CZECH TECHNICAL UNIVERSITY IN PRAGUE
FACULTY OF BIOMEDICAL ENGINEERING
Department of Biomedical Technology

Master Thesis

2019 Dana Hassan

CZECH TECHNICAL UNIVERSITY IN PRAGUE

FACULTY OF BIOMEDICAL ENGINEERING

Department of Biomedical Technology

Methods for Evaluation of Gait of Children with Cerebral Palsy

Master thesis

Study programme: Biomedical and Clinical Technology
Study branch: Biomedical Engineering

Supervisor: doc. Ing. Patrik Kutílek, MSc., Ph.D.

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Kladno, May 2019

MASTER'S THESIS ASSIGNMENT

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II. MASTER'S THESIS DETAILS

Master's thesis title in English:

Methods for evaluation of gait of children with Cerebral Palsy

Master's thesis title in Czech:

Metody hodnocení chůze dětí s mozkovou obrnou

Guidelines:

Design methods for evaluating kinematic data and EMG signal measured during walking of children with cerebral palsy. The camera system and the EMG recording system will be used to record body segment behavior during walking. For the evaluation of the data, you will use methods that are introduced in medical practice for assessing limb behavior during walking. These will be methods based on the evaluation of time and frequency domain data and the evaluation of the interdependence of the measured data. Implement the proposed methods in MATLAB sw. Test the proposed methods on at least 10 subjects and evaluate the applicability of methods in medical practice.

Bibliography / sources:

[1] Hollister S., Biomechanics, ed. 1, University of Michigan, 2007, ISBN NA
[2] Kayvan Najarian and Robert Splinter, Biomedical Signal and Image Processing, ed. 2nd, Columbia University in New York, 2012, ISBN 9781466506558
[3] Ron Seymour, Prosthetics and Orthotics: Lower Limb and Spine, ed. 1st, LWW, 2002, ISBN 10: 0781728541
[4] Michelle M. Lusardi, Orthotics and Prosthetics in Rehabilitation, ed. 2nd, Butterworth-Heinemann, 2006, ISBN 10: 0750674792

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Declaration

I hereby declare that I have completed this thesis having the topic Methods for Evaluation of Gait of Children with Cerebral Palsy independently and I have included a full list of used references.

I do not have a compelling reason against the use of this thesis within the meaning of Section 60 of the Act No 121/2000 Sb., on copyright and rights related to copyright and on amendment to some other acts (The Copyright Act), as amended.

In Kladno ……..... ……..……

Student´s signature

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Foremost, I would like to express my sincere gratitude to my thesis advisor, doc. Ing. Patrik Kutílek, MSc., Ph.D. for the continuous support of my MSc. study and research, for his patience, motivation, enthusiasm, and immense knowledge.

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Master's Thesis title:

Methods for Evaluation of Gait of Children with Cerebral Palsy

Abstract:

The development of motion capture system has attracted the interest of researches for studying the gait analysis using mathematical and statistical methods. Gait analysis has been applied in Biomechanics to investigate the difference in performance between healthy individuals and patients of a specific disease for medical studies. This study aims to select and design methods to evaluate the Kinematic data and EMG signal obtained during gait analysis before and after RAGT using time and frequency domains.

Twelve spastic diparesis/diplegia CP children (5-17 years old) met all the inclusion criteria, participated in this experimental study. Kinematic and EMG data were collected using a Camera motion capture system (Vicon Motion Systems Ltd) and 8-channel EMG (Noraxon TeleMyo 2400T, Noraxon U.S.A. Inc.). The measured data were analyzed and evaluated MATLAB®, The MathWorks, Inc., Natick, MA).

Statistical significance ($p<0.05$) was evident in single joint motion, couple joint coordination and muscle activity. Furthermore, strong spearman's correlation (> 0.5) demonstrated between time-domain and frequency-domain analysis of the muscle activity.

The results obtained confirm that time-domain and frequency-domain methods used in this study can identify significant improvements in the gait pattern and help better understand the relationship between the joint angles and muscle activity before and after rehabilitation.

Key words:

Cerebral Palsy, Spasticity, robotic-assisted gait training, kinematics, electromyography, time-domain and frequency domain.

Název diplomové práce:

Metody hodnocení chůze dětí s mozkovou obrnou

Abstrakt:

Vývoj systému pro záznam pohybu vede k vyššímu zájmu výzkumů o studium a analýzu chůze pomocí matematických a statistických metod hodnocení pohybových dat. V biomechanice byla použita řada metod analýz chůze, které zkoumají rozdíl v pohybu mezi zdravými jedinci a pacienty specifického onemocnění. Tato studie si klade za cíl vybrat a navrhnout metody pro hodnocení kinematických dat a EMG signálu získaného při analýze chůze před a po RAGT s použitím metod hodnocení dat v časových a frekvenčních oblastech. Dvanáct dětí spastické diparézy / diplegie CP (5-17 let) splnilo veškerá kritéria zahrnutí a zúčastnilo se experimentální studie. Kinematická a EMG data byla shromážděna za použití kamerového systému pro zachycení pohybu (Vicon Motion Systems Ltd) a 8 kanálového EMG (Noraxon TeleMyo 2400T, Noraxon U.S.A. Inc.). Naměřená data byla analyzována a vyhodnocena pomocí MATLAB® sw (The MathWorks, Inc., Natick, MA).

Byla zjištěna statistická významnost rozdílu ($p<0,05$) před a po aplikaci RAGT v konkrétních případech úhlů v kloubech dolní končetiny, ve společné koordinaci pohybu končetin a svalové aktivitě. Silná spearmanova korelace (> 0,5) prokázala korelaci mezi vybranými určovanými parametry získané zpracováním dat v časové a frekvenční oblasti. Získané výsledky potvrzují, že metody v časové oblasti a ve frekvenční oblasti používané v této studii mohou identifikovat významná zlepšení ve způsobu chůze a lépe porozumět vztahu mezi úhly kloubů a svalovou aktivitou před a po rehabilitaci.

Klíčová slova:

Mozková obrna, spasticita, robotický asistovaný trénink chůze, kinematika, elektromyografie, časová doména a frekvenční doména.

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List of symbols and abbreviations

RAGT	Robot-assisted gait training
SA	Symmetry Analysis
SI	Symmetry Index
RI	Ratio Index
GA	Gait Asymmetry
EMG	Electromyography
Ag	Agonist
Antag	Antagonist
Normative	Norm
Flex/Ext	Flexion/ Extension
ABD/ADD	Abduction Adduction
vs	versus
Max	Maximum
Min	Minimum
ROM	Range of motion
Fft	Fast Fourier transform
Deg	Degree
N-dom	Non-dominant
Dom	Dominant
B/A	Before/After
RF	Rectus Femoris
BF	Biceps Femoris
TA	Tibialis Anterior
MG	Medial Gastrocnemius

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1 Introduction

Cerebral palsy is defined as a disorder of movement, muscle tone or posture that is a result of a damage or abnormality that occurs to the immature developing brain, usually before a child is born. Cerebral palsy is a caused by several factors that include mutations in genes leading to brain abnormality, maternal infections affecting developing fetus, fetal stroke due to an insufficient blood supply to the developing brain and etc…

Cerebral palsy is associated with movement and coordination problems which include either too stiff or too floppy muscle tone, spasticity (exaggerated reflexes), rigidity, ataxia (lack of muscle coordination), writhing movements, seizures, difficulties in walking, sucking and precise motions and delays in speech and reaching motor skills milestones [1].

Spasticity is the most common type of cerebral palsy which corresponds to hypertonia mediated by the stretch reflex. Hyper-excitability of the stretch reflex results in a velocity-dependent increase in the muscle tone [2, 3]. Symptoms involve uncontrollable muscle spasms, stiffening and abnormal muscle tone. The few myofibrils with decreased longitudinal length present in the affected muscles, cause deformations in the musculoskeletal system.

Conditions like affected locomotor ability and decreased mobility due to Spasticity can be enhanced by several methods that include supportive treatments, therapies and surgeries. Locomotor training focuses more on the retraining of motor function via plastic change [4]. The rehabilitation of the human locomotion after a spinal cord injury is a neurophysiological mechanism that enhances the afferent input to the spinal cord and activates the central pattern generators (CPG) embedded within the lumbosacral spinal cord [5].

Robotic-assisted gait training is a rehabilitation method that involves repetitave gait movement using bilateral robotic orthosis, body-weight support and treadmill. The Patient is suspended in a harness over the treadmill, and the robotic frame is fitted to the client's legs. The robotic frame then moves the client's legs (with or without the client's

active participation) in a natural walking pattern. The computer-controlled guidance allows individual adjustments of different gait parameters such as stride length and amount of weight-bearing [6].

Figure 1: Robot-assisted gait training for pediatrics (https://www.cincinnatichildrens.org/giving/how-you-help/stories/ftc/archives/spring-2012/lokomat).

1.1 Literature Review

Human motion analysis techniques have been in application since the 1970s to study and understand the mechanical function of the musculoskeletal system during the execution of a motor task. New technological advancements has given rise to devices and techniques which provide specialists with efficient measurements and a large amount of reliable data on patient's gait to allow objective evaluation of different gait parameters [7]. Human motion analysis allows the identification of altered kinematic, kinetic or EMG patterns that can be used to evaluate the neuro-musculoskeletal conditions to improve subsequent treatment planning and/or to assess the efficacy of treatment in various patient groups [8]. Gait analysis have been successfully implemented in clinical applications to study gait deviations of cerebral palsy patients [9].

The development of robotic technology in rehabilitation techniques and programs has facilitated the process of improving gait patterns. Advances in treadmill and robotic technology, RAGT (robotic-assisted gait training), have refined ways to support the person's body weight, while helping the lower limbs and torso to maintain appropriate alignment and patterns when the person initiates and performs gait [10]. This achieved

by the robotic-controlled exoskeleton or footplates which can assist with the specific guidance of hip, knee and ankle movements, instead of the therapist supporting or guiding the person's body segment positioning [11].

Several methods have been implemented to evaluate the rehabilitation process for the purpose of improving gait patterns for patients suffering from cerebral palsy. Widely used methods are cyclograms which evaluate the movement of one limb and symmetry analysis which studies the coordination of the movement of two limbs [12].

Cyclograms are angle-angle diagrams known to be reliable for statistical studies of cyclic processes, such as gait [12]. Cyclograms are best defined as closed trajectories generated by simultaneously plotting two (or more) joint quantities [13]. C. Hershler *et al.* (1980) described in their paper that the quantification and physical interpretations of the parameters extracted from the angle-angle diagrams not only provided a valuable adjunct to visual assessment of the gaits but also elicited significant information regarding overall coordination and control during each gait [17]. Their work consisted of the assessment of three geometric characteristics of the closed-loop cyclograms of normal healthy gaits, the perimeter P, the area A, and the dimensionless ratio $\frac{P}{\sqrt{A}}$. The results showed a linear relationship between the perimeter and the area with the the average walking speed, while the quantity $\frac{P}{\sqrt{A}}$ stayed constant. Cyclogram area is intuitively related to the conjoint range of the angular movements concerned. The larger the range, the larger the cyclogram area [23].

Human gait is often assumed to be symmetrical with right and left sides performing identical motions [18]. Sadeghi H *et al.* published a paper to review the work done over the last few decades in demonstrating: (a) whether or not the lower limbs behave symmetrically during able-bodied gait; and (b) how limb dominance affects the symmetrical or asymmetrical behavior of the lower extremities [19]. Variables such as stride and step lengths as well as ranges of joint motion have all been observed to differ between sides of the body [18].

Stefanyshyn DJ *et al.* mentioned in their work that Rehabilitation of the ankle joint complex after injury is often considered complete when the injured ankle has the same

range of motion and strength as the uninjured contralateral limb even though this symmetry has never been quantified [20].

The asymmetry of gait can be quantified by using statistical approaches such as symmetry index (SI), ratio index (RI), symmetry angle and gait asymmetry [12 - 14].
The SI factor is a method of assessment of the differences between the kinematic and kinetic parameters for both lower limbs during walking. [11, 14]

$$SI = \frac{ROMnondominant\ (before)}{ROM\ \ dominant\ (after)}$$

Where ROM is the range of motion of joint of the non-dominant side before treatment divided by the ROM of the dominant side after treatment.
The RI factor indicates which of the variables has the highest value, in other words, it evaluates the maximum of right and left joint angles according to the below equation [14].

$$RI = \left(\frac{Xr}{Xl}\right)$$

The GA factor represents a logarithmic transform of the RI factor [14]. It is used to calculate asymmetry on the basis of the duration of the swing phase according to the below equation [14]:

$$GA = ln\left(\frac{Xr}{Xl}\right).100\%$$

Symmetry index and the ratio index compare bilateral variables such as maximum joint angles. The area within the bilateral cyclogram and its orientation are two parameters used to assess the symmetry of joint angle progressions [14-15]. If the area within the curve equals to zero and the orientation of the curve is forty five degrees, then gait is absolutely symmetrical [14-15].

Other methods are being implemented using the data measured from electromyography of gastrocnemius, tibialis anterior, hamstrings, and quadriceps muscle groups to evaluate the muscle coactivation about the knee (quadriceps versus hamstrings) and ankle (gastrocnemius versus tibialis anterior). This method help assess the balance of muscle activity before and after treatment by describing antagonistic activity as a

percentage of total myoelectric energy about the joint of interest relative to the agonist behavior [16].

$$Coactivity = \left\{1 - \frac{EMG\ (AG) - EMG\ (Antag)}{EMG\ (AG) + EMG\ (Antag)}\right\} * 100$$

In this relation, EMGAg represents the normalized myoelectric activity in the primary agonist muscle and EMGAntag represents that in the antagonist [16].

Richard T. Lauer et al. used the continuous wavelet transform (CWT) to analyze the EMG data collected from 50 children with cerebral palsy (CP). The CWT describes a series of mathematical techniques that can be used to analyze a complex time series signal with variable power or magnitude in a wide range of frequencies [21].

