeks to create a feedback loop that incorporates measurements of EMG, torque, and limb position to facilitate a more objective, efficient, and personalized approach to patient care.

Based on a comprehensive literature review, specifications were formulated for diagnostic and rehabilitation protocols to be integrated with Luna EMG and Stella BIO devices. These protocols include but are not limited to, Force isometric test, Force isokinetic test, Joint position sense evaluation, Muscle spasticity test, Maximum Voluntary Isometric Contraction (MVIC) EMG test, ROM measurement, the Glazer protocol, Muscle fatigue test, and Luna EMG initial evaluation. Validation and use of the developed protocols were presented in the following co-authored scientific publications: isokinetic strength test [6, 7], muscle fatigue test [8] and proprioception test [2, 3, 5]. Research on the use of robot movement initiated by the level of the electromyographic signal in the feedback loop was presented in the work [4].

In order to confirm the hypotheses presented in the doctoral dissertation, an evaluation of the formulated diagnostic and therapeutic procedures was carried out based on own research using data from clinical trials. The muscle strength test was performed in both the control group and the stroke group. The protocol focused on the upper limbs and included biceps and triceps EMG recordings, position, and torque. Validation of the Muscle Spasticity Test was performed on 68 healthy subjects and 116 stroke survivors, focusing on the upper limbs. It included EMG measurements of the biceps and triceps brachii, torque and position. Assessment of the Glazer Protocol was performed remotely in patients with stress urinary incontinence using a telemedicine rehabilitation program. Additionally, studies on the effectiveness of EMG-triggered exercise therapy in knee joint rehabilitation in stroke patients were presented.

Specialized research equipment was used: a Luna EMG rehabilitation robot and a Stella BIO electromyograph with electrostimulation, as well as software components for data acquisition, processing, and analysis, ensuring the highest standards of precision, reliability, and scalability in the study of patient diagnostics and rehabilitation. Luna EMG (Figure 1), manufactured by EGZOTech Sp. z o. o., is a multifunctional rehabilitation robot intended for medical purposes: rehabilitation, physiotherapy, and occupational therapy, including therapy and assessment of the patient's condition. This device is equipped with a position sensor, a dynamometer, and an electromyograph, offering various operating modes, including continuous passive movement, isokinetic movement, isotonic movement, isometric movement, electromyography measurement and biofeedback, EMG-triggered movement, proprioception assessment, and rehabilitation games. Stella BIO (Figure 2), also produced by EGZOTech Sp. z o. o., is an electromyographic biofeedback device with electrostimulation, designed to evaluate EMG signals from the pelvic floor and superficial muscles. This device supports telerehabilitation processes by enabling specialists to establish assessment and treatment protocols and providing them with continuous access to patient results.

Figure 1: Luna EMG with an upper limb extension and a Mezos SIT examination and treatment chair

In the research project of The National Centre for Research and Development (NCBR) "Development of innovative methods of automatic diagnostic and rehabilitation using robots and bioelectric measurements" POIR.01.01.01-00-2077/15, I contributed as a Product

Engineer, overseeing the development of the Luna EMG rehabilitation robot, encompassing the research, innovation, and development of the Stella BIO electromyography biofeedback device, which incorporates electrical stimulation, and the Mezos SIT examination and treatment chair, presented in Figure 1. whose technology was covered by two patent applications (P.440692 and P.440693). Another research project of the NCBR is "Development of an innovative rehabilitation splint for the lower limbs for neurological and orthopaedic patients using electromyography and electrostimulation" POIR.01.01.01-00-0855/20, I held the roles of Research and Development Project Manager and Biomedical Engineer. The Sidra LEG, a lower limbs rehabilitation robot, was certified under the EU Regulation 2017/745 MDR (TNP/MDR/0015/4038/2023) on November 28, 2023, and is subject to a patent application no P.445951. Furthermore, in the project of "Development of an innovative robot for automated hand neurorehabilitation and occupational therapy using electromyography" POIR.01.01.01-00-1859/20, where I served as a Biomedical Engineer, the Meissa OT, an upper limb rehabilitation robot, obtained certification under the same EU regulation on November 28, 2023. This technology is also pending patent protection no P.445950.

Figure 2: Use of the Stella BIO device during pelvic floor muscle therapy[1]

Automatization in diagnostics - Force Isokinetic Test

Two groups of participants took part in the research: one consisting of ten people suffering from a neurological disorder due to stroke (Group 1), and the other consisting of ten healthy people (Group 2). The tests were performed in three separate sessions, two of which took place on the same day (S1 and S2) and the third a few days later (S3). Bioelectrical activity was monitored for the triceps brachii (CH1) and biceps brachii (CH2). An isokinetic assessment was performed, including five cycles of maximum flexion and extensions of the elbow joint at a velocity of 50°/s. All test procedures were performed at the "AMED" Rehabilitation Clinic in Katowice, Poland, using the Luna EMG rehabilitation robot.

The results for the dominant upper limb (Table 1) indicate high reliability (ICC > 0.90) in the case of the average EMG RMS level (EMG CH1) for the triceps muscle during flexion (flex), average torque (Torque) for extension (ext) in sessions S1 and S2 and peak flexion torque (Peak T) measurements in all sessions. Moderate to good reliability was also obtained for several other parameters, including those derived from biceps electromyographic measurements and extension torque. In the group of healthy people, better results were observed in all parameters, presented in Tables 2 and 3. However, only a few significant differences were found when comparing the non-impaired upper limb of people with neurological disorders to both upper limbs of healthy people.

The results highlight the potential benefits and obstacles of using isokinetic dynamometry and surface electromyography tests to assess muscle strength and activity. The study provided a strong case for the use of isokinetic force testing using rehabilitation robots, which enable both measurements, offering valuable metrics for monitoring progress in neurological disorders, which is beneficial to clinical practitioners.

Automatization of diagnostics of stroke patients - Muscle stiffness and spasticity

Spasticity is a common symptom associated with changes in upper motor neurons, characterized by increased muscle tone and stiffness and increased reflex excitability, leading to uncontrolled muscle contractions or jerky movements. This research aimed to evaluate a system for automatic diagnosis of muscle stiffness and spasticity based on a test procedure performed on the Luna EMG rehabilitation robot. The first step was a pilot study of the muscle stiffness and spasticity test. The second was to check the reliability and repeatability of the prepared diagnostic test, improved based on the results and conclusions from the pilot study. The third was to find appropriate biomechanical and bioelectrical parameters and high-accuracy algorithms to classify a person as healthy or post-stroke.

The study included 116 stroke survivors and 68 healthy adults who met specific inclusion and exclusion criteria to ensure the validity and safety of the study. The research was carried out at the "Excelsior" Spa and Rehabilitation Hospital in Iwonicz-Zdrój and at the Laboratory of Innovative Biofeedback Methods of the University of Rzeszów.

