Development of innovative training solutions in the field of functional evaluation aimed at updating of the curricula of health sciences schools

MODULE BIOMECHANICS OF GAIT

Didactic Unit D: INTRUMENTED ANALYSIS OF GAIT

D.3 Interpretation of the biomechanical gait analysis in pathological cases

D.3 How do I interpret a biomechanics instrumented analysis' report in a case of gait pathology?

I. Objectives

II. Biomechanical gait impairment in people with joint replacement

III. Biomechanical gait alteration in people after a stroke

IV. Key ideas

V. References

D.3 How do I interpret a biomechanics instrumented analysis' report in a case of gait pathology?

I. Objectives

I. OBJECTIVES

1. To know the gait impairments through biomechanical evaluation in different pathologies.

2. To identify what the alterations in the biomechanical parameters in gait means in different pathologies.

3. Recognize an altered gait pattern through biomechanical assessment techniques.

D.3 How do I interpret a biomechanics instrumented analysis' report in a case of gait pathology?

II. Biomechanical gait impairment in people with joint replacement

II. BIOMECHANICAL GAIT IMPAIRMENT IN JOINT REPLACEMENT

- Both lower limb osteoarthritis and joint replacement in that is performed to provide a therapeutic response to joint damage, can affect the gait of patients in different ways.

Figure 1 – Example of lower limb replacement in hip and knee.

II. BIOMECHANICAL GAIT IMPAIRMENT IN JOINT REPLACEMENT

Spatiotemporal parameter

Are the values recorded from patients similar to the values recorded in healthy participants?

II. BIOMECHANICAL GAIT IMPAIRMENT IN JOINT REPLACEMENT

Spatiotemporal parameter

Table 1: Spatiotemporal outcomes from gait analysis in patients with joint replacement

	Hip replacement		Knee replacement	
	Patients	**Healthy Controls**	**Patients**	**Healthy Controls**
Velocity (m/s)	0.70, 0.92 [1]	1.31, 1.34 [1]	1.01, 1.05 [3] 0.74, 0.77 [5]	1.04 [5]
Stride length (m)	1.3 [2] 0.97, 1 m [5]	1.5 [2] 1.2 [5]	1.18, 1.20 m [3] 0.90, 0.75 [6]	1.16 [6]
Step length (m)	0.47, 0.49 [5]	0.52 [5]	0.45, 0.54 [4]	-
Cadence (steps/min)	91.3, 93.9	103.2	102.19, 105.19 [3] 99.25, 93.96 [6]	100.21 [6]

Table 1 – Spatiotemporal gait values for total hip replacement, and total and unicondylar knee arthroplasty. [1]Ewen A. et al. 2012. [2]Beaulieu M. et al. 2010. [3]Hyodo K. et al. 2020. [4]Agarwal A. et al. 2019. [5]Temportiti F. et al. 2019. [6]Temportiti F. et al. 2019.

II. BIOMECHANICAL GAIT IMPAIRMENT IN JOINT REPLACEMENT

Kinematics parameter: hip replacement

Morphology of kinematic curve

Do the patients present a joint movement curve with all the milestones that we observe in a curve of healthy participants?

Range of motion and peak value

Do patients perform the same range of motion than healthy people? Do the patients reach the peak values of joint movement than healthy participants?

Angular velocity

Do patients move at the same speed as healthy participants?