A. Mostayed et al. used the Discrete Fourier Transform (DFT) followed by Discrete Wavelet transform (DWT) analysis approach to detect abnormal gait patterns of joint angles 'ankle-knee', 'knee-hip' and 'hip-ankle'. The joint angle characteristics in were analyzed in the frequency domain and used the harmonic coefficient to recognize abnormal gait [22].

GyuTae Kim et al. described how the analysis of data collected from gait in the frequency domain seeks to measure parameters, which describe specific aspects of the frequency spectrum of the signal. The spectral analysis of the measured data determines if there were any changes in selected spectral parameters between healthy children and children with cerebral palsy [23].

Peter Valkovic et al. applied Discrete Fourier analysis to quantify the distribution of frequencies in the frequency spectrum of body sway to determine the accuracy of diagnoses made with artificial neural network techniques (ANNW) that identify postural sway patterns typical for balance disorders. Furthermore, the sum activity of body sway in different frequency ranges was determined as the integral (S(xi)) of the frequency spectrum in the specified range. Frequency ranges of interest were predefined as follows: low frequency range (FFTl: 0.1–2.4 Hz, dominant in normal subjects); middle frequency range (FFTm: 2.43–3.5 Hz, to allow the identification of patients with anterior lobe cerebellar atrophy (3 Hz sway) and PPV patients; high frequency range (FFTh: 3.53–8.0

Hz, to allow the identification of patients with PPV); and very high frequency range (FFTvh: 11–19 Hz, to allow the identification of patients with orthostatic tremor) [24].

1.2 Aims of thesis

The aim of this study is to select and design methods to evaluate the Kinematic data and EMG signal obtained during gait analysis before and after RAGT. The methods will be based on the application of time and frequency domain and the evaluation of interdependence of the measured data. The results of the evaluation will help us test whether there is the potential to enhance neuroplasticity of walking during intensive repetitive stimulation. Added to that we aim to objectify, quantify and find common indicators of changes.

2 Methods

2.1 Ethics Committee Approval

This experimental study took place at the University Rehabilitation Institute (URI), Republic of Slovenia. Ethical approvals for this study were obtained from both URI and Charles University, Faculty of Sport and Physical Education, in the Czech Republic.

2.2 Subjects

Eligible subjects that participated in the study were selected based on the following criteria: twelve patients (P1 – P12) between five to seventeen years old are diagnosed with cerebral palsy diplegia/ diparesis where solely one limb is affected more than the other, Gross Motor Function Classification (GMFCS) I-III, femur length min. 21 cm, ability to walk independently or with walker for at least short distances, ability to communicate fear, pain or discomfort, ability to follow simple instructions, no botulinum toxin in the last 3 months before RAGT, no antispastic medications, no severe contractures, and an ability to attend RAGT every single day [25, 26]. Parental written informed consent was signed prior to the procedure.

Clinical and medical examinations using goniometry and Gross Motor Function Measurement were done to determine which spastic lower limb is dominantly affected. This allowed us to differentiate patients with the left lower limb being dominantly affected (P1 to P6, P8, P9 and P12) and patients with right lower limb being dominantly affected (P7, P10 and P11).

2.3 Gait Data Collection

Camera motion capture system (Vicon Motion Systems Ltd) and 8-channel EMG (Noraxon TeleMyo 2400T, Noraxon U.S.A. Inc.) system were used for the measurement of the data needed for the analysis. Motion capture system is used for recording the movement of objects or people. The system originated in the life science market for gait analysis to capture joint angle data like pelvic tilt, pelvic obliquity, pelvic rotation, hip flexion / extension, hip abduction / adduction, hip external / internal rotation, knee flexion / extension, knee abduction / adduction and ankle flexion / extension. Electromyography (EMG) is used to measure the electrical activity associated with the muscle. The data measured by EMG was from tibialis anterior, gastrocnemius, rectus femoris, biceps femoris. This data is often interpreted in gait analysis using the simultaneously obtained signal from camera motion capture system to identify phases of the gait cycle.

Table 1: List of muscles EMG was recorded from and list of Joint angles Kinemitcs were calculated from.

EMG	Kinematics
Tibialis Anterior	Pelvic tilt, Pelvic obliquity, Pelvic rotation
Gastrocnemius	Hip flexion / extension, Hip abduction / adduction, Hip external / internal rotation
Rectus Femoris	Knee flexion / extension, Knee abduction / adduction
Biceps Femoris	Ankle flexion / extension

In accordance with the system manufacturer's recommendations, EMG was performed by two well-trained physiotherapists and two biomechanics experts from the URI Laboratory of Clinical Kinesiology. Skin preparation was performed before the EMG evaluation. A non-conductive layer of the skin was removed using a gentle abrasive material, Red Dot Skin Prep, to achieve better conductivity and adhesion of electrodes. 3M™ Red Dot™ 2560 & 2570 Multi-purpose Monitoring Electrodes with sticky gel were used.

Vicon Nexus 1.8.3. and Polygon software 3.5.1. (Oxford Metrics, Oxford, UK) were used to define the gait cycles. The gait cycle was represented by 50 evenly spaced samples (0–100% in 2% steps). Pre- and post-treatment data from both methods were compared with a normative. Normative data was included and generated by the Vicon

software by default to represent a sample of healthy subjects (a control group). Joint angle data and SD EMG evaluation were performed at the start and at the end of the 4-week therapy protocol.

2.4 Gait Data Analysis

The measured data was analyzed and evaluated in the time domain and in the frequency domain using MATLAB 2014a (MathWorks Inc, USA).

2.4.1 Time Domain

From the measured data, joint angles were calculated and Gait patterns were defined in the sagittal plane, frontal plane and transverse plane for flexion-extension, adduction-abduction movements and internal-external rotations respectively [27].

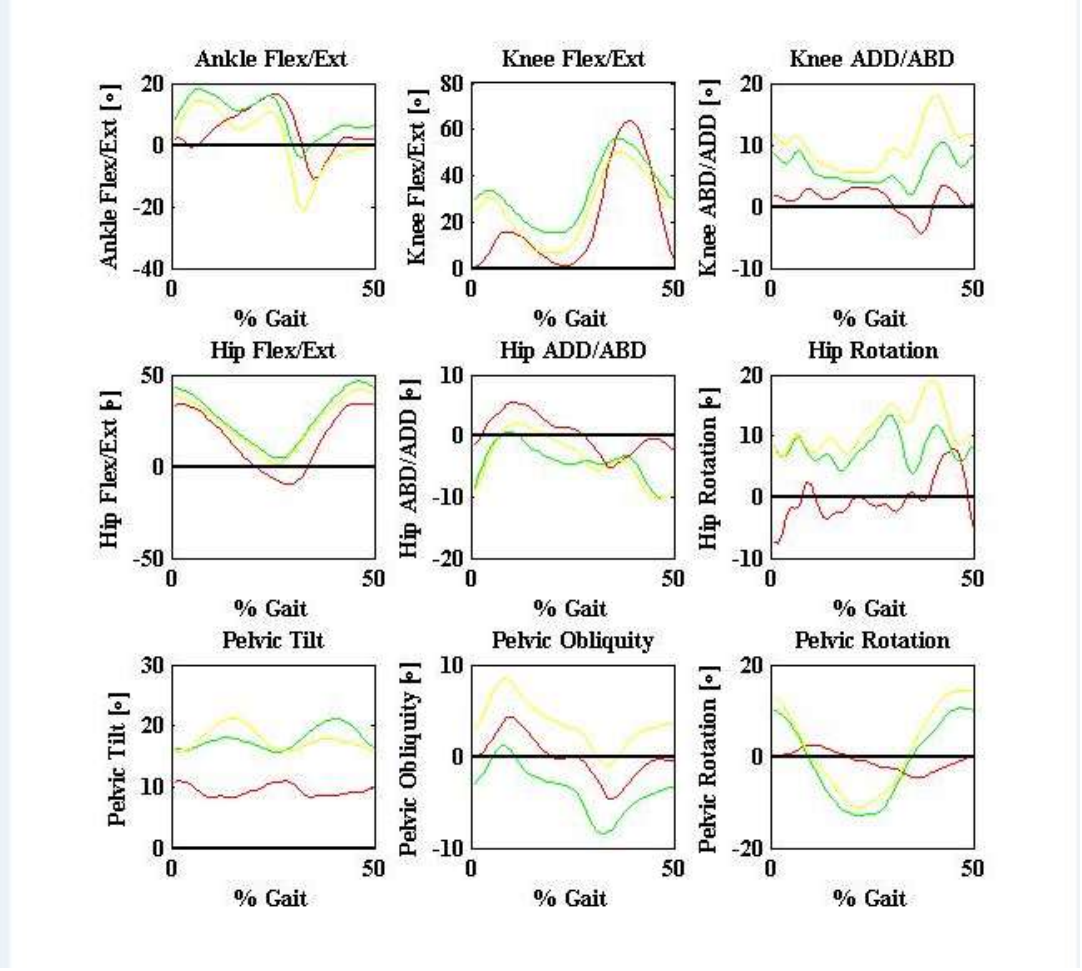

Figure 2: Kinematics of dominant (yellow) and non-dominant (green) sides of P2 versus normative (red) data before RAGT.

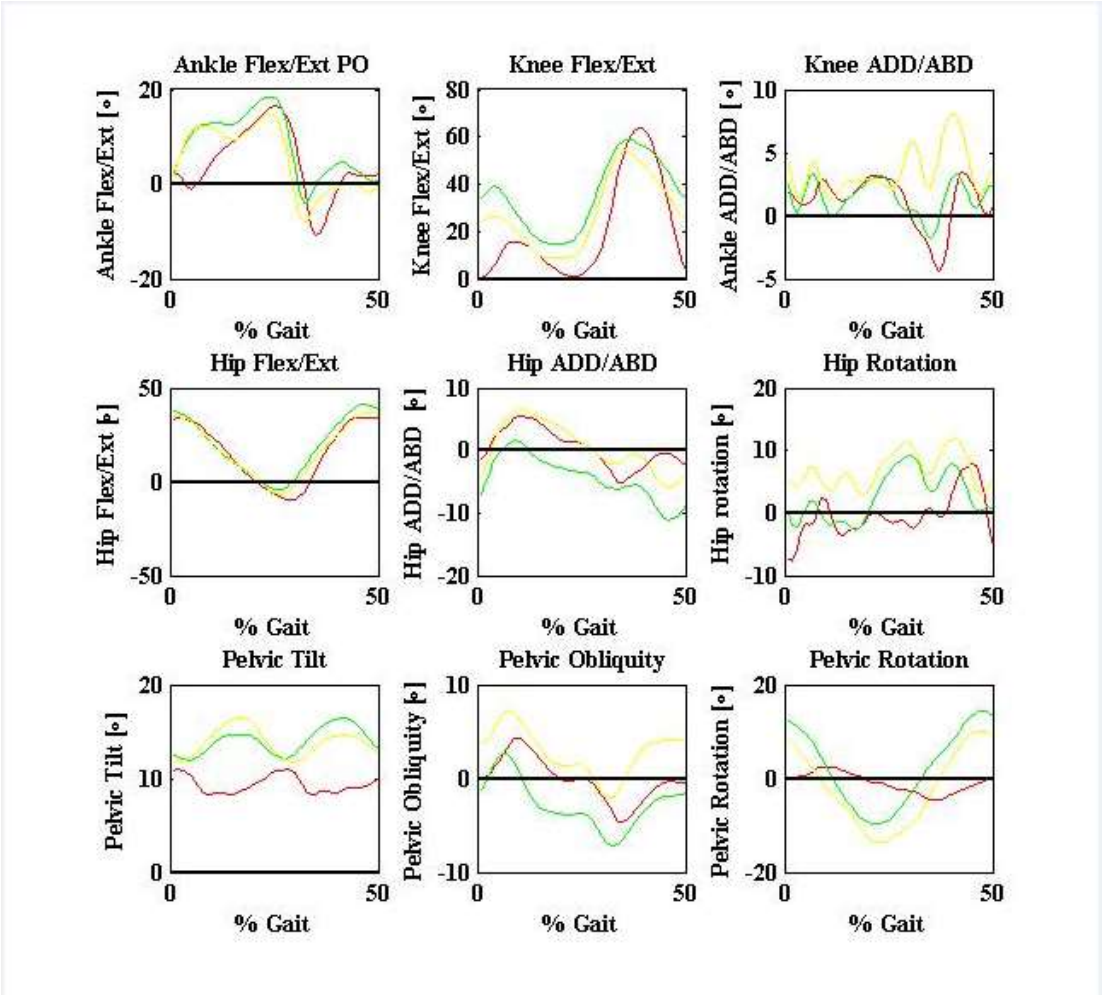

Figure 3: Kinematics of dominant (yellow) and non-dominant (green) sides of P2 versus normative (red) data after Locomat Treatment.

Angle-angle cyclograms were created to evaluate the movement of the lower limbs of Ankle Flex/Ext vs Hip Flex/Ext, Knee Flex/Ext vs Hip Flex/Ext, Knee ABD/ADD vs Hip ABD/ADD, Knee Flex/Ext vs Ankle Flex/Ext, Knee Flex/Ext vs Knee ABD/ADD and Hip Flex/Ext vs Hip ABD/ADD for each patient. After creating the cyclograms, the area under the curve was calculated and compared to that of a normative subject.