The test was performed using the Luna EMG rehabilitation robot, which enables simultaneous measurement of the kinematic, biomechanical, and electrophysiological response of spastic stretch reflexes. The participant sat in a treatment chair and was securely at-

Table 1: Reliability and repeatability of results for the healthy group, dominant upper limb

Parameters	S	Mean	SD	CV(%)	SEM	p	Corr	ICC3
EMG CH1 ext	S1	146.54	97.28	66.39	30.76	0.2547	0.85	0.79
	S2	210.28	141.01	67.06	44.59			
EMG CH1 flex	S1	79.90	63.42	79.37	20.05	0.0273	0.95	**0.96**
	S2	96.20	75.72	78.70	23.94			
EMG CH2 ext	S1	60.98	42.40	69.53	13.41	0.0645	0.70	0.87
	S2	79.30	57.60	72.63	18.21			
EMG CH2 flex	S1	204.15	84.92	41.60	26.86	0.3028	0.62	0.58
	S2	254.98	125.50	49.22	39.69			
Torque ext	S1	11.07	4.37	39.48	1.38	0.1565	0.92	**0.91**
	S2	14.14	4.93	34.82	1.56			
Torque flex	S1	-16.88	7.97	-47.24	2.52	0.3121	0.84	0.81
	S2	-21.13	10.19	-48.21	3.22			
Peak T ext	S1	23.63	8.51	36.00	2.69	0.2531	0.82	0.81
	S2	28.56	10.07	35.28	3.19			
Peak T flex	S1	-28.67	12.86	-44.86	4.07	0.3674	0.95	**0.93**
	S2	-34.53	15.36	-44.50	4.86			
EMG CH1 ext	S1	146.54	97.28	66.39	30.76	0.016	0.93	0.77
	S3	200.64	178.37	88.90	56.40			
EMG CH1 flex	S1	79.90	63.42	79.37	20.05	0.469	0.89	0.47
	S3	56.87	27.42	48.22	8.67			
EMG CH2 ext	S1	60.98	42.40	69.53	13.41	0.031	1.00	0.84
	S3	71.46	41.39	57.92	13.09			
EMG CH2 flex	S1	204.15	84.92	41.60	26.86	0.469	0.86	0.81
	S3	222.51	132.02	59.33	41.75			
Torque ext	S1	11.07	4.37	39.48	1.38	0.156	0.86	0.75
	S3	13.96	8.74	62.62	2.76			
Torque flex	S1	-16.88	7.97	-47.24	2.52	0.219	0.96	0.89
	S3	-18.43	11.57	-62.79	3.66			
Peak T ext	S1	23.63	8.51	36.00	2.69	0.031	0.96	0.88
	S3	27.42	13.91	50.71	4.40			
Peak T flex	S1	-28.67	12.86	-44.86	4.07	0.156	0.96	**0.93**
	S3	-28.70	14.65	-51.03	4.63			
EMG CH1 ext	S2	210.28	141.01	67.06	44.59	0.156	0.93	0.77
	S3	200.64	178.37	88.90	56.40			
EMG CH1 flex	S2	96.20	75.72	78.70	23.94	0.219	0.89	0.39
	S3	56.87	27.42	48.22	8.67			
EMG CH2 ext	S2	79.30	57.60	72.63	18.21	0.297	0.82	0.76
	S3	71.46	41.39	57.92	13.09			
EMG CH2 flex	S2	254.98	125.50	49.22	39.69	0.938	0.68	0.84
	S3	222.51	132.02	59.33	41.75			
Torque ext	S2	14.14	4.93	34.82	1.56	0.938	0.89	0.79
	S3	13.96	8.74	62.62	2.76			
Torque flex	S2	-21.13	10.19	-48.21	3.22	0.938	1.00	**0.94**
	S3	-18.43	11.57	-62.79	3.66			
Peak T ext	S2	28.56	10.07	35.28	3.19	0.813	0.96	0.84
	S3	27.42	13.91	50.71	4.40			
Peak T flex	S2	-34.53	15.36	-44.50	4.86	0.578	0.96	**0.98**
	S3	-28.70	14.65	-51.03	4.63			

Mean - average, SD - standard deviation, S - session, CV - coefficient of variation, SEM - standard error of measurement, p - Wilcoxon test result, Corr - Spearman's correlation coefficient, ICC - intraclass correlation coefficient

tached to the apparatus using straps. The range of motion was determined to be between approximately 90° and 180° of elbow flexion. Before the procedure, the rehabilitation robot weighs the upper limb to reduce its influence on torque measurements. EMG signals were measured from surface electrodes on the biceps brachii - channel 1 (ch1) and triceps - channel 2 (ch2). The device initially places the limb in a resting position depending on the movement being tested (flexion or extension). Then it makes a single movement at a velocity of 10°/s and returns to the resting position at the same pace. This operation is followed by a 60-second rest period. Then, analogous movements are performed at speeds of 50°/s and 100°/s. Subjects were instructed to remain relaxed during the examination.

Table 2: Results of the t-student test of the disabled limb from the neurological group (G1) compared to the dominant limb of the healthy group (G2)

		MEAN		t	df	p	N		SD	
		G1	G2				G1	G2	G1	G2
EMG CH1	flex	31.5	79.97	-3.96	53	**0.0002**	28	27	18.25	61.61
	ext	113.78	184.17	-1.95	53	0.0563	28	27	131.89	135.57
EMG CH2	flex	97.17	227.73	-5.19	54	**0.000003**	29	27	74.22	111.70
	ext	30.69	70.48	-4.19	54	**0.0001**	29	27	19.08	47.23
Torque	flex	8.20	18.86	-5.02	54	**0.000006**	29	27	5.98	9.61
	ext	6.50	12.96	-4.24	54	**0.00009**	29	27	5.47	5.90
Peak T	flex	14.71	30.85	-5.10	54	**0.000005**	29	27	9.35	14.03
	ext	14.88	26.44	-4.23	54	**0.00009**	29	27	9.98	10.48

Table 3: Results of the t-student test of the disabled limb from the neurological group (G1) compared to the non-dominant limb of the healthy group (G2)

		MEAN		t	df	p	N		SD	
		G1	G2				G1	G2	G1	G2
EMG CH1	flex	31.85	73.72	-5.41	53	**0.000002**	28	27	18.25	36.48
	ext	113.78	198.21	-2.27	53	**0.027**	28	27	131.89	143.85
EMG CH2	flex	97.17	189.13	-3.93	54	**0.0002**	29	27	74.22	99.65
	ext	30.69	57.52	-3.26	54	**0.002**	29	27	19.08	39.62
Torque	flex	8.20	14.59	-3.76	54	**0.0004**	29	27	5.98	6.74
	ext	6.50	13.95	-4.48	54	**0.00004**	29	27	5.47	6.92
Peak T	flex	14.71	26.57	-4.28	54	**0.00008**	29	27	9.35	11.35
	ext	14.88	24.80	-3.68	54	**0.0005**	29	27	9.98	10.21

Figure 3 shows the data collected while performing a spasticity test on a person after a stroke.

Repeatability and reliability data were assessed using the Wilcoxon test or t-student test, the latter being applied to variables with a normal distribution (marked with an asterisk "*" in the tables) and p-values exceeding 0.05, suggesting no significant differences. Spearman or Pearson correlation with the latter applied to normally distributed variables (marked "*" in the tables) and the intraclass correlation coefficient (ICC). The variability of the data set was characterized by calculating the arithmetic means (Mean), standard deviations (SD), and 95% confidence intervals (CI) for the ICC values, along with the calculation of coefficients of variation (CV) and standard error of measurement (SEM). To assess differences between the stroke group and the group of healthy people, first, the normality of distribution was verified using the Shapiro-Wilk test, and then the Mann-Whitney U test or t-student test was used with p-values indicating the level of significance ($p<0.05$).

The tables presented in the chapter consist of biomechanical and bioelectrical parameters: Torque (T), EMG RMS from channel 1 (Ch1) and EMG RMS from channel 2 (Ch2), Position (Pos) for Maximum or Minimum torque (T) and EMG RMS (CH1 or