II. BIOMECHANICAL GAIT IMPAIRMENT IN JOINT REPLACEMENT

Kinematics parameter: hip replacement

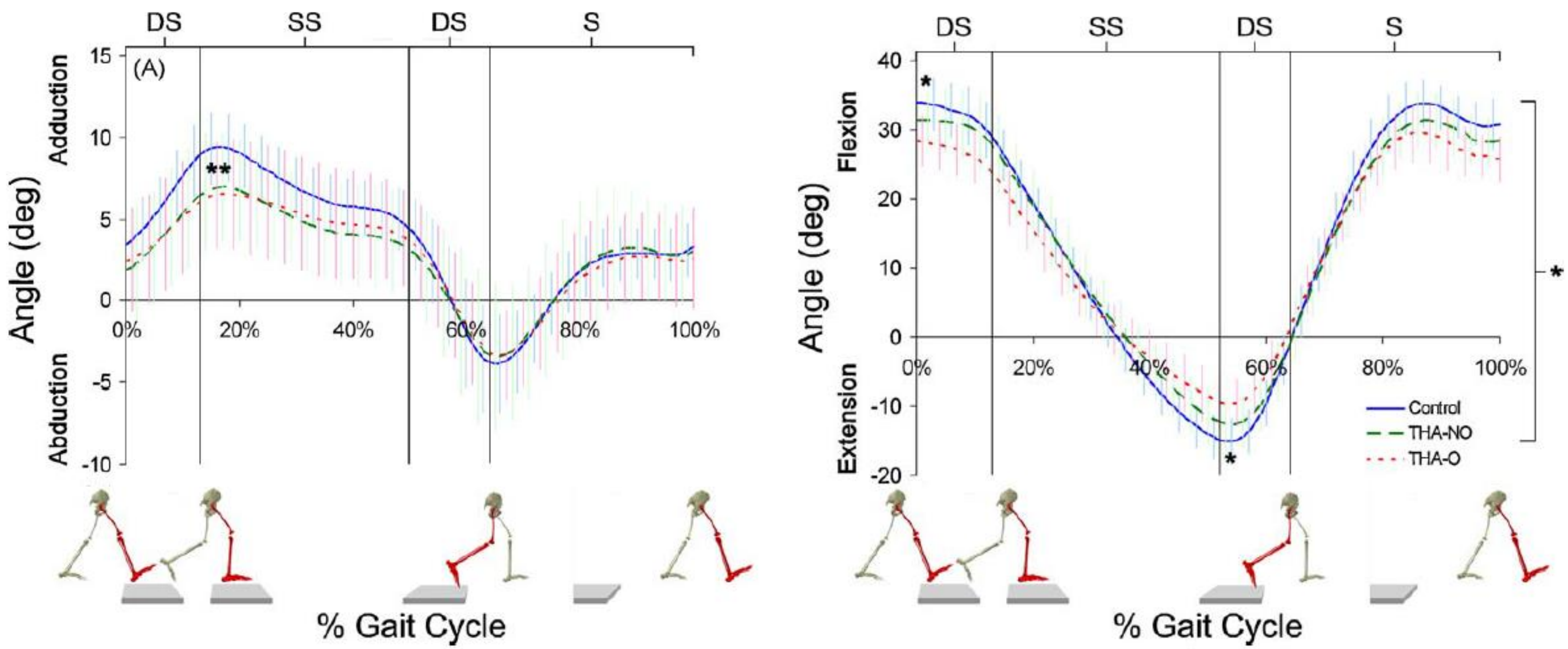


Figure 2 – Abduction/adduction and flexion/extension hip movement from Beaulieu M. et al. 2010 study.

II. BIOMECHANICAL GAIT IMPAIRMENT IN JOINT REPLACEMENT

Kinematics parameter: hip replacement

Table 2: Kinematics performance during gait cycle of patients with hip replacement		
	Patients	**Healthy Controls**
Flexion-extension ROM (º)	23.1º to 40.7º [1] 40.7 [2]	31º to 51º [1] 51.0 [2]
Flexion Peak (º)	28.4 [2]	33.9 [2]
Extension Peak (º)	-10.1 [2]	-15.1 [2]
Adduction Peak (º)	7.6 [2]	9.8 [2]
External rotation Peak (º)	0.6 [2]	-3.5 [2]

Table 2 – kinematics gait values for total hip replacement. [1]Ewen A. et al. 2012. [2]Beaulieu M. et al. 2010.