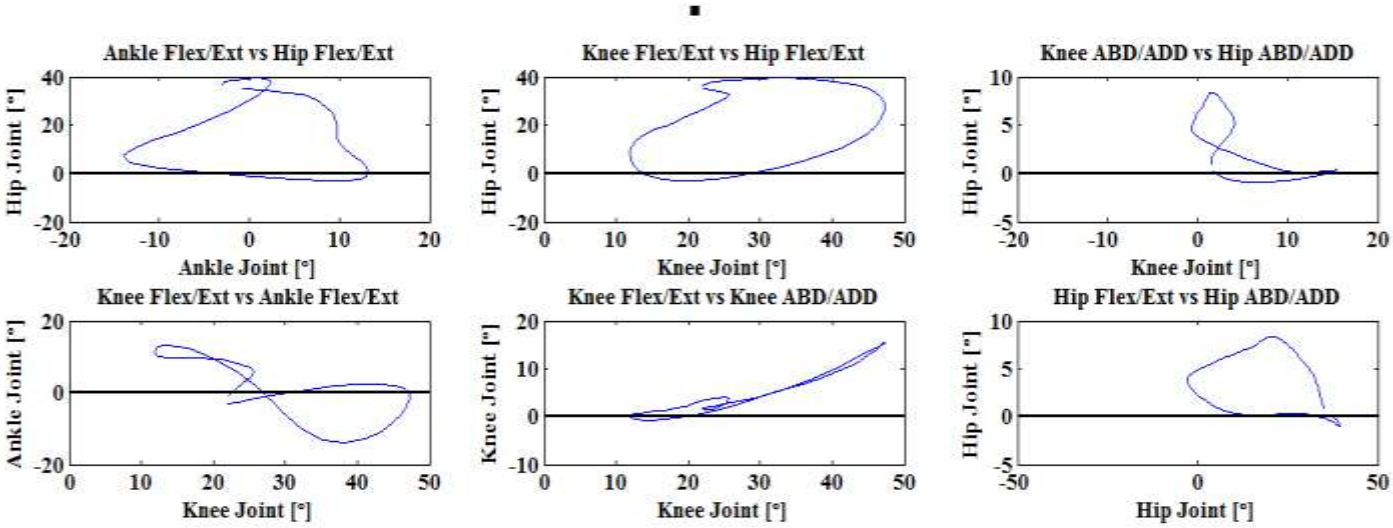

Figure 4: Examples of angle-angle cyclograms of average joint angles of the dominant side before RAGT.

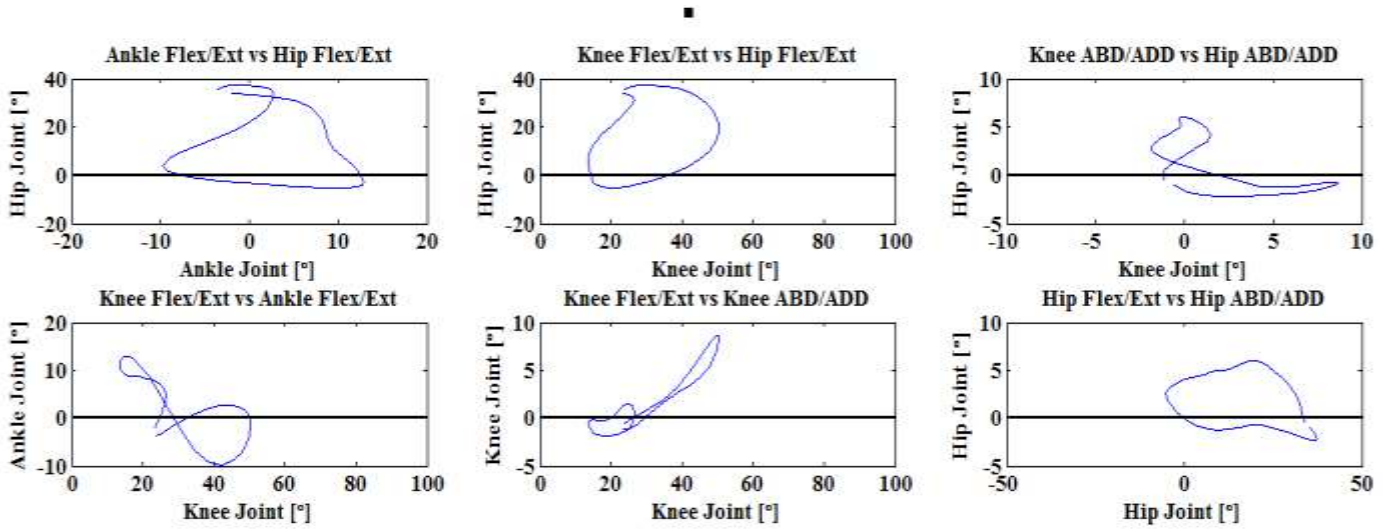

Figure 5: Examples of angle-angle cyclograms of average joint angles of the dominant side after RAGT.

For the dominant and non-dominant sides of each patient, before and after treatment, range of motion of joint angles were calculated and minimum and maximum values were determined. We then evaluated the coordination of the movement between the two sides by creating bilateral cyclograms (fig 5).

Figure 6: Example of a bilateral cyclogram of the average Ankle joint angles.

To study the symmetry of these graphs, we used the linear regression to determine the inclination of the angle-angle cyclogram (figure 2) according to the formula:

$$X(left) = b1X(right) + b0$$

The above formula represents the formula of a straight line that should pass through the origin inclined at an angle α that can be calculated by the simple formula tanα = b1. For ideal symmetry line, the inclination should be 45°. This angle represents absolutely symmetrical movement of healthy people [13]. Any deviation from the 45º angle determines the degree of asymmetry and by specifying the decreasing or increasing value of the difference, changes in asymmetry can be evaluated in the rehabilitation process [6].

Table 2: A summary of the methods used in the evaluation of Gait wit the time domain.

Methods	Input	Parameters	Description
SA	X_R, X_L	Symmetry Index	X_R and X_L are the values of the specified parameter for the right and left limbs
Movement around a joint	Max ($X_{R/L}$) Min ($X_{R/L}$)	ROM	Maximum and minimum values of both the right and left limbs
Cyclogram	Angle values	Area	Area under curve
Bilateral Cyclograms	Angle values	A, α	Area under curve, Angle of inclination
Coactivity percentage	EMGAg & EMGAntag	Coactivity	Normalized myoelectric activity in the primary agonist and antagonist muscles respectively

2.4.2 Frequency Domain

After the raw EMG signal was recorded and sampled at a frequency of 1 kHz, raw EMG data was low-pass filtered using a 4th-order butterworth filter with cutoff frequency of 20Hz. Besides the low pass filtering, the raw EMG signal was rectified due to its biphasic nature [28, 29]. This resulted in a smoothed enveloped EMG (fig 6).

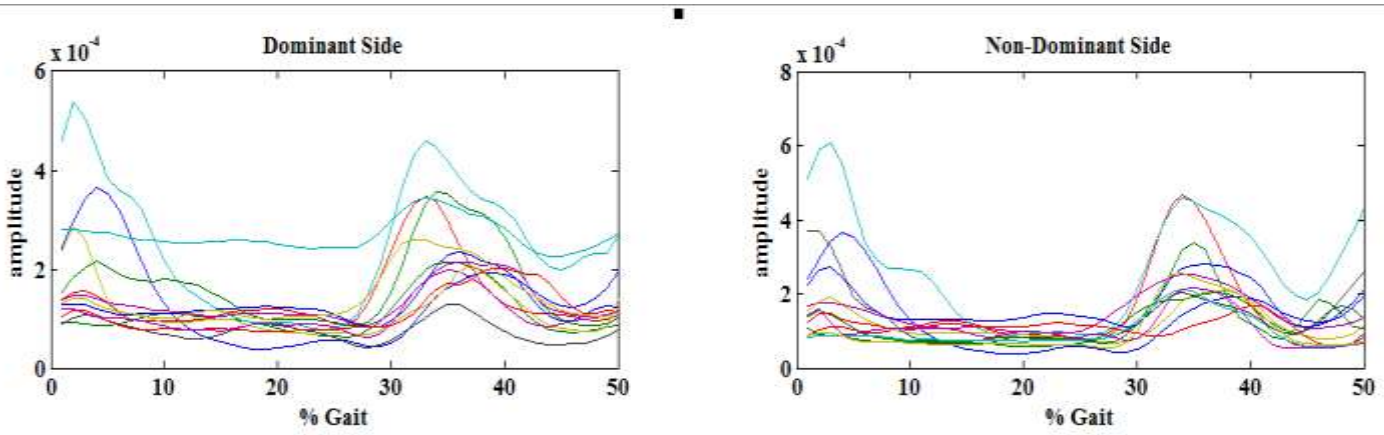

Figure 7: Tibialis Anterior EMG Signal after being rectified, enveloped and gait cycle normalized

All the recorded sEMG signals for the tibialis anterior, gastrocnemius, rectus femoris, biceps femoris muscles for each gait cycle were resampled to 50 points representing the gait from 0% to 100% in 2% increments.

The EMG signals were then analyzed with a Fast Fourier Transform (fft, customized software MATLAB®, The MathWorks, Inc., Natick, MA) (fig 7). Fourier analysis is extremely useful for data analysis, as it breaks down a signal into constituent sinusoids of different frequencies [30].

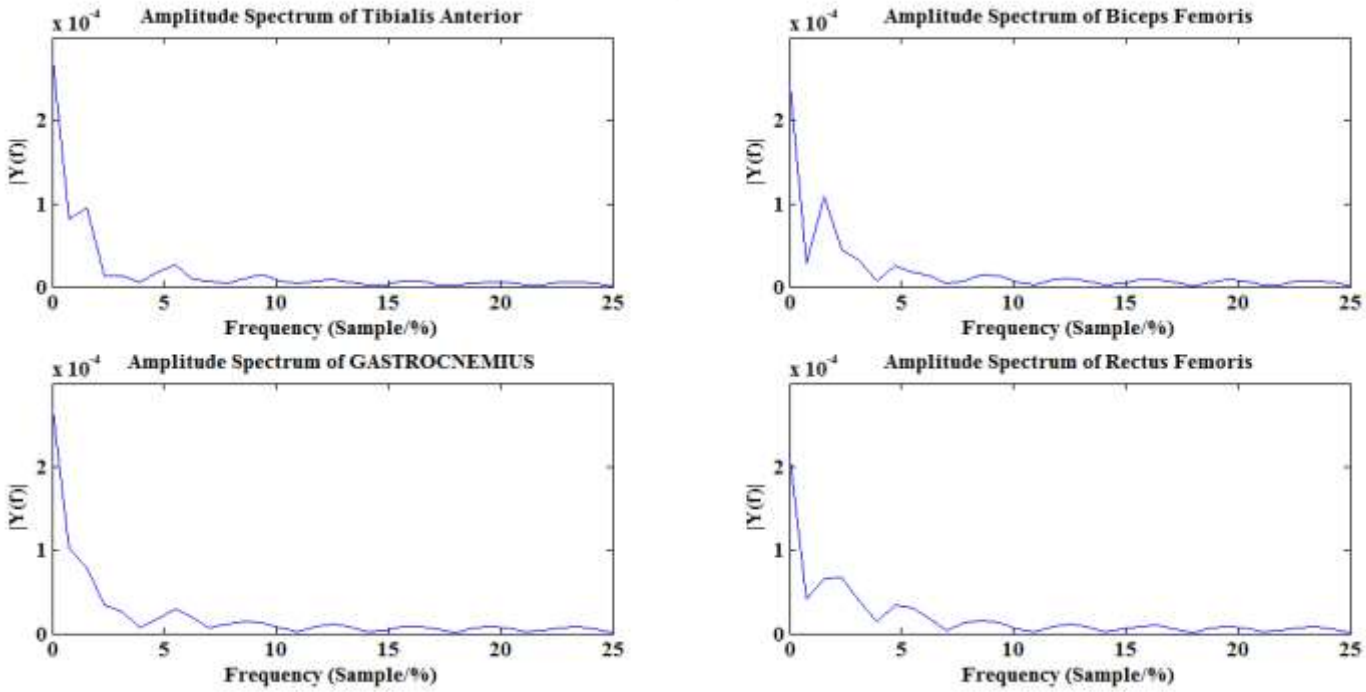

Figure 8: Single Sided Amplitude Spectrum of EMG data of a randomly picked patient before RAGT.

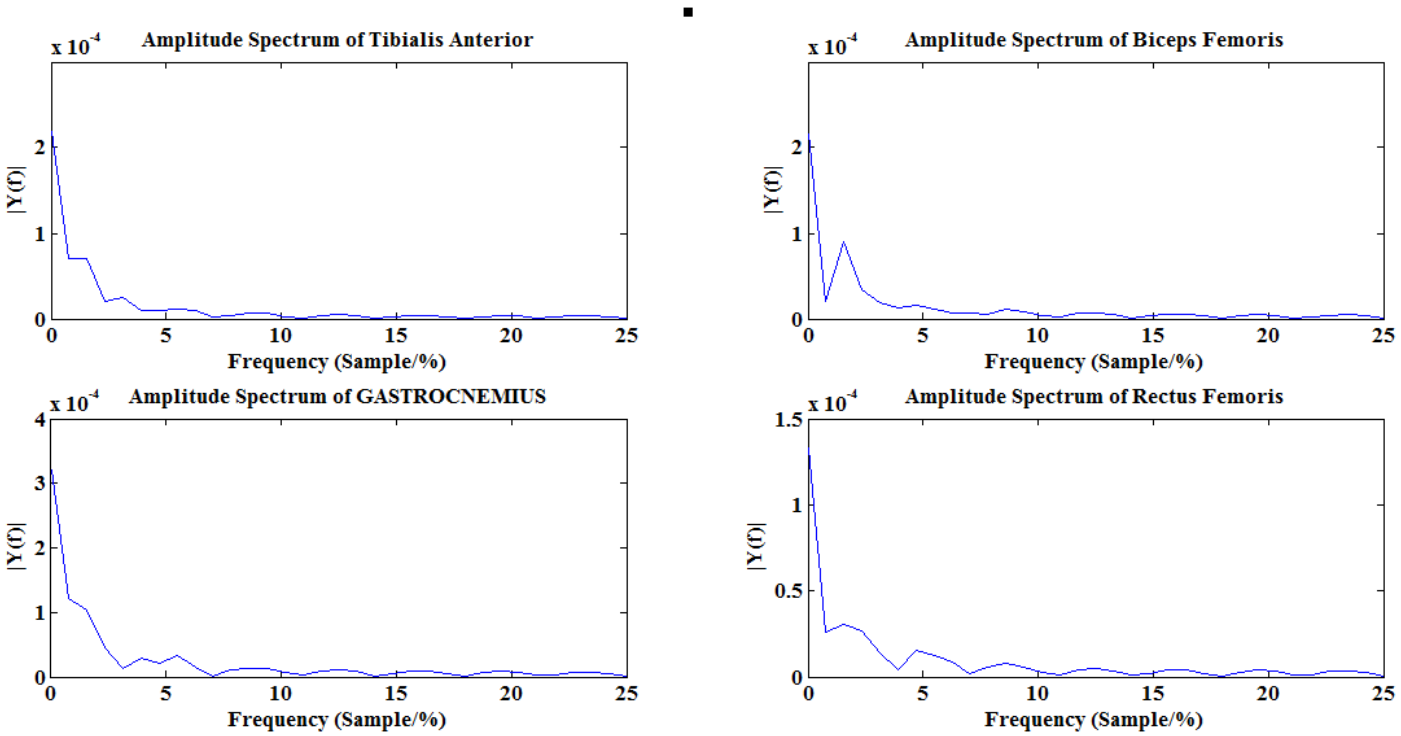

Figure 9: Single Sided Amplitude Spectrum of EMG data of a randomly picked patient After RAGT.