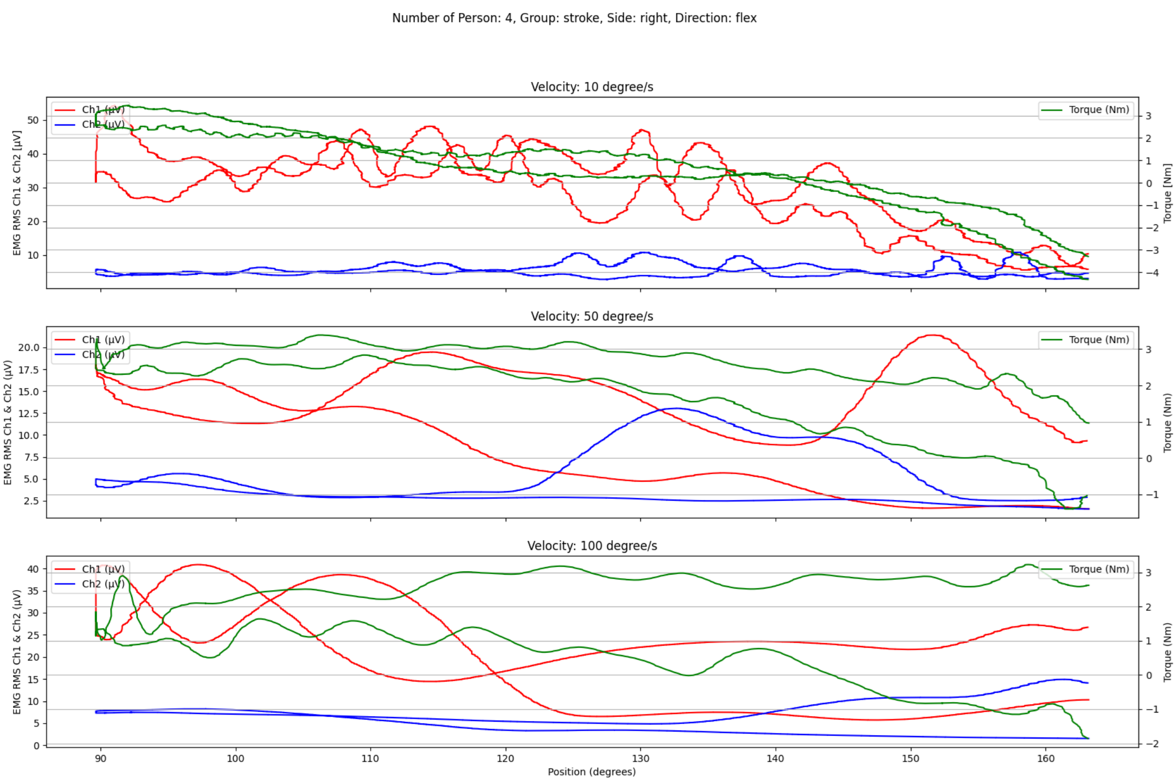

Figure 3: Measurement results from the test performed for a person after a stroke

CH2), all parameters are labeled 10, 50 and 100 denoting the velocity of movement. Selected results of statistical tests of repeatability and reliability with an ICC3 of 0.50 are presented in Tables 4 and5 for the group of stroke survivors.

In the control group, a comprehensive analysis of limb movements was performed to establish the basis for proper functioning and to assess the repeatability and reliability of machine-assisted diagnostics.

Right Limb Extension (Table 4): Analysis of right limb extension revealed noticeable variability in torque measurements. Nevertheless, moderate levels of reliability were observed for some variables, and the lack of significant differences between sessions suggested good repeatability of these measures. Several variables showed high reliability, with ICC values greater than 0.75, suggesting that these parameters are consistent across sessions. This includes T10 Min, Ch1 10 Zero Crossing (ZC), Ch1 50 Mean and Ch1 100 Mean. There were significant changes between sessions for some parameters, with p values less than 0.05. This includes parameters such as T50 Position Min (Pos Min), Ch1 50 Mean, and Ch1 50 cross-correlation of torque and peak EMG (CC Peak), indicating significant differences between sessions for these parameters.

Right limb flexion: The considerable variation in certain parameters, particularly at lower velocities, could compromise the dependability of these metrics for objectively evaluating a patient's state. Flexion movements of the right limb, similar to extension movements,

Table 4: Control group right limb extension movement

Parameter	S	Mean	SD	CV(%)	SEM	p	Corr	ICC3
T10 Min	1	-1.72	1.99	-116.07	0.30	0.31	0.76	0.84 (0.72-0.91)
	2	-1.41	1.38	-97.79	0.21			
T50 Min	1	-1.33	1.45	-108.77	0.22	0.49	0.63	0.54 (0.29-0.72)
	2	-1.21	0.87	-71.23	0.13			
T10 Pos Min	1	158.94	18.00	11.33	2.68	**0.05**	0.58	0.58 (0.34-0.74)
	2	162.61	17.55	10.79	2.62			
T100 Pos Min	1	123.62	36.86	29.82	5.50	0.11	0.50	0.54 (0.30-0.72)
	2	133.74	38.01	28.42	5.67			
T10 Min	1	7.53	1.84	24.38	0.27	0.87	0.63	0.57 (0.33-0.74)
	2	7.39	1.80	24.37	0.27			
Ch1 10 Mean	1	18.86	13.31	70.58	1.98	0.06	0.68	0.75 (0.59-0.86)
	2	22.36	42.89	191.80	6.39			
Ch1 10 Max	1	61.87	40.88	66.08	6.09	0.47	0.67	0.65 (0.44-0.79)
	2	79.46	148.10	186.38	22.08			
Ch1 10 ZC	1	2651.20	920.26	34.71	137.18	**0.05**	0.79	0.82 (0.69-0.90)
	2	2751.07	808.01	29.37	120.45			
Ch1 50 Mean	1	18.62	19.13	102.72	2.85	**0.03**	0.65	0.83 (0.72-0.90)
	2	15.48	16.77	108.31	2.50			
Ch1 50 Max	1	62.35	71.34	114.43	10.64	**0.05**	0.67	0.75 (0.59-0.86)
	2	46.77	50.09	107.10	7.47			
Ch1 50 MNF	1	277.61	9.06	3.27	1.35	0.20	0.49	0.66 (0.45-0.80)
	2	278.30	8.00	2.87	1.19			
Ch1 100 Mean	1	22.53	29.47	130.78	4.39	0.99	0.79	0.78 (0.63-0.87)
	2	20.11	18.47	91.85	2.75			
Ch1 100 Max	1	73.06	111.66	152.83	16.65	0.80	0.75	0.64 (0.42-0.79)
	2	62.77	53.44	85.14	7.97			
Ch1 100 CV	1	0.89	0.35	39.36	0.05	0.44*	0.64*	0.62 (0.40-0.77)
	2	0.85	0.29	33.45	0.04			
Ch1 100 Time Min	1	1.07	0.71	66.20	0.11	**0.01**	0.49	0.51 (0.26-0.70)
	2	0.80	0.70	87.46	0.10			
Ch1 100 MNF	1	277.88	9.52	3.43	1.42	0.91	0.53	0.66 (0.45-0.80)
	2	278.77	9.27	3.33	1.38			
Ch2 10 Mean	1	7.58	12.80	168.75	1.91	0.90	0.48	0.62 (0.39-0.78)
	2	6.77	6.50	96.00	0.97			
Ch2 10 Min	1	1.46	0.94	64.73	0.14	0.17	0.74	0.57 (0.32-0.75)
	2	1.33	0.81	60.79	0.12			
Ch2 50 Mean	1	8.97	10.47	116.71	1.56	0.29	0.63	0.53 (0.27-0.71)
	2	8.20	7.04	85.88	1.05			
Ch2 50 Pos Min	1	122.96	28.68	23.33	4.28	0.63	0.52	0.50 (0.24-0.69)
	2	123.84	28.55	23.05	4.26			
Ch2 50 MNF	1	293.07	13.76	4.69	2.05	0.75	0.60	0.65 (0.44-0.79)
	2	293.72	14.20	4.83	2.12			
Ch2 50 MDF	1	77.30	35.14	45.46	5.24	0.39	0.58	0.66 (0.45-0.80)
	2	82.14	35.79	43.57	5.34			
Ch2 100 Mean	1	10.19	9.85	96.73	1.47	0.19	0.73	0.51 (0.25-0.70)
	2	9.96	9.15	91.91	1.36			
Ch2 100 Min	1	1.85	1.19	64.62	0.18	0.62	0.56	0.72 (0.54-0.84)
	2	1.86	1.18	63.13	0.18			
Ch2 100 CV	1	0.74	0.33	44.94	0.05	0.77*	0.55*	0.54 (0.29-0.72)
	2	0.72	0.36	49.50	0.05			
Ch2 100 MNF	1	292.06	12.56	4.30	1.87	0.51	0.62	0.67 (0.47-0.81)
	2	292.26	15.70	5.37	2.34			
Ch2 100 MDF	1	75.04	32.67	43.54	4.87	0.18	0.67	0.71 (0.53-0.83)
	2	78.30	38.89	49.67	5.80			
Ch2 100 ZC	1	575.68	117.35	20.38	17.49	0.60*	0.69*	0.69 (0.50-0.82)
	2	568.20	120.68	21.24	17.99			

were characterized by high variability. However, these moves also showed moderate reliability and repeatability across sessions, indicating a consistent pattern of objectivity. The moderate to high reliability of some variables, such as the zero crossing (ZC) of Ch2 100 (ICC of 0.80), supports the potential of using EMG signals and torque measurements in objective assessments, provided that higher reliability variables are prioritized.