II. BIOMECHANICAL GAIT IMPAIRMENT IN JOINT REPLACEMENT

Kinematics parameter: knee replacement

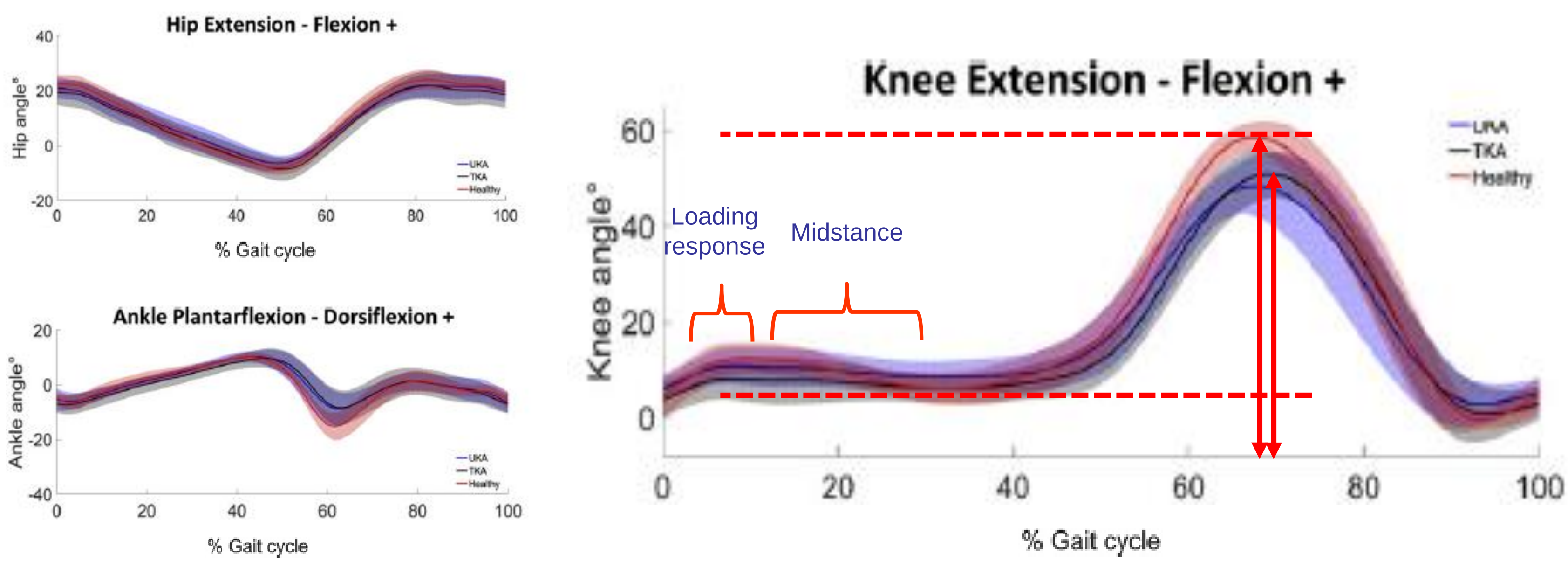


Figure 3 – Movement in the sagittal plane for hip, ankle, and knee joint after one year of total knee arthroplasty (TKA) and unicondylar knee arthroplasty (UKA) compared with healthy people. De Vroey H. et al. 2019.