The peak values were then collected for each patient before and after RAGT. Areas of 3 intervals from the fft graph were calculated as well [31]:

- Interval A: 1-19 (Sample/%)
- Interval B: 3-8 (Sample/%)
- Interval C: 8-19 (Sample/%)

After we obtained the areas of the intervals, we calculated the percentage of B and C from A and compared them with each other before and after RAGT.

2.5 Statistical Evaluation

The Jarque-Bera test was used to verify data normality. As normal data distribution has been rejected at the 0.05 significance level, the non-parametric Wilcoxon sign rank test was used for further statistical calculation (0.05 significance level). Spearman's correlation coefficient was used to test the correlation between the frequency analysis and time-domain analysis. A large correlation is 0.5, medium is 0.3 and small is 0.1 [32]. The statistical evaluation was done using a custom written MatLab program (MatLab R2014a, Mathworks, Inc., Natick, MA, USA).

3 Results

Only results with significant values are represented in this section.

The difference between the area under curve of the dominant side before/after RAGT showed statistical significance ($p < 0.05$) for Ankle Flex/Ext vs Hip Flex/Ext and Knee Flex/Ext vs Hip Flex/Ext cyclograms. Statistical significance was also evident in Knee Flex/Ext vs Hip Flex/Ext cyclogram between the non-dominant side and dominant side before/after RAGT with ($p<0.01$) (fig 9). As for the other cyclograms, Knee ABD/ADD vs Hip ABD/ADD, Knee Flex/Ext vs Ankle Flex/Ext, Knee Flex/Ext vs Knee ABD/ADD and Hip Flex/Ext vs Hip ABD/ADD, statistical significance was not demonstrate between neither same side comparison before/after RAGT, nor dominant/non-dominant before and after RAGT.

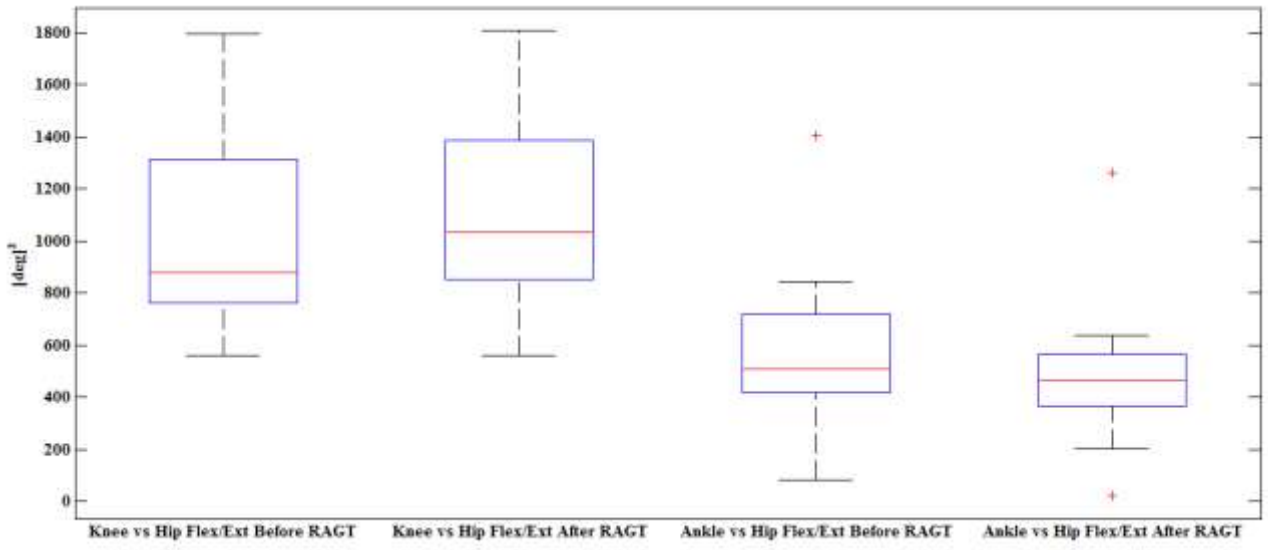

Figure 10: Comparison of the area of the Knee Flex/Ext vs Hip Flex/Ext and Ankle vs Hip Flex/Ext cyclograms of the dominant side before and after RAGT

Table 3 represents the symmetry index and angle of inclination of the bilateral cyclogram between the dominant and non-dominant sides of the Ankle Flex/Ext before and after RAGT.

Table 3: The symmetry index and angle of inclination values of the Ankle FLex/Ext before and after RAGT.

	SI Before	SI After	Angle [deg] Before	Angle [deg] After
Norm	1	1	45	45
P1	0.6	1.0	57.1	45.4
P2	0.9	1.0	48.5	43.8
P3	1.3	1.5	37.7	34.9
P4	1.1	1.3	43.0	34.9
P5	0.6	0.9	57.2	45.0
P6	0.9	1.2	47.4	40.0
P7	0.5	0.6	55.2	52.3
P8	1.0	1.1	41.6	40.9
P9	0.9	0.8	49.2	42.8
P10	0.9	0.9	51.3	44.2
P11	1.3	1.2	23.9	28.0
P12	1.0	0.8	43.0	51.7

Ankle Flex/Ext was the only limb were statistical significance was evident between the symmetry index before/after ($p = 0.04$) and angle of inclination before/after in the ($p = 0.05$).

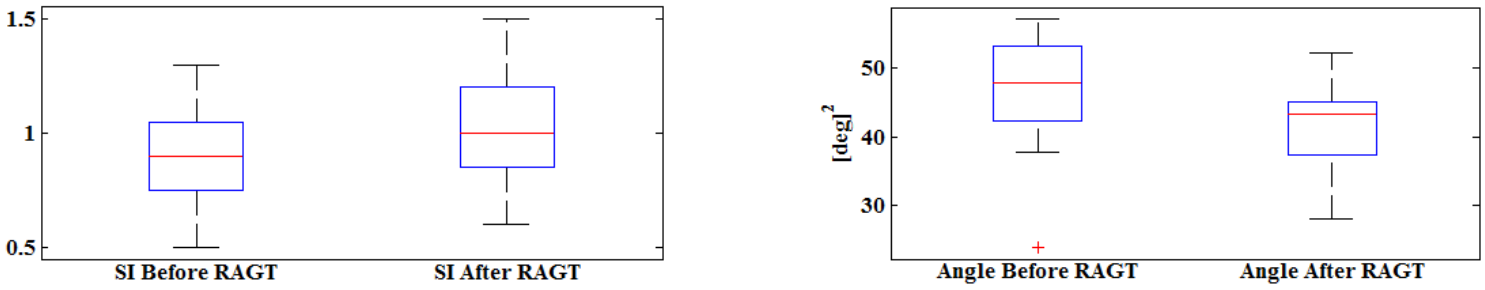

Figure 11: Comparison of the Symmetry Index and angle of inclination of the Ankle Flex/Ext before and after RAGT.

Statistical significance was calculated between dominant side before and dominant side after, non-dominant side before and non-dominant side after, dominant and non-dominant before and dominant and non-dominant sides after:

- Dominant-Dominant Before and After (D-D)
- NonDominant-NonDominant Before and After (N-N)

- NonDominant-Dominant Before (N-D)
- NonDominant-Dominant After (N-D)

Statistical significance was also calculated between each side and the normative values, but since $p>0.05$ in all cases, it will not be mentioned.

The below tables summarize the p-values of rest of the time-domain analysis including range of motion, minimum and maximum comparison for the joint angles. The Knee Flex/Ext (table 4) and Hip Flex/Ext (table 5) shows statistical significance of ($p<0.01$) between the NonDominant-Dominant sides before and NonDominant-Dominant sides after for the ROM and maximum values only. Statistical significance of ($p<0.01$) was evident for Ankle Flex/Ext between Dominant-Dominant Before and After for ROM only. While no statistical significance was demonstrated between any of the sides before or after RAGT for the minimum values.

Table 4: Statistical analysis of Knee Flex/Ext.

ROM	**p-values**	Max	**p-values**	Min	**p-values**
N-N Before/After	0.1	**N-N Before/After**	0.3	**N-N Before/After**	0.3
D-D Before/After	0.4	**D-D Before/After**	0.2	**D-D Before/After**	0.09
N-D Before	0.01	**N-D Before**	<0.01	**N-D Before**	0.1
N-D After	0.01	**N-D After**	0.02	**N-D After**	0.7

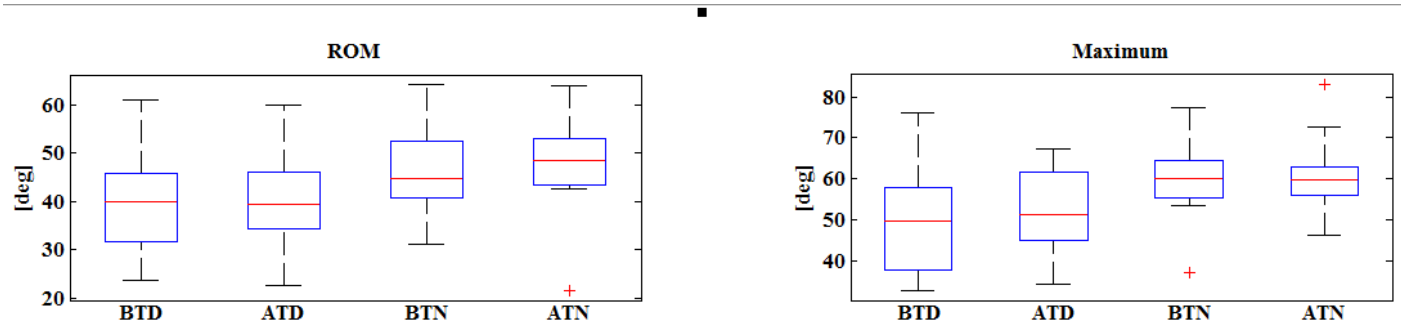

Figure 12: Comparison of ROM and Max values for the Knee FLex/Ext between dominant before treatmentt (BTD) with dominant after treatment (ATD) and non-dominant before treatmentt (BTD) with non-dominant after treatment (ATD)

Table 5: Statistical analysis of Hip Flex/Ext.

ROM	p-values
N-N Before/After	0.9
D-D Before/After	0.2
N-D Pred	0.02
N-D Po	0.01

Max	p-values
N-N Before/After	0.1
D-D Before/After	0.5
N-D Pred	<0.01
N-D Po	0.01

Min	p-values
N-N Before/After	0.3
D-D Before/After	0.2
N-D Pred	0.9
N-D Po	0.6

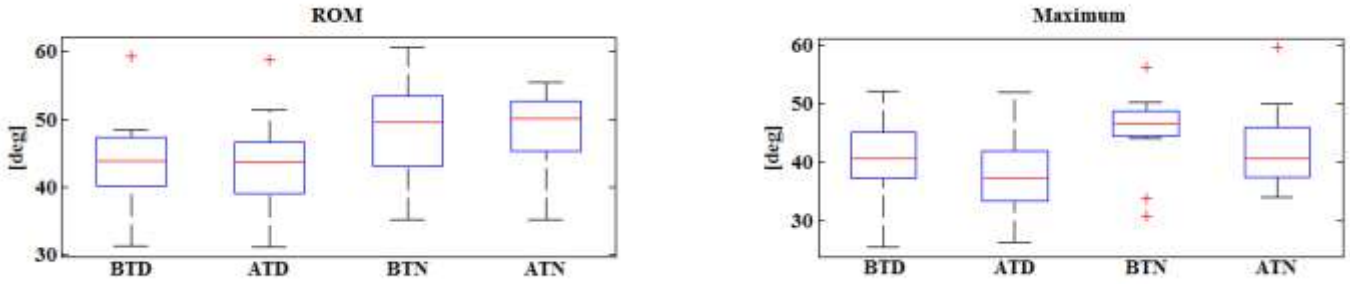

Figure 13: Comparison of ROM and Max values for the Hip FLex/Ext between dominant before treatmentt (BTD) with dominant after treatment (ATD) and non-dominant before treatmentt (BTD) with non-dominant after treatment (ATD)

However, Hip rotation (table 6), Biceps Femoris (table 7) and Gastrocnemius (table 8) show statistical significance between single sided limbs before and after RAGT for the minimum and maximum values only. While no statistical significance was demonstrated between each side before and after for the minimum values.

Table 6: Statistical analysis of Hip Rotation.