Left Limb Extension: For left limb extension, the control group demonstrated consistent

performance across all sessions. Despite variability, some parameters showed moderate to high reliability, and the lack of significant differences between sessions indicated good repeatability of movements.
Left limb flexion: Left limb flexion movements showed a similar pattern to extension movements, with stable performance across sessions. High reliability was reported for key parameters, confirming the consistency of calculations despite inherent variability in assessment.

The analysis included stroke survivors to assess the sensitivity and usefulness of diagnostic procedures in the context of rehabilitation.
Right limb extension (Table 5): The lack of significant changes between sessions for most variables suggests that the measurements are repeatable, which is crucial for assessing the progress or improvement of stroke survivors over time. The variability of some parameters highlights the need for careful consideration when interpreting these measurements, as large variability can affect the reliability of the estimates. The moderate to high reliability of some variables (e.g. T10 Max, Ch2 100 CC Time with an ICC of 0.73) supports the use of these measurements in the objective assessment of the patient's condition after stroke.
Right Limb Flexion: Several parameters such as T10 Max, T50 Max, Ch1 10 CC Peak and Ch1 ZC showed statistically significant changes between sessions with p-values of 0.04 or 0.02, suggesting significant differences in these measurements between sessions. Intraclass correlation coefficient (ICC) values vary across variables, with some showing moderate to good reliability, such as the Ch2 100 zero crossing with an ICC of 0.86, indicating consistent measurement of these variables across sessions. Despite considerable variability, some variables showed high reliability, highlighting their potential to reliably assess changes in status over time.
Left limb extension: Left limb extension movements in stroke survivors showed stable performance across sessions based on minimal changes in mean values for most variables and no significant between-session differences for most parameters. The high reliability of some parameters, such as T10 Min, T50 Min and T100 Min (ICC 0.88, 0.89 and 0.87, respectively), highlights their potential usefulness in the objective assessment and monitoring of the condition of stroke survivors over time.
Left limb flexion: Similar to extension movements, left limb flexion in stroke survivors showed stable performance across sessions. High reliability in terms of key variables such as, among others: mean and maximum torque values were recorded for all speeds, suggesting consistency in these measurements despite the inherent variability.

The selected Table 6 contains detailed references to the results of tests carried out in the field of flexion movement of the left upper limb. There was a noticeable reduction in the coefficient of variation (CV) of muscle activity (Ch1 CV and Ch2 CV) in stroke patients, indicating a more uniform response compared to the more variable response in healthy subjects. Significant differences in torque values were observed (left limb: T Mean

Table 5: Post-stroke group right limb extension movement

Parameter	S	Mean	SD	CV[%]	SEM	p	Corr	ICC3
T10 Max	1	2.94	1.49	50.67	0.30	0.79	0.57	0.76 (0.53-0.89)
	2	2.90	1.47	50.66	0.29			
T100 Max	1	2.58	1.05	40.57	0.21	0.71	0.55	0.50 (0.14-0.74)
	2	2.71	1.25	46.16	0.25			
T10 Min	1	-2.55	3.79	-148.90	0.76	0.73	0.70	0.68 (0.40-0.85)
	2	-2.03	2.33	-114.90	0.47			
T50 Min	1	-1.58	2.27	-144.00	0.45	0.87	0.66	0.57 (0.23-0.78)
	2	-1.51	1.79	-118.23	0.36			
T100 Min	1	-1.86	2.57	-137.94	0.51	0.37	0.61	0.53 (0.18-0.76)
	2	-1.29	1.44	-111.60	0.29			
T50 Pos Max	1	124.09	28.98	23.35	5.80	0.94	0.47	0.53 (0.17-0.76)
	2	125.87	33.35	26.49	6.67			
T100 Pos Max	1	145.42	28.06	19.30	5.61	0.92	0.45	0.55 (0.21-0.77)
	2	138.96	34.72	24.99	6.94			
Ch1 10 Mean	1	26.15	23.32	89.18	4.66	0.11	0.85	0.84 (0.63-0.93)
	2	31.02	40.75	131.40	8.15			
Ch1 10 Max	1	112.88	141.86	125.67	28.37	0.35	0.81	0.78 (0.52-0.90)
	2	106.51	173.05	162.48	34.61			
Ch1 10 ZC	1	2784.67	723.22	25.97	144.64	0.87*	0.57*	0.56 (0.18-0.80)
	2	2814.90	935.33	33.23	187.07			
Ch1 50 Mean	1	21.11	17.28	81.85	3.46	**0.02**	0.84	0.83 (0.62-0.93)
	2	24.82	23.75	95.70	4.75			
Ch1 50 Max	1	60.13	54.28	90.26	10.86	**0.01**	0.79	0.72 (0.42-0.88)
	2	76.52	75.21	98.28	15.04			
Ch1 50 CC Peak	1	99437.66	113965.65	114.61	22793.13	0.06	0.57	0.53 (0.15-0.77)
	2	177607.14	329691.52	185.63	65938.30			
Ch1 50 CC Time	1	3.86	2.03	52.64	0.41	0.88	0.64	0.63 (0.29-0.83)
	2	3.62	2.15	59.23	0.43			
Ch1 100 Mean	1	22.05	17.83	80.86	3.57	0.14	0.56	0.62 (0.28-0.82)
	2	25.06	16.75	66.85	3.35			
Ch1 100 Max	1	61.28	46.91	76.56	9.38	**0.05**	0.61	0.59 (0.24-0.80)
	2	76.26	58.59	76.84	11.72			
Ch1 100 CC peak	1	66430.74	72495.46	109.13	14499.09	0.14	0.60	0.63 (0.32-0.82)
	2	83547.74	74137.86	88.74	14827.57			
Ch2 10 Mean	1	11.21	18.27	162.96	3.65	0.71	0.76	0.99 (0.96-1.00)
	2	13.01	19.66	151.20	3.93			
Ch2 10 Max	1	38.52	75.58	196.18	15.12	0.24	0.68	0.73 (0.34-0.90)
	2	59.87	103.76	173.33	20.75			
Ch2 10 CV	1	0.48	0.25	51.42	0.05	0.11*	0.80*	0.71 (0.30-0.89)
	2	0.66	0.44	67.20	0.09			
Ch2 10 MNF	1	290.62	11.86	4.08	2.37	0.99*	0.66*	0.62 (0.20-0.85)
	2	288.64	19.66	6.81	3.93			
Ch2 10 MDF	1	69.20	31.54	45.58	6.31	0.41*	0.63*	0.61 (0.20-0.84)
	2	73.58	44.60	60.61	8.92			
Ch2 10 CC Peak	1	226584.63	501100.38	221.15	100220.08	0.23	0.56	0.95 (0.87-0.98)
	2	303423.90	696293.78	229.48	139258.76			
Ch2 50 Mean	1	12.59	17.97	142.77	3.59	**0.003**	0.67	0.95 (0.89-0.98)
	2	17.31	24.13	139.44	4.83			
Ch2 50 Max	1	36.76	58.44	158.97	11.69	**0.008**	0.51	0.63 (0.28-0.83)
	2	77.33	152.46	197.14	30.49			
Ch2 50 Min	1	3.92	3.01	76.85	0.60	0.81	0.50	0.64 (0.30-0.84)
	2	3.84	2.63	68.50	0.53			
Ch2 50 CC Peak	1	76634.30	133078.40	173.65	26615.68	**0.05**	0.30	0.61 (0.26-0.82)
	2	140664.77	292785.53	208.14	58557.11			
Ch2 50 CC Time	1	4.14	1.96	47.31	0.39	0.06*	0.58*	0.58 (0.22-0.80)
	2	4.40	1.81	41.08	0.36			
Ch2 100 Mean	1	13.70	19.34	141.15	3.87	0.26	0.62	0.56 (0.21-0.79)
	2	16.71	20.80	124.49	4.16			
Ch2 100 Min	1	4.02	2.96	73.65	0.59	0.36	0.53	0.50 (0.12-0.75)
	2	3.96	2.46	62.20	0.49			
Ch2 100 Pos Min	1	131.37	26.54	20.21	5.31	**0.01**	0.53	0.56 (0.21-0.78)
	2	114.28	30.08	26.32	6.02			
Ch2 100 CC Time	1	2.69	0.97	36.20	0.19	**0.02**	0.69	0.73 (0.48-0.88)
	2	2.97	0.92	30.89	0.18			