II. BIOMECHANICAL GAIT IMPAIRMENT IN JOINT REPLACEMENT

Kinematics parameter: knee replacement

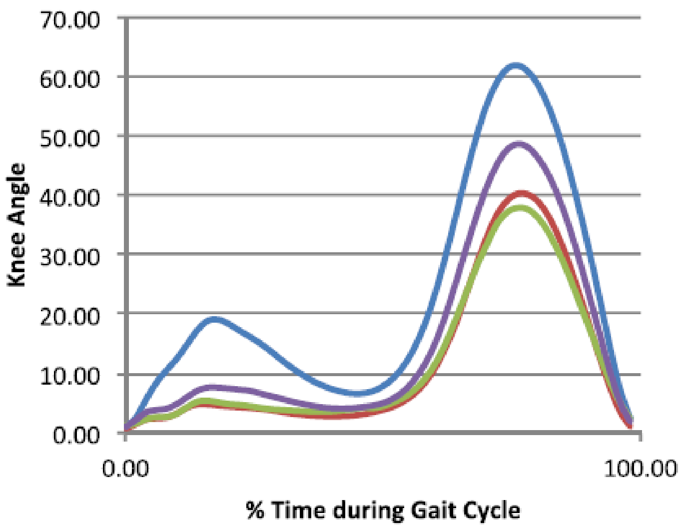


Figure 4 – Total knee arthroplasty patients before surgery and at 8- and 52-weeks post-surgery. Rahman J. et al. 2015.

Table 3: Kinematics performance during gait cycle of patients with hip replacement

	Patients	Healthy Controls
Flexion-extension ROM (º)	23.1º to 40.7º [1] 49.3, 56.1 [2] 41.49, 46.58 [4]	31º to 51º [1] 60.7 [2]
Flexion Peak during loading response (º)	10.8, 17.8 [2] 10.98, 6.86 [3]	19.0 [2] 13.43 [3]
Flexion Peak during swing (º)	47.3, 55.6 [2] 49.82, 47.56 [3] 47.92, 51.01 [4]	61.7 [2] 59.87 [3]
Extension Peak (º)	-0.7, 0.1 [2] 7.63, 5.31 [3] 7.17, 3.96 [4]	2.2 [2] 6.12 [3]

Table 3 – kinematics gait values for knee replacement. [1]Ewen A. et al. 2012. [2]Esposito F. et al. 2020. [3]De Vroey H. 2019. [4]Coll A. et al. 2019.

II. BIOMECHANICAL GAIT IMPAIRMENT IN JOINT REPLACEMENT

Kinetics parameter: hip replacement

Morphology of ground reaction force curve

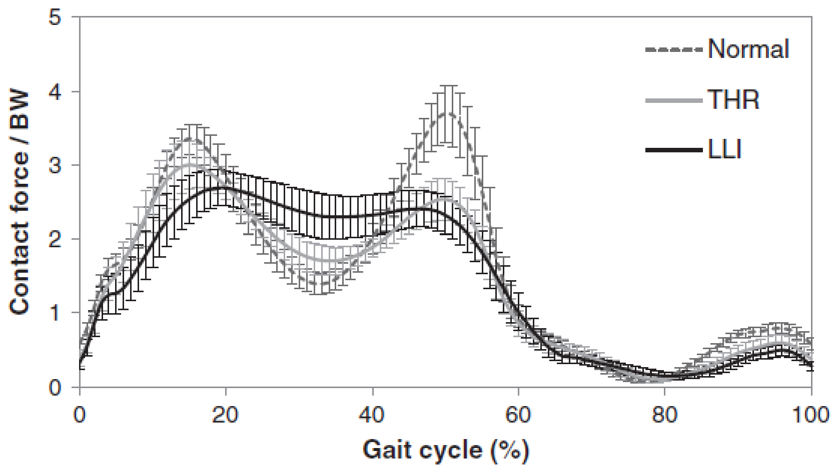
Do the patients present a ground reaction force curve with all the milestones that we observe in a curve of healthy participants?

Values of ground reaction forces

Do patients perform the same ground reaction force (newton / body weight) than healthy people?