ROM	p-values
N-N Before/After	0.9
D-D Before/After	0.7
N-D Pred	0.7
N-D Po	0.7

Max	p-values
N-N Before/After	0.05
D-D Before/After	<0.01
N-D Pred	0.06
N-D Po	0.2

Min	p-values
N-N Before/After	0.03
D-D Before/After	<0.01
N-D Pred	0.1
N-D Po	0.2

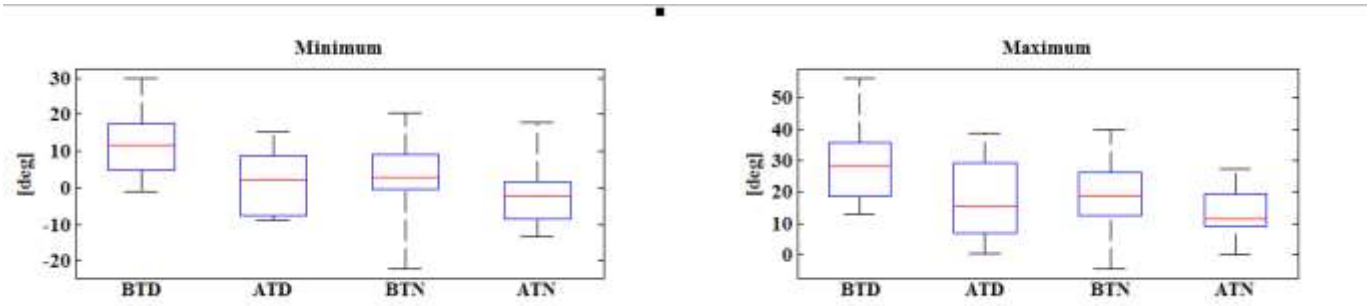

Figure 14: Comparison of Min and Max values for the Hip Rotation between dominant before treatmentt (BTD) with dominant after treatment (ATD) and non-dominant before treatmentt (BTD) with non-dominant after treatment (ATD)

Table 7: Statistical analysis of Biceps Femoris.

ROM	p-values
N-N Before/After	0.2
D-D Before/After	0.5
N-D Pred	0.6
N-D Po	0.6

Max	p-values
N-N Before/After	<0.01
D-D Before/After	<0.01
N-D Pred	0.8
N-D Po	0.6

Min	p-values
N-N Before/After	0.02
D-D Before/After	<0.01
N-D Pred	0.6
N-D Po	0.4

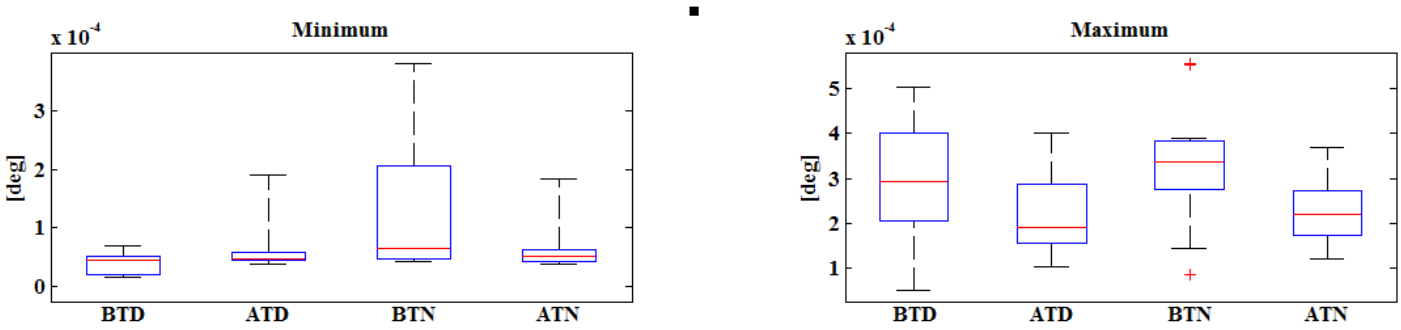

Figure 15: Comparison of Min and Max values for the Biceps Femoris between dominant before treatmentt (BTD) with dominant after treatment (ATD) and non-dominant before treatmentt (BTD) with non-dominant after treatment (ATD)

Table 8: Statistical analysis of Gastrocnemius.

ROM	p-values
N-N Before/After	0.9
D-D Before/After	0.7
N-D Pred	0.4
N-D Po	0.7

Max	p-values
N-N Before/After	<0.01
D-D Before/After	<0.01
N-D Pred	0.26
N-D Po	0.38

Min	p-values
N-N Before/After	0.04
D-D Before/After	<0.01
N-D Pred	0.62
N-D Po	0.62

Minimum and maximum values demonstrated a statistical significance of ($p<0.05$) between non-dominant side before and non-dominant side after and ($P<0.01$) between dominant side before and dominant side after.

Rectus Femoris (table 9) was the only muscle that demonstrated statistical significance ($p<0.05$) between Dominant-Dominant Before and After, NonDominant-NonDominant Before and After for all the parameters in table 15

Table 9: Statistical analysis of Rectus Femoris.

ROM	p-values
N-N Before/After	0.02
D-D Before/After	<0.01
N-D Pred	0.57
N-D Po	0.42

Max	p-values
N-N Before/After	<0.01
D-D Before/After	<0.01
N-D Pred	0.26
N-D Po	0.38

Min	p-values
N-N Before/After	0.04
D-D Before/After	<0.01
N-D Pred	0.62
N-D Po	0.62

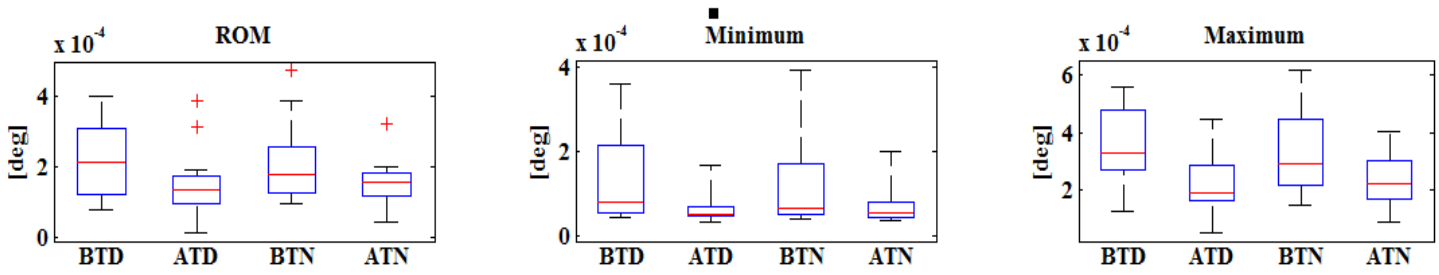

Figure 16: Comparison of ROM, Min and Max values for the Rectus Femoris between dominant before treatmentt (BTD) with dominant after treatment (ATD) and non-dominant before treatmentt (BTD) with non-dominant after treatment (ATD)

As for the peak values from the Fourier transform of the Biceps Femoris, Tibialis Anterior, Rectus Femoris and Gastrocnemius muscle activity, statistical significance is hugely evident for all the muscles measured between the non-dominant side before and non-dominant side after and dominant side before and dominant side after. This is also evident in the Hip ABD/ADD and Hip Rotation, while the others either show one side with statistical evidence before and after or does not demonstrate any statistical evidence.

After calculating the areas from intervals A, B and C before and after RAGT for the dominant and non-dominant sides of the rectus femoris muscle, percentages of intervals C and D that were then calculated from A and presented in table 10.

Table 10: Percentages of intervals C and D from A [%] before and after for dominant and non-dominant sides of the Rectus Femoris muscle.

		Before		After	
		% C from A	% D from A	% C from A	% D from A
Norm	N-Dom	4.9	0.5	4.9	0.5
	Dom	4.9	0.5	4.9	0.5
P1	N-Dom	6.4	3.8	4.5	4.1
	Dom	2.6	4.6	2.8	2.1
P2	N-Dom	11.0	6.4	11.1	7.8
	Dom	3.8	4.8	1.9	5.5
P3	N-Dom	3.7	5.0	0.7	5.1
	Dom	5.2	5.7	5.6	4.2
P4	N-Dom	3.4	1.7	1.6	1.5
	Dom	3.7	2.0	2.6	1.9
P5	N-Dom	2.9	2.9	3.5	0.7
	Dom	3.6	1.5	2.7	2.4
P6	N-Dom	2.3	2.9	2.1	3.1
	Dom	1.8	2.5	1.5	3.5
P7	N-Dom	7.9	3.1	6.7	0.9
	Dom	5.5	3.3	4.2	2.7
P8	N-Dom	1.7	2.5	5.8	4.4
	Dom	6.9	1.9	8.6	6.6
P9	N-Dom	3.7	1.6	2.9	1.4
	Dom	3.3	1.6	3.4	0.6
P10	N-Dom	3.6	1.2	4.5	1.4
	Dom	4.0	1.4	5.4	1.5
P11	N-Dom	3.2	1.7	0.9	1.8
	Dom	3.1	1.1	2.6	1.9
P12	N-Dom	5.1	5.1	4.3	3.2
	Dom	3.8	3.5	3.1	1.6

Statistical significance was not demonstrated between neither the percentage of C from A before and after RAGT, nor from the percentage of D from A before and after RAGT. However, a statistical significance was evident between interval A before and interval A after for both dominant and non-dominant sides ($p < 0.01$).

Coactivity between the Coactivity of Tibialis vs GASTROCNEMIUS muslces did not demonstrate and statistical significance between neither the dominant sides before and after nor the non-dominant sides before and after.

Spearman's correlation between peak values and ROM, min and max values for joint angles returned a small correlation <0.1 with $p>0.05$. However, the correlation between peak values and ROM, min and max values for EMG data of the muscles returned a strong correlation >0.5 and $p < 0.01$.

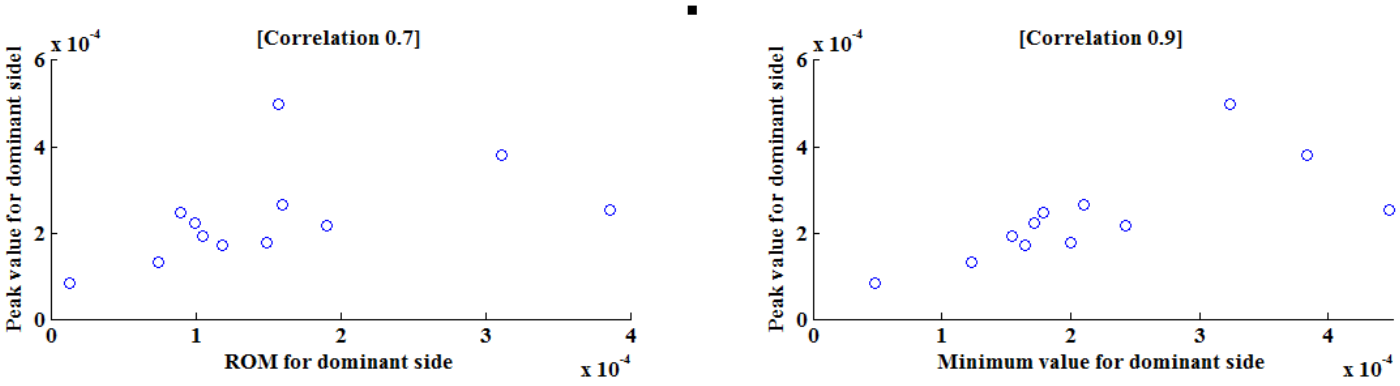

Figure 17: Spearman's correlation graph of the peak values with the ROM and minimum values of the Rectus Femoris.

4 Discussion

4.1 Fulfilling the Objectives of the Thesis

This study was performed to design methods to evaluate gait of patients with CP, more specifically, spasticity. Studying joint kinematics individually and as coupled evolutions of two joints along with EMG of the muscle activity using several methods in the time-domain and frequency domain allowed us to explore significant outcomes to better evaluate gait.

4.2 Time-Domain Interpretation

Cyclograms allowed us to observe a firmly coordinated movement between knee-hip and ankle-hip plots by reflecting gait kinematics during a complete gait cycle and studying the area under it. The plots provided us with a clear indication of the alteration the coupled joint angles had undergone during gait before and after treatment and the progression they achieved [33].

However, the study of bilateral cyclograms based on the angle inclination and symmetry index did not show any significant changes after RAGT expect for the Ankle flex/ ext. When assessing symmetry analysis, there are some disadvantages and limitations. Several factors are involved which might include the large number of gait parameters that should be evaluated at the same time which results in moderately low symmetry, and failure to provide information regarding the location of the asymmetry [34].

The ROM was very helpful studying joints individually, mainly in the hip flex/ext and knee flex/ext where it showed statistical significance that suggests an improved gait pattern [35]. The reduced ROM of the knee is mainly affected by the increased activity of the Rectus Femoris. Hip flex/ext and knee flex/ext angles play a significant role in the functional activities and this suggests a link with the statistical significance obtained from

different joints and muscles, not necessarily in the ROM, but in the minimum and maximum values which is discussed in the next section. It was previously mentioned In the literature review, cyclogram area is intuitively related to the conjoint range of the angular movements concerned. The larger the range, the larger the cyclogram area [23]. By comparing the ROM of the hip flex/ext and knee flex/ext with the areas of the Knee - Hip Flex/Ext cyclogram (tables found in appendix) we can see that both values increased after RAGT for most of the patients. Both methods demonstrated significant results which proves that the ROM and area are related and can maybe both yield to the same results.

4.3 Frequency-Domain Interpretation

Jacquelin Perry *et al.* mentioned in her study that three steps are involved in providing a meaningful numerical value for the muscles' EMG. The raw EMG is rectified, digitized, and normalized (Figure 7). Normalization permits the comparison of effort changes among two or more muscles despite the inability to either determine or control the number of muscle fibers that an electrode samples [40].

FFT was used to decompose the signals as a summation (or integral) of sinusoidal or complex exponential functions of different frequencies, amplitudes and phases.

$$x(t) = 12\pi\int \int_{-\infty}^{\infty} X(\omega)ej\omega td\omega$$

In terms of physical meaning, the Fourier transforms says how the “energy” of a time signal x(t) is distributed in the “spectrum” X(ω), that is in the ω domain. The peak represents the most dominant frequency in our signal, peaks are evident when specific frequencies are particularly strong.