and T Min, right limb: T Mean and T Max) for all velocities, indicating greater resistance encountered by the robot from the limbs of stroke patients during flexion and extension movements. Minimum torque values were significantly lower in the healthy group in the right limb flexion range, suggesting that these subjects were able to assist the robot. For the extension movement of both limbs, EMG measurements showed a noticeable increase in muscle activation of both biceps and triceps at all speeds, indicating increased activity in stroke patients compared to healthy subjects at both mean and trough values. However, in the case of flexion movement, only electromyography of the triceps brachii muscle showed a significant increase in the obtained values (greater activity) between the groups for the average, maximum, and minimum values. Moreover, it was found that the values of frequency parameters in the EMG of the biceps muscle (Ch1) differ significantly in the case of extension movement of both limbs.

Table 6: Results from spasticity test of stroke survivors (G1) and control group (G2) for left limb flexion

Param	Velocity 10			Velocity 50			Velocity 100		
	$\bar{x}$±SD G1	$\bar{x}$±SD G2	p-value	$\bar{x}$±SD G1	$\bar{x}$±SD G2	p-value	$\bar{x}$±SD G1	$\bar{x}$±SD G2	p-value
T Mean	-0.81±1.51	-0.36±1.01	**7.81E-08**	-0.60±1.79	-0.34±1.05	**0.0002**	-0.62±1.85	-0.34±1.03	**8.47E-06**
T Max	1.70±3.69	1.19±1.20	0.531	1.42±3.47	0.91±1.15	0.696	1.45 ± 3.61	1.25±1.18	**0.044**
T Min	-2.65±1.98	-1.42±1.39	**5.72E-16**	-2.22±1.51	-1.38±1.22	**4.00E-11**	-2.50±1.31	-1.80±1.00	**7.01E-09**
T CV	-1.76±7.51	-0.82±17.98	0.256	0.14±7.41	-0.45±3.53	0.095	1.83±31.02	-0.13±10.30	**0.024**
T Pos Max	204.67±31.07	204.77±37.20	0.152	215.08±38.10	226.50±43.91	**0.006**	238.91±38.33	236.19±43.60	0.363
T Pos Min	244.49±24.75	243.69±29.73	0.972	235.28±28.74	225.91±36.37	**0.004**	210.62±28.76	206.85±33.28	0.294
T Time Max	9.57±6.83	9.87±5.91	0.586	2.15±1.69	2.72±1.29	**0.029**	1.86±1.24	1.68±0.72	**0.009**
T Time Min	9.18±2.90	8.22±3.13	**0.004**	2.70±4.94	2.39±1.38	0.554	1.07±1.22	1.55±1.17	**5.56E-05**
Ch1 Mean	25.83±23.58	20.61±18.90	**0.006**	31.06±30.80	24.40±22.46	**0.0006**	32.82±33.07	23.90±22.93	**0.0001**
Ch1 Max	71.66±71.33	67.30±63.79	0.356	70.81±75.56	64.28±63.84	**0.016**	71.22±73.58	59.69±60.79	**0.006**
Ch1 Min	3.72±2.93	1.34±1.46	**2.00E-24**	5.23±5.86	2.08±4.00	**3.02E-20**	5.39±4.62	2.40±4.73	**3.88E-19**
Ch1 CV	0.65±0.24	0.83±0.35	**3.61E-05**	0.58±0.21	0.74±0.32	**7.53E-06**	0.58±0.20	0.75±0.32	**9.77E-06**
Ch1 Pos Max	241.51±26.93	235.77±37.25	0.170	246.18±30.34	241.93±37.85	0.318	248.70±29.50	245.07±39.26	0.691
Ch1 Pos Min	210.34±22.42	212.34±22.97	0.401	197.32±19.87	199.59±24.76	0.072	196.64±18.26	199.03±23.86	0.200
Ch1 Time Max	6.01±3.12	6.30±3.36	0.622	2.03±1.62	2.45±5.05	0.788	1.41±1.09	1.87±5.03	0.281
Ch1 Time Min	7.68±5.98	9.66±4.96	**0.008**	1.91±2.31	1.88±4.57	0.465	0.73±1.15	1.01±4.42	0.608
Ch1 MNF	279.27±8.03	278.20±10.77	**2.48E-06**	278.51±6.26	277.98±8.57	**0.006**	278.08±6.36	277.56±8.78	**0.0002**
Ch1 MDF	50.11±18.05	48.75±28.88	**2.68E-06**	49.06±15.06	47.08±17.77	**0.001**	48.37±13.72	47.25±20.26	**0.0005**
Ch1 CC Peak	433257±2350270	200473±1200595	0.076	251641±1070676	47248±125174	0.169	121967±695064	35424±82349	**0.0007**
Ch1 CC Time	19.68±11.32	18.16±9.97	**0.034**	4.38±3.52	5.03±2.89	0.302	4.38±2.62	3.72±1.44	**0.001**
Ch1 ZC	3031±3500	2808±1169	0.473	1167±5484	929±2039	0.887	437±261	665±2060	0.432
Ch2 Mean	11.18±10.20	6.87±8.70	**2.87E-08**	9.20±6.40	6.59±9.37	**4.38E-07**	9.67±7.19	7.06±9.12	**2.47E-08**
Ch2 Max	43.27±58.68	32.26±41.70	0.058	31.00±64.29	22.68±30.27	0.056	26.95±36.56	22.80±33.75	**0.016**
Ch2 Min	3.47±2.40	1.29±0.84	**1.11E-23**	3.57±2.44	1.49±1.07	**6.91E-20**	4.02±3.35	1.60±1.34	**3.13E-19**
Ch2 CV	0.61±0.34	0.77±0.45	**0.0002**	0.50±0.39	0.64±0.33	**2.82E-06**	0.48±0.28	0.65±0.34	**1.45E-06**
Ch2 Pos Max	206.34±27.97	210.83±32.84	**0.032**	213.69±32.83	220.74±37.82	**0.009**	220.06±36.41	230.61±38.87	**0.013**
Ch2 Pos Min	218.99±26.21	218.34±26.99	0.995	203.77±24.60	202.41±28.08	0.388	207.13±30.82	203.65±30.26	0.793
Ch2 Time Max	8.08±6.33	6.78±5.57	0.132	2.63±5.44	2.88±7.05	0.909	1.44±1.08	2.16±7.03	0.485
Ch2 Time Min	7.54±5.47	8.79±4.78	**0.026**	1.45±2.25	1.93±5.49	0.102	0.90±1.14	1.28±5.40	0.931
Ch2 MNF	291.94±12.70	289.21±12.19	**0.008**	287.67±10.22	285.94±10.74	0.066	285.84±9.59	286.04±10.86	0.340
Ch2 MDF	76.58±32.27	68.00±33.00	**0.002**	67.51±23.67	60.82±30.52	**0.002**	62.42±21.94	60.27±27.15	**0.029**
Ch2 CC Peak	166384±826665	56071±233942	0.610	36323±140738	16136±104234	0.552	32401±166197	11585±42749	**0.005**
Ch2 CC Time	17.69±12.85	17.09±11.12	0.183	4.66±3.57	5.24±3.04	0.421	4.57±2.55	3.91±1.34	**0.0006**
Ch2 ZC	3509±3513	3321±1084	0.789	937.85±1085.90	1104.67±2182.18	0.468	531.97±228.30	784.27±2209.72	0.093