Significant changes were evident in the rectus femoris and biceps femoris from both the time and frequency domains. Both muslces switch between two different functions at the same time thoughout the whole gait cycle. The RF is active during the swing phase as hip flexor, whereas during stance phase as a knee extensor. As for the BF, it is mostly active during mid-swing and continues up to mid stance where it acts as a hip extensor and knee flexor [36]. However, in patients with CP, due to BF muscle weakness, knee joint contractures and dominant activity of spastic RF antagonist [25, 37], the differentiation between flexion and extension is hard. The statistical significance obtained

while studying the RF and BF muscles suggests that the CP patients were able to adopt an improved gait pattern with decreased spastic RF activity and increased BF acitivity. We can also assume, that the significant changes seen in the knee and hip joints from cyclograms and ROM values, play a huge role in the analysis of the results of the RF and BF.

Furthermore, CP patients face difficulties with weakened TA and spastic MG functions resulting in spastic calf muscles and deformities [38]. Calf muscles negatively influence both ankle and knee joints which as a result cause abnormal gait patterns [38]. Stretching the calf muslces, result in an increased ROM of the ankle joint. The significant changes of the ROM in the ankle joints obtained in this study assumes an improvement in the TA muscle and a decreases MG spactisity. This was evident by the statistical significance obtained while studying the TA and MG muscles in both the time-and frequency domains.

The above findings can in some way interpret the strong correlation obtained from the spearman's test between peak values and ROM, min and max values for the EMG data of the muscles. Although figure 17 did not show a monotonic relationship between the parameters, however, it showed that the peak value is increasing with the increase of ROM/ minimum values, which indicates a positive correlation.

5 Conclusions and future work

This study aimed to design methods to evaluate the gait of children with cerebral palsy before and after RAGT. Although, the work proposed in this study did not describe all the possible ways that can be applied. However, the mathematical quantities derived from each method completed the role of the others. The results obtained from the time-domain and frequency-domain methods used in this study have identified significant improvements in the gait pattern after the application of RAGT. The application of both methods provides a better understanding of the relationship between the joint angles and muscle activity before and after rehabilitation.

The designed methods demonstrated in this study tested only on children with spastic diparesis-diplegia type. This study can not be generalized to all kinds of CP. Future studies include applying the methods proposed in this study to evaluate other types of disabilities after collecting more reliable and precise data using high-quality MoCap systems and EMG devices.

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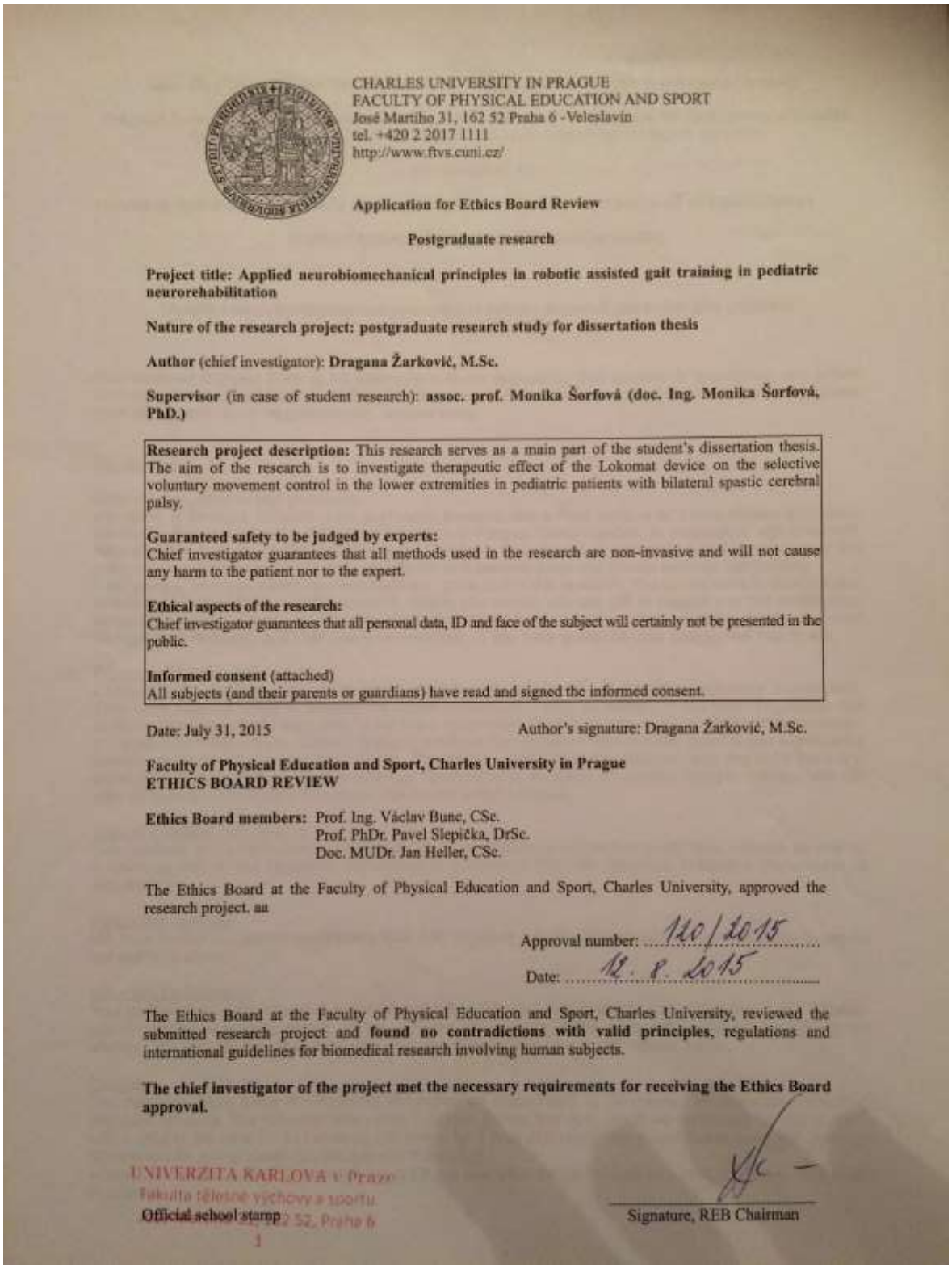
List of Appendices

Appendix 1: Ethics Board Review



CHARLES UNIVERSITY IN PRAGUE
FACULTY OF PHYSICAL EDUCATION AND SPORT
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Application for Ethics Board Review

Postgraduate research

Project title: Applied neurobiomechanical principles in robotic assisted gait training in pediatric neurorehabilitation

Nature of the research project: postgraduate research study for dissertation thesis

Author (chief investigator): **Dragana Žarković, M.Sc.**

Supervisor (in case of student research): **assoc. prof. Monika Šorfová (doc. Ing. Monika Šorfová, PhD.)**

Research project description: This research serves as a main part of the student's dissertation thesis. The aim of the research is to investigate therapeutic effect of the Lokomat device on the selective voluntary movement control in the lower extremities in pediatric patients with bilateral spastic cerebral palsy.

Guaranteed safety to be judged by experts:
Chief investigator guarantees that all methods used in the research are non-invasive and will not cause any harm to the patient nor to the expert.

Ethical aspects of the research:
Chief investigator guarantees that all personal data, ID and face of the subject will certainly not be presented in the public.

Informed consent (attached)
All subjects (and their parents or guardians) have read and signed the informed consent.

Date: July 31, 2015 Author's signature: Dragana Žarković, M.Sc.

Faculty of Physical Education and Sport, Charles University in Prague
ETHICS BOARD REVIEW

Ethics Board members: Prof. Ing. Václav Bunc, CSc.
Prof. PhDr. Pavel Slepička, DrSc.
Doc. MUDr. Jan Heller, CSc.

The Ethics Board at the Faculty of Physical Education and Sport, Charles University, approved the research project. aa

Approval number: 120/2015

Date: 12. 8. 2015

The Ethics Board at the Faculty of Physical Education and Sport, Charles University, reviewed the submitted research project and **found no contradictions with valid principles**, regulations and international guidelines for biomedical research involving human subjects.

The chief investigator of the project met the necessary requirements for receiving the Ethics Board approval.

UNIVERZITA KARLOVA v Praze
Fakulta tělesné výchovy a sportu
162 52, Praha 6

Official school stamp

Signature, REB Chairman

Univerzitetni rehabilitacijski inštitut
Republike Slovenije -
Soča

Mag. Katja Groleger Sršen, dr. med..
- tu;

Datum: 5. oktober 2015

Spoštovani!

Komisija za medicinsko etiko je na seji dne 5. oktobra 2015 obravnavala vlogo za mnenje o etični ustreznosti raziskovalnega projekta »Applied neurobiomechanical principles in robotic assisted gait training in pediatric neurorehabilitation« mag. Dragane Žarkovič pod mentorstvom prof. Monike Šorfove in somentorstvom mag. Katje Groleger Sršen, dr. med.. in odgovorne zdravnice mag. Katje Groleger Sršen, dr. med..

Člani komisije za medicinsko etiko so menili, da je raziskovalni projekt »Applied neurobiomechanical principles in robotic assisted gait training in pediatric neurorehabilitation« mag. Dragane Žarković pod mentorstvom prof. Monike Šorfove in somentorstvom mag. Katje Groleger Sršen, dr. med. in odgovorne zdravnice mag. Katje Groleger Sršen, dr. med., etično ustrezen ob sodelovanju strokovnih sodelavcev teama za kineziološko analizo.

Predsednica komisije za medicinsko etiko URI-Soča:
prim. Tatjana Erjavec, dr. med.

Appendix 2: Area Under Cyclograms

		Ankle Flex/Ext vs Hip Flex/Ext		Knee Flex/Ext vs Hip Flex/Ext		Hip Flex/Ext vs Hip ABD/ADD	
		Before	After	Before	After	Before	After
Norm	N-Dom	568.4	568.4	1863.7	1863.7	297.5	297.5
	Dom	568.4	568.4	1863.7	1863.7	297.5	297.5
P1	N-Dom	500.4	447.6	1057.8	1204.6	79.2	211.6
	Dom	736.7	586.4	1003.4	1279.6	190.4	265.4
P2	N-Dom	472.0	514.6	1721.4	1525.9	222.1	201.5
	Dom	470.8	386.2	929.5	897.0	174.2	139.9
P3	N-Dom	999.4	928.3	1767.1	1709.8	532.3	406.2
	Dom	689.9	540.3	1474.6	1480.1	429.8	372.4
P4	N-Dom	480.3	683.6	833.5	1186.1	235.7	74.2
	Dom	434.4	474.6	830.5	1107.6	134.2	117.7
P5	N-Dom	445.8	495.5	549.9	494.2	133.8	189.8
	Dom	845.0	501.2	789.2	687.2	340.9	246.0
P6	N-Dom	535.1	557.5	1160.8	1103.2	369.0	366.7
	Dom	548.2	362.7	558.1	558.1	243.3	207.5
P7	N-Dom	0.7	254.3	2042.9	1906.5	510.8	522.0
	Dom	346.8	365.2	1302.2	1297.1	316.1	426.2
P8	N-Dom	1361.5	1230.0	1899.2	1899.1	248.8	282.8
	Dom	1402.4	1262.7	1796.0	1807.7	279.3	357.1
P9	N-Dom	423.9	521.5	1716.6	2066.2	122.9	180.7
	Dom	408.0	202.9	1321.9	1735.6	71.1	92.7
P10	N-Dom	456.7	427.7	1322.0	1481.7	161.7	334.1
	Dom	427.7	457.0	828.5	962.6	197.5	181.2
P11	N-Dom	194.2	51.4	1168.6	952.7	220.5	388.4
	Dom	83.4	22.3	594.5	815.9	47.4	255.5
P12	N-Dom	734.2	387.5	1168.3	1170.1	292.3	316.1
	Dom	702.6	638.7	735.4	885.4	208.6	190.0

		Knee ABD/ADD vs Hip ABD/ADD		Knee Flex/Ext vs Knee ABD/ADD		Knee Flex/Ext vs Ankle Flex/Ext	
		Before	After	Before	After	Before	After
Norm	N-Dom	2.2	2.2	190.7	190.7	253.0	253.0
	Dom	2.2	2.2	190.7	190.7	253.0	253.0
P1	N-Dom	0.3	0.2	140.0	32.8	231.7	29.5
	Dom	7.7	27.5	146.7	6.7	464.8	54.6
P2	N-Dom	5.0	1.0	171.5	103.1	287.9	299.1
	Dom	11.5	19.2	126.5	152.5	47.0	3.8
P3	N-Dom	5.5	4.6	369.7	301.2	905.6	744.0
	Dom	68.2	12.8	134.9	306.7	563.8	414.1
P4	N-Dom	125.7	56.5	31.5	4.4	121.7	363.5
	Dom	29.4	102.9	13.5	119.9	99.3	230.8
P5	N-Dom	34.0	17.3	38.6	37.6	149.9	26.7
	Dom	40.9	78.4	30.2	16.4	293.4	51.8
P6	N-Dom	78.9	10.1	184.2	204.7	429.3	343.2
	Dom	0.2	30.1	145.2	74.8	99.8	127.2
P7	N-Dom	9.7	6.4	195.5	196.1	76.9	452.8
	Dom	23.5	18.6	25.3	55.1	46.5	203.7
P8	N-Dom	3.7	11.5	183.4	177.9	898.5	756.6
	Dom	30.5	15.6	151.2	129.4	1269.4	935.9
P9	N-Dom	15.2	22.2	8.3	13.2	35.9	121.6
	Dom	69.5	0.0	35.0	3.3	64.9	366.5
P10	N-Dom	32.6	47.2	160.5	104.6	223.8	77.3
	Dom	3.8	6.0	42.2	24.5	95.9	151.3
P11	N-Dom	85.0	72.4	77.7	90.7	82.5	193.1
	Dom	141.0	70.9	168.0	108.7	154.5	149.2
P12	N-Dom	168.1	8.9	53.1	102.7	272.9	247.8
	Dom	58.0	4.5	319.1	190.5	410.7	324.9