This study also focuses on the use of robot-assisted diagnostics and machine learning (ML) techniques to assess spasticity in stroke survivors. Comparison of the control group with stroke survivors highlights the potential of robot-assisted diagnostics. Consistent results in the control group provide a reliable basis, while variability in measurements in stroke survivors highlights the importance of selecting appropriate biomechanical and bioelectrical parameters for accurate assessment. The study emphasizes the importance of objective, quantitative measurements, such as electromyography and torque measurements. The variability of mean values and standard deviations in flexion and extension movements of both limbs shows the variety of manifestations of problems with spasticity and motor control. This variability highlights the complexity of assessing and treating post-stroke spasticity. The use of HistGradientBoostingClassifier (accuracy 92.24%, Figure 4) and other ML techniques in diagnostics differentiates people after stroke from healthy ones, emphasizing the importance of appropriate selection of models and their parameters to improve predictive accuracy.

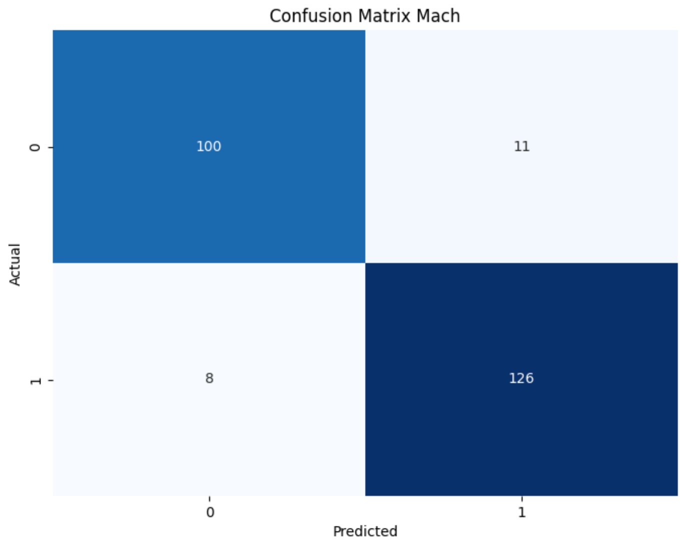

Figure 4: Confusion Matrix Mach

The research supports the hypothesis that machine-assisted diagnostic procedures can provide an objective assessment of a patient's condition, demonstrating the effectiveness of robot-assisted diagnostics in differentiating the function of healthy and affected individuals or limbs.

Automatization of diagnostics and rehabilitation of urinary incontinence patients

This research aims to evaluate the effectiveness of EMG biofeedback exercises for telerehabilitation using the Stella BIO device in the treatment of stress urinary incontinence (SUI) in perimenopausal women. The study involved 20 women with SUI aged 52 ±6.83. Before starting the pelvic floor muscle training program using Stella BIO, patients were examined by a urogynecological physiotherapist and received instructions for using the device. Participants completed the ICIQ-LUTSqol SF, a questionnaire assessing the quality of life of patients with urinary incontinence, used in research and clinical practice. Then, each patient received the Stella BIO device along with a telemedicine training program to be performed at home for about 8 weeks. The program included an initial and final Glazer protocol test (Figure 5) to assess muscle health. Data were collected from

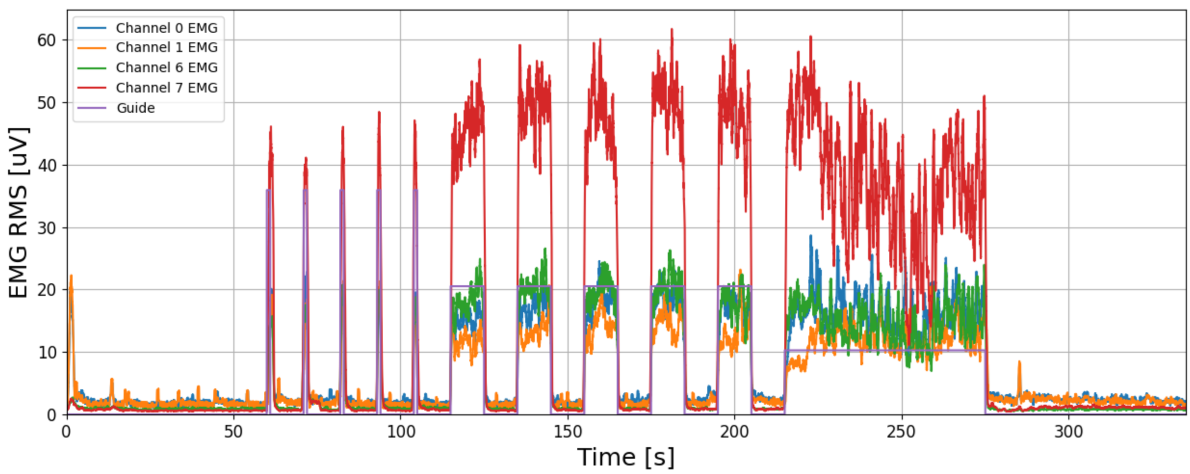

Figure 5: An example of EMG signals from the Glazer protocol from the conducted research

4 muscle channels: right transverse abdominis (ch 1), left transverse abdominis (ch 2), right part of the pubococcygeus muscle (ch 7) and left part of the pubococcygeus muscle (ch 8). The Wilcoxon signed rank test was used to determine the significance of differences in the calculated parameters before and after telemedicine treatment. The sEMG signal parameters were calculated in the manner described in detail in the doctoral dissertation, including the following stages: pre-baseline, fast contractions, tonic contractions, endurance stage and post-baseline.

The ICIQ-LUTSqol SF results were presented as follows: before treatment they were 10.93±3.47, and after treatment they were 6.46±3.95, with a statistically significant difference between them (p=0.005). Selected results from the two phases are presented as mean, standard deviation (SD) and p-value from the Wilcoxon test in Tables 7 and 8.

Improving phasic contraction phase parameters:

- Average amp from rest phase: Improvements were seen in channels 7 and 8 (p=0.005 and p=0.001 respectively), suggesting better muscle function.

- Time before peak: Also improved in channels 7 and 8 (p=0.049 and p=0.009), indicating faster muscle response.

- Reduction in Contraction duration (onset to offset) and Time of amp increase (onset to peak)): Significant improvement is observed in channels 7 and 8 (p=0.001 for both), indicating the faster ability of muscles to contract and achieve full strength.

- Shorter muscle relaxation times (Time after peak)

- Changes in average peak amplitude and standard deviation (SD) after treatment

Table 7: Results of Phasic Contraction Stage

Parameter	**Before**		**p**	**After**	
	Mean	**SD**		**Mean**	**SD**
Average peak amplitude [µV](7)	11.67	10.68	0.053	30.62	62.41
Average peak amplitude [µV](8)	25.75	64.10	**0.027**	22.13	25.70
Average mean amp from rest phase[µV](7)	2.61	1.97	**0.005**	1.46	1.04
Average mean amp from rest phase[µV](8)	2.57	2.06	**0.001**	1.54	1.20
Time before peak[s] (7)	1.10	0.44	**0.049**	1.17	1.68
Time before peak[s] (8)	1.17	0.53	**0.009**	0.79	0.20
Time after peak[s] (7)	1.54	1.13	0.295	1.22	0.89
Time after peak[s] (8)	1.40	0.82	0.687	1.32	1.06
Time of amp increase (onset to peak)[s](7)	5.12	3.20	**0.001**	2.48	1.72
Time of amp increase (onset to peak)[s](8)	5.37	3.26	**0.001**	3.06	1.81
Contraction duration (onset to offset)[s](7)	6.49	4.15	0.064	4.21	2.26
Contraction duration (onset to offset)[s](8)	6.49	3.32	0.084	4.83	2.50

The digit in the bracket designates the channel number corresponding to the muscle.

Improvement in the phase of tonic contractions:

- Median frequency: Significant increase in channel 7 from 44.99 Hz to 72.85 Hz (p=0.024), suggesting more effective muscle fiber recruitment.

- Activation and Release Time (Onset and Offset): Significant improvement for channel 7, from -0.22 seconds to -0.03 seconds (p=0.003), suggesting faster muscle activation. For channel 8, the offset time improved from 0.22 seconds to -0.11 seconds (p=0.030), indicating faster muscle relaxation.

- Time of amp decrease (peak to offset): Significant increase observed in both channels; in channel 7 from 6.41 seconds to 7.58 seconds (p=0.048), and in channel 8 from 6.27 seconds to 7.36 seconds (p=0.017), suggesting a longer duration of muscle contraction after treatment, which may indicate to improve muscle endurance.

Table 8: Results of Tonic Contraction Stage

Parameter	**Before**		**p**	**After**	
	Mean	**SD**		**Mean**	**SD**
Average mean amplitude work [µV] (7)	9.15	6.30	0.421	12.39	10.88
Average mean amplitude work [µV] (8)	10.94	10.47	0.391	11.23	7.81
Average peak amplitude [µV] (7)	13.26	9.11	0.277	17.91	13.87
Average peak amplitude [µV] (8)	15.88	14.64	0.241	16.91	10.60
Median frequency [Hz] (7)	44.99	18.04	**0.024**	72.85	36.81
Median frequency [Hz] (8)	44.92	17.25	0.320	61.91	30.81
Onset [s] (7)	-0.22	0.41	**0.003**	-0.03	0.22
Onset [s] (8)	-0.09	0.44	0.391	-0.003	0.41
Offset [s] (7)	0.03	1.66	0.639	-0.13	1.66
Offset [s] (8)	0.22	1.52	**0.030**	-0.11	2.23
Time of amp decrease (peak to offset)[s](7)	6.41	1.85	**0.048**	7.58	1.96
Time of amp decrease (peak to offset)[s](8)	6.27	2.27	**0.017**	7.36	2.34

The digit in the bracket designates the channel number corresponding to the muscle.

The research demonstrated that a telerehabilitation treatment protocol, employing EMG biofeedback, notably enhanced muscle control, functionality, and stamina. This was evidenced by improvements in ICIQ-LUTSqol SF test scores and various muscle performance parameters across different stages: pre-baseline, during phasic and tonic phases, throughout endurance testing, and post-baseline. The observed improvements in muscle control, enhanced recruitment of muscle fibers, quicker activation and relaxation times, and increased endurance underscore the potential of telerehabilitation as an effective method for managing stress urinary incontinence, with positive outcomes on muscle control and functionality.

The study involved analyzing the EMG signals from the pelvic floor muscles at each treatment phase, providing a comprehensive evaluation of the rehabilitation program's effects on different aspects of pelvic floor muscle functionality, including endurance, rapid response capability, initial conditions, and the maintenance of tonic contractions. Through an in-depth, step-by-step analysis, the research was able to pinpoint specific areas needing enhancement or further intervention, thereby facilitating the creation of more targeted and efficient rehabilitation strategies for the pelvic floor muscles.

In sum, this study underscores the viability of telerehabilitation as an effective approach for treating stress urinary incontinence, shedding light on both the benefits and challenges associated with its application.

Automatization of rehabilitation - EMG-triggered movement exercises

The research aimed to showcase the outcomes of treatments utilizing feedback-driven exercises, which incorporate electromyography, torque, and position measurements, facilitated by a rehabilitation robot. The study encompassed 7 individuals who had experienced an ischemic stroke. These participants engaged in a rehabilitation exercise regimen for two weeks, attending sessions five days a week, with each session ranging between 90 to 120 minutes. The rehabilitation approach melded individualized standard physiotherapy with sessions conducted using a rehabilitation robot, specifically targeting the lower limb with the Luna EMG rehabilitation robot. The therapy included a 5-minute continuous passive movement (CPM) session for knee flexion and extension; a 10-minute segment of EMG-triggered exercise using the activity of the rectus femoris (CH1) to assist knee extension; another 10-minute EMG-triggered exercise session utilizing the biceps femoris (CH2) for knee flexion; and a concluding 5-minute CPM session for the lower limb. The evaluation protocol involved a 1-minute EMG-triggered exercise for the rectus femoris (CH1) muscle, after a 3-minute knee CPM warm-up. Assessments were conducted at the start (S1) and after two weeks of therapy (S2).

Table 9 outlines the comparative results from the assessments conducted before and after the two-week treatment period. The findings from the study pointed to significant enhancements in certain parameters following the two weeks of therapy employing feedback exercises with the Luna EMG rehabilitation robot. Notable changes were seen in EMG measures and repetition times, reflecting an uptick in muscle activation and a boost in their performance efficiency.

There was a notable increase in the average and peak EMG RMS CH2 readings during phase 2 ($p=0.022$), indicating enhanced activation of the biceps femoris muscle. The time taken for maximum repetitions in both phases 1 and 2 decreased significantly ($p=0.047$ and $p=0.011$, respectively), reflecting quicker muscle response times and a sustained ability for muscle contraction. Additionally, the minimum repetition times in phase 2 showed significant improvement ($p=0.047$), underscoring a heightened efficiency in muscle reactions.

However, certain measurements, such as the average EMG RMS CH1 value in phase 1 and average torque in both phases, did not demonstrate significant alterations, pointing out the diverse effects of therapy.

This pilot study demonstrates that rehabilitative exercises, guided by feedback and facilitated by the Luna EMG rehabilitation robot, can significantly enhance muscle activation and performance in individuals recovering from an ischemic stroke. The findings indicate that incorporating this method could be beneficial alongside conventional stroke rehabilitation practices. To validate the efficacy of this rehabilitative strategy further and its application in tailored therapy plans, it is advised that future research involve larger participant groups and extended therapy durations.

Table 9: Results of test before (S1) and after 2 weeks of treatment (S2

Parametry	S	Mean	SD	CV[%]	SEM	p
EMG CH1 mean ph1	S1	44.88	45.62	101.65	17.24	0.469
	S2	31.04	23.56	75.91	8.91	
EMG CH1 mean ph2	S1	35.64	13.76	38.63	5.20	0.882*
	S2	33.88	27.29	80.55	10.31	
EMG CH2 mean ph1	S1	12.88	4.19	32.54	1.58	0.219
	S2	21.35	12.80	59.93	4.84	
EMG CH2 mean ph2	S1	11.23	3.06	27.20	1.15	**0.022***
	S2	20.22	8.54	42.22	3.23	
Torque mean ph1	S1	8.72	11.61	133.09	4.39	0.938
	S2	8.02	6.02	75.03	2.27	
Torque mean ph2	S1	-4.74	6.08	-128.13	2.30	0.376*
	S2	-7.32	4.25	-58.03	1.61	
Rep time mean ph1	S1	4.31	2.03	47.05	0.77	0.109
	S2	3.22	0.34	10.55	0.13	
Rep time mean ph2	S1	3.22	0.53	16.41	0.20	0.209*
	S2	2.89	0.40	13.99	0.15	
EMG CH1 max ph1	S1	203.07	182.77	90.00	69.08	0.578
	S2	123.62	63.97	51.75	24.18	
EMG CH1 max ph2	S1	179.11	138.77	77.48	52.45	0.253*
	S2	111.66	53.61	48.01	20.26	
EMG CH2 max ph1	S1	41.07	13.49	32.84	5.10	0.131*
	S2	72.17	48.97	67.86	18.51	
EMG CH2 max ph2	S1	35.99	15.42	42.85	5.83	**0.022***
	S2	74.64	35.53	47.60	13.43	
Torque max ph1	S1	24.86	23.94	96.28	9.05	0.469
	S2	20.66	15.48	74.90	5.85	
Torque max ph2	S1	9.96	7.93	79.61	3.00	0.257*
	S2	6.17	2.88	46.77	1.09	
Rep time max ph1	S1	6.56	3.41	52.07	1.29	**0.047**
	S2	3.91	0.69	17.60	0.26	
Rep time max ph2	S1	5.95	1.93	32.52	0.73	**0.011***
	S2	3.55	0.82	23.09	0.31	
Number of rep	S1	10.00	3.16	31.62	1.20	0.497*
	S2	10.86	0.69	6.36	0.26	
Rep time min ph1	S1	2.27	2.10	92.40	0.79	0.600
	S2	2.38	1.07	44.82	0.40	
Rep time min ph2	S1	0.93	1.31	140.95	0.50	**0.047**
	S2	2.12	0.61	28.65	0.23	