Appendix 3: ROM, Min, and max values of the Knee Flex/Ext

		ROM B	ROM A	Min B	Min A	Max B	Max A
Norm	N-Dom	63.60	63.60	0.38	0.38	63.60	63.90
	Dom	63.60	63.60	0.38	0.38	63.90	63.90
P1	N-Dom	40.9	44.2	15.2	14.6	56.1	58.8
	Dom	43	45.4	6.9	8.9	49.9	54.3
P2	N-Dom	50.9	51.6	3.9	11.7	57.9	63.3
	Dom	37	35.2	6.3	8.6	43.2	43.8
P3	N-Dom	51.7	48.4	11.7	11	63.5	59.4
	Dom	47.6	47	2.2	1.3	49.8	48.3
P4	N-Dom	31.2	48.6	45.9	34.5	77.2	83.1
	Dom	28	33.3	41.7	33.9	69.7	67.2
P5	N-Dom	32.7	21.6	32.6	27.2	65.4	48.8
	Dom	40.1	31	35.8	35.5	76	66.5
P6	N-Dom	45.9	48	7.7	8.1	53.7	56.1
	Dom	23.7	22.6	13.1	11.7	36.7	34.3
P7	N-Dom	53.3	54.7	5.9	5.7	59.3	60.4
	Dom	44.2	40.8	-5.3	5.4	38.9	46.2
P8	N-Dom	64.1	64.1	-1.3	-1.3	62.9	62.8
	Dom	61	60.1	-2.2	0.8	58.8	60.8
P9	N-Dom	53.5	62.6	18.9	10	72.4	72.6
	Dom	53.4	55.3	3.3	7.3	56.7	62.6
P10	N-Dom	40.4	42.6	17.5	19.5	57.9	62.2
	Dom	30.3	36.4	21.1	22	51.4	58.5
P11	N-Dom	40.8	42.7	19.9	13.1	60.8	55.9
	Dom	32.9	37.8	3.5	5.5	36.4	43.3
P12	N-Dom	43.4	51.5	-6.3	-5.3	37.1	46.2
	Dom	39.7	45	-6.7	1.3	33	46.2

Appendix 4: ROM, Min, and max values of the Hip Flex/Ex

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		ROM B	ROM A	MinB	MinA	Max B	Max A
Norm	N-Dom	44.1	44.1	-9.8	-9.8	34.4	34.4
	Dom	44.1	44.1	-9.8	-9.8	34.4	34.4
P1	N-Dom	42.0	45.6	4.7	-4.5	46.7	41.2
	Dom	41.1	43.4	1.1	-6.5	42.2	36.9
P2	N-Dom	51.5	50.4	-7.5	-12.8	44.0	37.6
	Dom	41.4	43.3	-5.7	-9.2	35.8	34.1
P3	N-Dom	53.3	54.2	-5.6	-4.2	47.7	50.0
	Dom	47.1	45.6	-8.1	-5.3	39.0	40.3
P4	N-Dom	40.1	45.2	5.8	-10.7	45.9	34.4
	Dom	42.1	45.4	3.5	-11.6	45.7	33.7
P5	N-Dom	35.2	37.4	9.5	-3.5	44.7	33.9
	Dom	31.3	31.3	7.4	-5.0	38.7	26.2
P6	N-Dom	47.6	48.2	-13.8	-9.7	33.9	38.5
	Dom	33.4	35.3	-7.8	-5.9	25.6	29.4
P7	N-Dom	60.7	52.5	-12.8	-8.9	47.9	43.6
	Dom	45.5	47.8	-6.9	-10.2	38.5	37.5
P8	N-Dom	53.6	52.9	-22.9	-15.9	30.8	37.0
	Dom	59.4	58.8	-28.2	-19.3	31.2	39.5
P9	N-Dom	54.4	55.5	1.7	4.0	56.1	59.5
	Dom	46.4	44.1	2.0	7.9	48.4	52.0
P10	N-Dom	47.0	51.9	2.4	-3.7	49.3	48.2
	Dom	39.4	43.0	5.2	0.7	44.6	43.7
P11	N-Dom	44.2	35.2	6.1	4.9	50.2	40.1
	Dom	47.5	32.8	4.6	0.1	52.2	32.9
P12	N-Dom	52.2	49.7	-5.6	-7.2	46.6	42.5
	Dom	48.4	51.5	-5.3	-2.1	43.1	49.4

Appendix 5: ROM, Min, and max values of the Hip Rotation

		ROM B	ROM A	MinB	MinA	Max B	Max A
Norm	N-Dom	15.6	15.6	-7.8	-7.8	7.8	7.8
	Dom	15.6	15.6	-7.8	-7.8	7.8	7.8
P1	N-Dom	9.5	12.0	3.9	-2.8	13.4	9.2
	Dom	12.5	8.9	6.5	2.9	19.0	11.9
P2	N-Dom	12.9	16.3	20.5	-2.9	33.4	13.3
	Dom	13.5	11.3	2.0	-3.1	15.5	8.1
P3	N-Dom	17.6	19.2	-22.0	-11.9	-4.4	7.4
	Dom	13.3	12.3	18.3	10.2	31.6	22.6
P4	N-Dom	14.4	17.1	-2.0	-0.7	12.4	16.4
	Dom	14.1	19.8	21.9	14.2	36.0	34.1
P5	N-Dom	9.8	12.8	1.9	-1.9	11.7	10.9
	Dom	5.7	11.0	12.6	2.2	18.3	13.2
P6	N-Dom	24.6	18.1	-6.8	-9.0	17.8	9.1
	Dom	18.2	15.8	16.9	15.1	35.0	30.9
P7	N-Dom	16.7	10.6	4.5	1.1	21.3	11.7
	Dom	17.0	8.7	12.3	-8.5	29.3	0.2
P8	N-Dom	11.1	19.0	1.7	-8.2	12.8	10.8
	Dom	23.8	23.8	-1.0	-6.3	22.9	17.5
P9	N-Dom	18.5	13.5	1.1	-13.4	19.7	0.1
	Dom	16.7	14.1	10.9	-8.9	27.6	5.2
P10	N-Dom	10.7	7.4	17.7	18.0	28.4	25.4
	Dom	9.4	13.4	3.4	-8.5	12.7	4.9
P11	N-Dom	17.9	18.4	5.7	4.2	23.6	22.6
	Dom	34.9	25.2	7.7	2.2	42.6	27.4
P12	N-Dom	27.4	25.7	12.3	1.7	39.8	27.4
	Dom	26.3	31.7	30.0	7.0	56.4	38.8

Appendix 6: ROM, Min, and max values of the Biceps Femoris

		ROM B	ROM A	MinB	MinA	Max B	Max A
Norm	N-Dom	1.5E-04	1.5E-04	1.5E-05	1.5E-05	1.6E-04	1.6E-04
	Dom	1.5E-04	1.5E-04	1.5E-05	1.5E-05	1.6E-04	1.6E-04
P1	N-Dom	2.0E-04	1.5E-04	4.9E-05	4.7E-05	2.5E-04	2.0E-04
	Dom	1.6E-04	1.2E-04	4.7E-05	4.6E-05	2.1E-04	1.7E-04
P2	N-Dom	3.4E-04	2.7E-04	4.6E-05	5.0E-05	3.9E-04	3.2E-04
	Dom	3.8E-04	2.5E-04	4.5E-05	4.4E-05	4.3E-04	3.0E-04
P3	N-Dom	2.8E-04	2.3E-04	5.0E-05	4.5E-05	3.3E-04	2.8E-04
	Dom	2.1E-04	2.3E-04	5.4E-05	4.5E-05	2.6E-04	2.8E-04
P4	N-Dom	3.4E-04	1.0E-04	2.2E-04	8.7E-05	5.6E-04	1.9E-04
	Dom	1.1E-04	6.8E-05	1.9E-04	7.6E-05	3.0E-04	1.4E-04
P5	N-Dom	8.3E-05	1.8E-04	2.2E-04	5.9E-05	3.0E-04	2.4E-04
	Dom	1.3E-04	1.7E-04	1.5E-04	4.6E-05	2.9E-04	2.1E-04
P6	N-Dom	2.7E-04	1.6E-04	4.2E-05	4.3E-05	3.1E-04	2.0E-04
	Dom	1.3E-04	1.1E-04	4.7E-05	4.7E-05	1.8E-04	1.5E-04
P7	N-Dom	2.8E-04	2.0E-04	6.2E-05	6.8E-05	3.4E-04	2.7E-04
	Dom	2.7E-04	2.1E-04	6.2E-05	6.1E-05	3.3E-04	2.8E-04
P8	N-Dom	1.9E-04	2.0E-04	1.8E-04	3.9E-05	3.8E-04	2.4E-04
	Dom	2.8E-04	3.5E-04	1.9E-04	4.9E-05	4.7E-04	4.0E-04
P9	N-Dom	7.3E-05	1.0E-04	6.9E-05	5.4E-05	1.4E-04	1.6E-04
	Dom	1.3E-04	1.0E-04	7.0E-05	5.1E-05	2.0E-04	1.6E-04
P10	N-Dom	1.7E-04	1.9E-04	3.8E-04	1.8E-04	5.5E-04	3.7E-04
	Dom	1.6E-04	2.1E-04	4.9E-03	1.9E-04	5.0E-03	4.0E-04
P11	N-Dom	1.5E-04	6.5E-05	2.0E-04	5.5E-05	3.4E-04	1.2E-04
	Dom	1.7E-04	1.1E-04	2.0E-04	5.5E-05	3.7E-04	1.7E-04
P12	N-Dom	4.2E-05	1.1E-04	4.2E-05	4.0E-05	8.4E-05	1.5E-04
	Dom	1.0E-05	6.3E-05	4.0E-05	3.9E-05	5.0E-05	1.0E-04

Appendix 7: ROM, Min, and max values of the Gastrocnemius

		ROM B	ROM A	Min B	Min A	Max B	Max A
Norm	N-Dom	2.8E-04	2.8E-04	3.1E-05	3.1E-05	3.1E-04	3.1E-04
	Dom	2.8E-04	2.8E-04	3.1E-05	3.1E-05	3.1E-04	3.1E-04
P1	N-Dom	1.9E-04	3.1E-04	5.8E-05	5.0E-05	2.5E-04	2.5E-04
	Dom	1.8E-04	2.6E-04	5.0E-05	5.9E-05	2.3E-04	3.2E-04
P2	N-Dom	3.1E-04	2.7E-04	5.1E-05	4.9E-05	3.6E-04	3.6E-04
	Dom	5.4E-04	5.1E-04	5.4E-05	5.6E-05	5.9E-04	5.7E-04
P3	N-Dom	2.9E-04	2.8E-04	4.5E-05	4.4E-05	3.4E-04	3.4E-04
	Dom	2.2E-04	2.5E-04	5.0E-05	5.5E-05	2.7E-04	3.1E-04
P4	N-Dom	2.4E-04	2.5E-04	1.8E-04	8.7E-05	4.1E-04	4.1E-04
	Dom	3.8E-04	2.1E-04	1.9E-04	7.3E-05	5.7E-04	2.8E-04
P5	N-Dom	2.6E-04	2.9E-04	1.5E-04	5.0E-05	4.1E-04	4.1E-04
	Dom	4.3E-04	3.5E-04	1.6E-04	5.0E-05	5.9E-04	4.0E-04
P6	N-Dom	1.4E-04	1.3E-04	3.9E-05	4.1E-05	1.8E-04	1.8E-04
	Dom	1.9E-04	2.0E-04	5.3E-05	4.6E-05	2.5E-04	2.5E-04
P7	N-Dom	3.9E-04	2.7E-04	7.3E-05	7.1E-05	4.6E-04	4.6E-04
	Dom	3.1E-04	2.0E-04	6.2E-05	5.3E-05	3.7E-04	2.5E-04
P8	N-Dom	2.2E-04	3.4E-04	1.7E-04	4.6E-05	3.9E-04	3.9E-04
	Dom	2.2E-04	3.3E-04	1.9E-04	5.9E-05	4.1E-04	3.9E-04
P9	N-Dom	1.7E-04	1.2E-04	6.5E-05	5.0E-05	2.3E-04	2.3E-04
	Dom	1.7E-04	7.6E-05	7.6E-05	5.3E-05	2.5E-04	1.3E-04
P10	N-Dom	1.7E-04	1.7E-04	4.9E-03	1.9E-04	5.1E-03	5.1E-03
	Dom	1.8E-04	1.9E-04	1.1E-03	1.7E-04	1.2E-03	3.6E-04
P11	N-Dom	3.0E-04	2.1E-04	1.8E-04	5.4E-05	4.8E-04	4.8E-04
	Dom	1.7E-04	1.7E-04	1.7E-04	5.0E-05	3.3E-04	2.2E-04
P12	N-Dom	1.1E-04	1.5E-04	4.1E-05	4.3E-05	1.5E-04	1.5E-04
	Dom	1.2E-04	1.1E-04	5.2E-05	5.1E-05	1.7E-04	1.7E-04