* - student's T-test instead of the Wilcoxon test ph1 - extension phase, ph2 - flexion phase, Ch1 - rectus femoris muscle, Ch2 - biceps femoris muscle, Rep time - repetition time, Number of rep - number of repetitions

Conclusion

This dissertation has addressed a critical scientific challenge: the absence of comprehensive evidence supporting the effectiveness of methodologies and treatment protocols in robotic-assisted diagnostics and therapeutic interventions. The primary goal of this research was to lay the foundational methodological principles for an automated expert platform that aims to augment, improve, and automate the processes of diagnosis and rehabilitation.

The author's significant contribution is highlighted by their examination of bioelectrical and biomechanical parameters related to muscle function, such as EMG (electromyography) for muscle activity, along with torque and position measurements. There was also explored the application of machine learning techniques for objectively distinguishing between healthy and affected individuals. Moreover, biomechanical and bioelectrical parameters were researched to customize exercises to match the patient's capabilities using feedback loops. This approach offers a tailored, efficient, and more objective method of patient treatment. The research mainly targeted movements of the upper limbs, focusing on the extension and flexion of the elbow. It investigated the role of the biceps and triceps in determining isokinetic muscle strength, as well as in evaluating muscle spasticity and stiffness. The study also explored the effectiveness of EMG biofeedback for pelvic floor muscles in a telerehabilitation setting, employing a protocol for remote assessments. Additionally, research was conducted on rehabilitating knee motion triggered by EMG, particularly targeting the rectus femoris and biceps femoris muscles with the aid of a rehabilitation robot. The findings from this research validated the hypotheses proposed in the doctoral thesis.

Bioelectrical and biomechanical parameters were tested for their reliability and objectivity in diagnostic and therapeutic procedures, assisted by robotic technologies. Table 10 displays the parameters that demonstrated high reliability among individuals who have survived strokes and healthy participants, across various limbs or types of movements. The outcomes of the applied methodology support the possibility of developing a cohesive system for initiating and monitoring rehabilitation processes, thereby automating them.

In conclusion, this dissertation not only addresses a significant gap in the existing literature but also lays the groundwork for future innovations in the field of robotic-assisted healthcare and automatization. The presented results and approach effectively solve the outlined scientific problem and confirm the presented hypotheses, demonstrating the practicality and application of these parameters in automating and improving patient care.

Table 10: Biomechainal and bioelectrical parameters with good reliability

Test	**Parameters**	**Group**	**Limb and movement**
Muscle Force	Torque mean Peak torque	Healthy	Upper limb Extension and Flexion
Muscle Spasticity	Ch1 10 MNF Ch1 10 MDF	Healthy	Left Upper limb
Muscle Spasticity	Ch1 10 Mean Ch1 50 Mean	Healthy	Right Upper limb
Muscle Spasticity	Ch1 10 Mean Ch1 50 Mean Ch2 10 Mean	Post-stroke	Right Upper limb
Muscle Spasticity	T 10 Max T 100 Peak*	Post-stroke	Left Upper limb
Muscle Spasticity	Ch2 10 Mean Ch2 50 Mean	Post-stroke	Extension Upper limb
Muscle Spasticity	Ch1 10 Mean Ch1 50 Mean	Post-stroke	Flexion Upper limb

*Torque Peak means T Min for extension and T Max for flexion

Bibliography

[1] Egzotech. *Egzotech Website*. Accessed on 2024-01-30. 2023. URL: https://www.egzotech.com/.

[2] J. Leszczak, A. Wolan-Nieroda, M. Drużbicki, A. Poświata, M. Mikulski, A. Roksela and A. Guzik. 'Evaluation of Reliability of the Luna EMG Rehabilitation Robot to Assess Proprioception in the Upper Limbs in 102 Healthy Young Adults'. In: *Medical Science Monitor: International Medical Journal of Experimental and Clinical Research* 30 (2024), e942439. DOI: 10.12659/MSM.942439. URL: https://doi.org/10.12659/MSM.942439.

[3] Justyna Leszczak, Bogumiła Pniak, Anna Poświata, Anna Roksela, Michał Mikulski, Mariusz Drużbicki and Agnieszka Guzik. 'Assessment of external and internal compliance of the Luna EMG robots as a tool for assessing upper limb proprioception in people after stroke'. In: *Międzynarodowe Dni Rehabilitacji w Rzeszowie*. Poster presented at the Międzynarodowe Dni Rehabilitacji w Rzeszowie, 8-9 February 2024. 2024.

[4] Patrycja Lewandowska-Sroka, Rafał Stabrawa, Dominika Kozak, Anna Poświata, Barbara Łysoń-Uklańska, Katarzyna Bienias, Anna Roksela, Marcin Kliś and Michael Mikulski. 'The Influence of EMG-Triggered Robotic Movement on Walking, Muscle Force and Spasticity after an Ischemic Stroke'. In: *Medicina (Kaunas, Lithuania)* 57 (Mar. 2021), p. 227. DOI: 10.3390/medicina57030227.

[5] Łukasz Oleksy, Anna Mika, Iwona Sulowska-Daszyk, Ewelina Dušek, Renata Kielnar and Artur Stolarczyk. 'The Reliability of Pelvic Floor Muscle Bioelectrical Activity (sEMG) Assessment Using a Multi-Activity Measurement Protocol in Young Women'. In: *International Journal of Environmental Research and Public Health* 18 (Jan. 2021), p. 765. DOI: 10.3390/ijerph18020765.

[6] Anna Roksela, Anna Poswiata, Jarosław Śmieja, Dominika Kozak, Katarzyna Bienias, Jakub Ślaga and Michael Mikulski. 'Evaluation of Neurological Disorders in Isokinetic Dynamometry and Surface Electromyography Activity of Biceps and Triceps Muscles'. In: Sept. 2023, pp. 325–338. ISBN: 978-3-031-38429-5. DOI: 10.1007/978-3-031-38430-1_25.

[7] Krystyna Stańczyk, Anna Poświata, Anna Roksela and Michał Mikulski. 'Assessment of Muscle Fatigue, Strength and Muscle Activation During Exercises with the Usage of Robot Luna EMG, Among Patients with Multiple Sclerosis'. In: *Information Technology in Biomedicine*. Ed. by Ewa Pietka, Pawel Badura, Jacek Kawa and Wojciech Wieclawek. Cham: Springer International Publishing, 2019, pp. 117–128. ISBN: 978-3-030-23762-2.

[8] Ewa Zasadzka, Sławomir Tobis, Tomasz Trzmiel, Renata Marchewka, Dominika Kozak, Anna Roksela, Anna Pieczyńska and Katarzyna Hojan. 'Application of an EMG-Rehabilitation Robot in Patients with Post-Coronavirus Fatigue Syndrome (COVID-19) - A Feasibility Study'. In: *International Journal of Environmental Research and Public Health* 19.16 (2022). ISSN: 1660-4601. DOI: 10.3390/ijerph191610398. URL: https://www.mdpi.com/1660-4601/19/16/10398.