Appendix 8: ROM, Min, and max values of the Rectus Femoris

		ROM B	ROM A	MinB	MinA	Max B	Max A
Norm	N-Dom	5.4E-05	5.4E-05	7.4E-06	7.4E-06	6.2E-05	6.2E-05
	Dom	5.4E-05	5.4E-05	7.4E-06	7.4E-06	6.2E-05	6.2E-05
P1	N-Dom	1.5E-04	1.1E-04	4.3E-05	4.6E-05	2.0E-04	1.5E-04
	Dom	2.3E-04	7.4E-05	5.2E-05	4.9E-05	2.8E-04	1.2E-04
P2	N-Dom	3.9E-04	3.2E-04	5.4E-05	4.3E-05	4.4E-04	3.6E-04
	Dom	4.0E-04	3.9E-04	5.6E-05	6.1E-05	4.6E-04	4.5E-04
P3	N-Dom	1.9E-04	1.8E-04	7.0E-05	4.9E-05	2.6E-04	2.3E-04
	Dom	2.3E-04	1.5E-04	7.5E-05	5.1E-05	3.0E-04	2.0E-04
P4	N-Dom	1.2E-04	1.3E-04	1.8E-04	8.5E-05	3.0E-04	2.1E-04
	Dom	1.1E-04	8.9E-05	2.4E-04	8.9E-05	3.5E-04	1.8E-04
P5	N-Dom	4.7E-04	1.5E-04	6.5E-05	1.9E-04	5.4E-04	3.4E-04
	Dom	3.0E-04	3.1E-04	2.5E-04	7.2E-05	5.6E-04	3.8E-04
P6	N-Dom	9.8E-05	1.1E-04	4.7E-05	3.7E-05	1.4E-04	1.4E-04
	Dom	1.1E-04	1.2E-04	5.6E-05	4.6E-05	1.6E-04	1.6E-04
P7	N-Dom	2.2E-04	1.6E-04	6.0E-05	5.4E-05	2.8E-04	2.1E-04
	Dom	3.2E-04	1.6E-04	4.5E-05	5.0E-05	3.6E-04	2.1E-04
P8	N-Dom	2.9E-04	1.7E-04	1.6E-04	5.5E-05	4.5E-04	2.3E-04
	Dom	3.1E-04	1.9E-04	1.9E-04	5.3E-05	5.0E-04	2.4E-04
P9	N-Dom	1.3E-04	1.3E-04	1.0E-04	5.5E-05	2.3E-04	1.9E-04
	Dom	1.6E-04	1.0E-04	8.6E-05	7.2E-05	2.5E-04	1.7E-04
P10	N-Dom	2.3E-04	2.0E-04	3.9E-04	2.0E-04	6.2E-04	4.0E-04
	Dom	2.0E-04	1.6E-04	3.6E-04	1.7E-04	5.6E-04	3.2E-04
P11	N-Dom	1.6E-04	1.8E-04	2.0E-04	8.0E-05	3.6E-04	2.6E-04
	Dom	1.3E-04	1.0E-04	1.7E-04	5.0E-05	3.0E-04	1.5E-04
P12	N-Dom	1.1E-04	4.5E-05	4.1E-05	4.0E-05	1.5E-04	8.5E-05
	Dom	7.9E-05	1.3E-05	4.6E-05	3.5E-05	1.2E-04	4.8E-05

Appendix 9: Peak values from FFT

		Biceps Femoris		Tibialis Anterior		Rectus Femoris		Gastrocnemius	
		Peak B	Peak A	Peak B	Peak A	Peak B	Peak A	Peak B	Peak A
Norm	N-Dom	1.1E-04	1.1E-04	2.7E-04	2.7E-04	5.0E-05	5.0E-05	2.2E-04	2.2E-04
	Dom	1.1E-04	1.1E-04	2.7E-04	2.7E-04	5.0E-05	5.0E-05	2.2E-04	2.2E-04
P1	N-Dom	1.2E-04	8.8E-05	2.2E-04	2.2E-04	1.8E-04	1.6E-04	2.8E-04	3.4E-04
	Dom	1.1E-04	9.0E-05	2.7E-04	2.2E-04	2.1E-04	1.3E-04	2.7E-04	3.2E-04
P2	N-Dom	1.2E-04	8.8E-05	3.4E-04	2.9E-04	3.6E-04	3.0E-04	3.7E-04	3.3E-04
	Dom	1.1E-04	9.0E-05	3.2E-04	2.9E-04	2.7E-04	2.5E-04	5.7E-04	5.6E-04
P3	N-Dom	5.6E-05	6.0E-05	6.2E-04	5.4E-04	2.0E-04	1.6E-04	3.0E-04	3.3E-04
	Dom	4.4E-05	3.4E-05	6.0E-04	5.0E-04	2.7E-04	1.8E-04	2.6E-04	3.5E-04
P4	N-Dom	4.4E-05	2.4E-05	5.6E-04	3.0E-04	4.7E-04	3.3E-04	6.1E-04	4.6E-04
	Dom	3.1E-05	1.9E-05	2.9E-04	2.4E-04	5.6E-04	2.5E-04	7.4E-04	3.5E-04
P5	N-Dom	3.2E-05	2.4E-05	4.5E-04	2.3E-04	5.5E-04	5.8E-04	4.4E-04	3.1E-04
	Dom	2.6E-05	1.5E-05	3.7E-04	2.3E-04	6.7E-04	3.8E-04	4.9E-04	2.4E-04
P6	N-Dom	3.2E-05	2.4E-05	3.0E-04	2.8E-04	1.4E-04	1.3E-04	2.1E-04	2.0E-04
	Dom	2.6E-05	1.5E-05	1.8E-04	1.5E-04	1.9E-04	1.7E-04	2.7E-04	2.7E-04
P7	N-Dom	2.1E-05	2.2E-05	3.9E-04	3.4E-04	3.2E-04	2.7E-04	5.7E-04	4.4E-04
	Dom	1.8E-05	1.2E-05	2.3E-04	2.6E-04	3.8E-04	2.7E-04	4.4E-04	3.4E-04
P8	N-Dom	1.5E-05	1.3E-05	5.2E-04	2.5E-04	4.5E-04	2.0E-04	5.3E-04	4.2E-04
	Dom	1.4E-05	1.1E-05	3.4E-04	3.4E-04	5.6E-04	2.2E-04	6.0E-04	4.3E-04
P9	N-Dom	1.5E-05	1.3E-05	3.1E-04	2.3E-04	3.1E-04	2.6E-04	3.3E-04	2.4E-04
	Dom	1.4E-05	1.1E-05	3.0E-04	2.2E-04	3.1E-04	2.2E-04	3.0E-04	1.9E-04
P10	N-Dom	1.5E-05	1.3E-05	1.5E-03	2.0E-04	1.0E-03	6.4E-04	1.0E-02	5.8E-04
	Dom	1.4E-05	1.1E-05	8.9E-04	5.4E-04	9.0E-04	5.0E-04	2.3E-03	5.3E-04
P11	N-Dom	1.5E-05	1.3E-05	2.2E-04	2.1E-04	5.2E-04	2.7E-04	6.0E-04	2.9E-04
	Dom	1.4E-05	1.1E-05	5.2E-04	2.3E-04	4.2E-04	1.9E-04	5.0E-04	2.8E-04
P12	N-Dom	1.4E-05	1.1E-05	2.5E-04	2.0E-04	1.2E-04	1.0E-04	1.6E-04	2.1E-04
	Dom	1.2E-05	8.2E-06	1.8E-04	2.9E-04	1.2E-04	8.5E-05	1.9E-04	1.9E-04
p-value	N-N B/A	0.01		0.02		<0.01		0.02	
	D-D B/A	<0.01		<0.01		<0.01		0.01	

		Ankle Flex/Ext		Hip Flex/Ext		Hip ABD/ADD		Hip Rotation	
		Peak B	Peak A	Peak B	Peak A	Peak B	Peak A	Peak B	Peak A
Norm	N-Dom	8.9	8.9	30.8	30.8	4.06	4.06	3.05	3.05
	Dom	8.9	8.9	30.8	30.8	4.06	4.06	3.05	3.05
P1	N-Dom	18.4	16.4	53.6	38.1	8.4	8.9	16.1	5.3
	Dom	11.6	10.3	47.5	33.7	7.3	5.3	22.3	13.9
P2	N-Dom	16.2	23	41.3	29.7	5.3	4.4	55.1	10.5
	Dom	11.3	11.6	30.1	24.5	4.2	3.2	20.2	6.5
P3	N-Dom	11.2	10.2	46.7	50.4	7.7	5.9	23.7	4.3
	Dom	8.5	6.7	35.2	39.3	6.4	6.5	51.9	34
P4	N-Dom	27.1	16	52.2	23.2	8.3	4.7	13.5	13.6
	Dom	26.7	19.4	48.5	20.3	2.8	4.7	52.3	43.8
P5	N-Dom	11.6	11.8	54	29.9	6.5	3.7	12.6	7.7
	Dom	18.3	11.9	46.3	20.3	15.1	6.8	31.7	16.3
P6	N-Dom	12.6	11.8	26.7	34.2	7.5	5.6	11.4	4.7
	Dom	11.1	7.9	18	23.8	10.3	5	47.3	44.6
P7	N-Dom	19.9	10.4	45.7	39.9	9.4	10.1	26.6	12.5
	Dom	11.2	8	29	27.4	6.6	7.3	43	5.9
P8	N-Dom	17.5	15	20.8	25	11.1	8.5	15.2	5.3
	Dom	13.5	11.7	22.1	25.6	7.5	7.3	12.9	8.3
P9	N-Dom	7.1	11.4	50	54.4	13.6	11.7	16.9	14
	Dom	9	10	44.5	51	19.2	5.4	37	5.3
P10	N-Dom	30.7	25.7	55	46.7	10.9	5.9	43.4	43.2
	Dom	33.5	20.8	49.7	45.6	11.3	11.4	14.5	3.7
P11	N-Dom	20.1	15.4	53.7	38.5	12.7	8.8	28.02	23.2
	Dom	20.3	7.4	53	27.1	25.3	12.4	42.8	25.4
P12	N-Dom	10.7	6	42.7	34.2	5.7	5.5	53.6	31.8
	Dom	9	8.5	41.7	48.8	5.3	3.9	82.2	42.2
p-value	N-N B/A	0.09		0.02		<0.01		<0.01	
	D-D B/A	<0.01		0.3		0.05		<0.01	

Appendix 10: Areas of intervals A, B and C of the FFT of Rectus Femoris

Table 11: calculated from the fft graph of the EMG data collected from the rectus femoris muscles before and after RAGT.

		Area B			Area A		
		A	B	C	A	B	C
Norm	N-Dom	2.71E-04	1.33E-05	1.39E-06	2.71E-04	1.33E-05	1.39E-06
	Dom	2.71E-04	1.33E-05	1.39E-06	2.71E-04	1.33E-05	1.39E-06
P1	N-Dom	9.92E-04	6.39E-05	3.80E-05	8.89E-04	4.02E-05	3.68E-05
	Dom	1.11E-03	2.90E-05	5.10E-05	7.54E-04	2.09E-05	1.61E-05
P2	N-Dom	1.88E-03	2.07E-04	1.21E-04	1.58E-03	1.76E-04	1.23E-04
	Dom	1.38E-03	5.28E-05	6.57E-05	1.26E-03	2.39E-05	6.92E-05
P3	N-Dom	1.06E-03	3.92E-05	5.28E-05	8.44E-04	6.26E-06	4.34E-05
	Dom	1.47E-03	7.71E-05	8.35E-05	9.84E-04	5.49E-05	4.10E-05
P4	N-Dom	2.71E-03	9.17E-05	4.59E-05	1.88E-03	3.04E-05	2.86E-05
	Dom	3.28E-03	1.22E-04	6.63E-05	1.42E-03	3.72E-05	2.76E-05
P5	N-Dom	3.05E-03	8.98E-05	8.75E-05	3.36E-03	1.19E-04	2.27E-05
	Dom	3.84E-03	1.40E-04	5.71E-05	2.10E-03	5.73E-05	5.10E-05
P6	N-Dom	8.02E-04	1.88E-05	2.30E-05	6.90E-04	1.46E-05	2.11E-05
	Dom	1.10E-03	1.95E-05	2.78E-05	9.60E-04	1.48E-05	3.32E-05
P7	N-Dom	1.83E-03	1.45E-04	5.62E-05	1.57E-03	1.05E-04	1.43E-05
	Dom	2.05E-03	1.12E-04	6.86E-05	1.48E-03	6.25E-05	4.02E-05
P8	N-Dom	2.49E-03	4.31E-05	6.32E-05	1.12E-03	6.50E-05	4.95E-05
	Dom	3.22E-03	2.21E-04	6.11E-05	1.17E-03	1.01E-04	7.72E-05
P9	N-Dom	1.76E-03	6.53E-05	2.83E-05	1.47E-03	4.31E-05	2.04E-05
	Dom	1.76E-03	5.80E-05	2.81E-05	1.28E-03	4.39E-05	7.85E-06
P10	N-Dom	5.99E-03	2.15E-04	7.43E-05	3.72E-03	1.66E-04	5.32E-05
	Dom	5.27E-03	2.10E-04	7.53E-05	2.89E-03	1.56E-04	4.26E-05
P11	N-Dom	2.99E-03	9.49E-05	5.09E-05	1.52E-03	1.37E-05	2.79E-05
	Dom	2.46E-03	7.65E-05	2.65E-05	1.08E-03	2.78E-05	2.02E-05
P12	N-Dom	6.81E-04	3.50E-05	3.47E-05	5.72E-04	2.44E-05	1.81E-05
	Dom	6.48E-04	2.47E-05	2.25E-05	4.96E-04	1.55E-05	8.06E-06

Appendix 11: Coactivity between Tibialis Anterior vs GASTROCNEMIUS

Coactivity of Tibialis vs GASTROCNEMIUS

		Before	After
Normative	Non-Dom	89.9	89.9
	Dom	89.9	89.9
P1	Non-Dom	110.5	120.9
	Dom	99.0	118.8
P2	Non-Dom	105.5	105.8
	Dom	127.9	132.4
P3	Non-Dom	64.4	76.6
	Dom	61.1	75.7
P4	Non-Dom	104.1	121.8
	Dom	143.3	117.8
P5	Non-Dom	98.6	113.4
	Dom	114.9	101.0
P6	Non-Dom	83.3	82.8
	Dom	119.8	127.6
P7	Non-Dom	119.2	111.9
	Dom	131.3	112.6
P8	Non-Dom	101.4	125.9
	Dom	127.9	111.9
P9	Non-Dom	102.5	103.3
	Dom	100.2	92.2
P10	Non-Dom	174.4	148.9
	Dom	144.5	99.3
P11	Non-Dom	145.4	115.6
	Dom	97.9	109.7
P12	Non-Dom	77.0	102.0
	Dom	101.5	79.3