II. BIOMECHANICAL GAIT IMPAIRMENT IN JOINT REPLACEMENT

Kinetics parameter: hip replacement



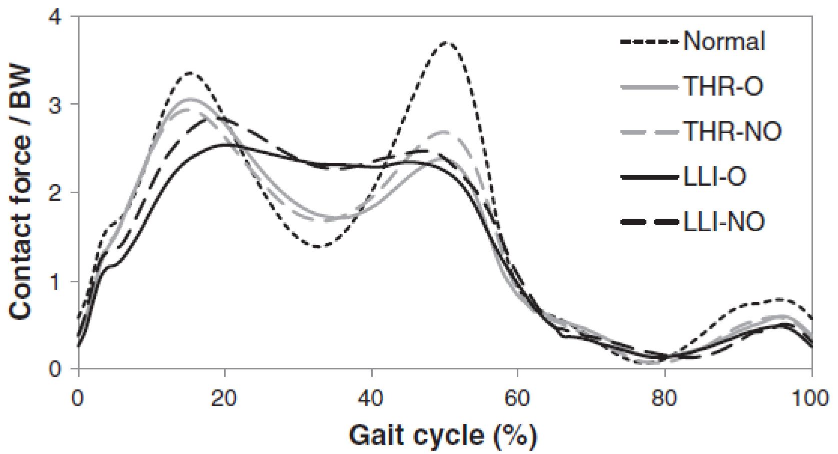


Figure 5 – Vertical ground reaction force during gait cycle of people with total hip replacement (THR), with total hip replacement and length inequality (LLI) and healthy controls. Right: Vertical force for LLI patients compared to the normal individuals and THR patients. Left: Vertical force or the operated (O) and non-operated (NO) limbs of the LLI and THR. Results from Li J. et al 2015.

II. BIOMECHANICAL GAIT IMPAIRMENT IN JOINT REPLACEMENT

Kinetics parameter – plantar pressure

Maximum plantar pressure values

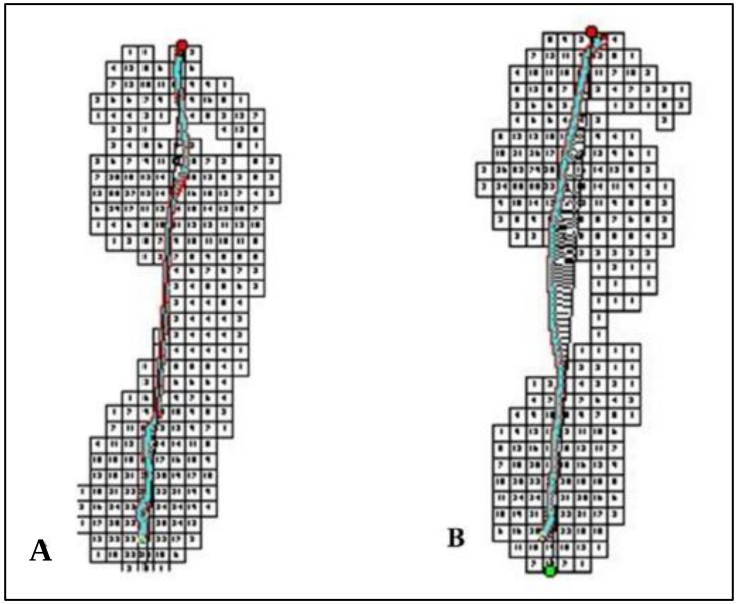
Do patients perform the same plantar pressures during gait as healthy people?

Pattern of the centre of pressures

The excursion of the centre of pressure through the sole of the foot has a similar path in patients than in healthy people?

II. BIOMECHANICAL GAIT IMPAIRMENT IN JOINT REPLACEMENT

Kinetics parameter – plantar pressure



Stance phase time
Pre-surgery: 987 ms
Post-surgery: 801.5 ms

Mean total plantar pressures
Pre-surgery: 1257.75 N/cm2
Post-surgery: 1436.0 N/cm2

COP pattern
Pre-surgery: lateral location
Post-surgery: medial location

Figure 6 –. The curve represents the average COP spatial evolution during the whole stance phase of gait before (a) and after (b) total knee arthroplasty in the same patient. Mediolateral area difference was 0.69% in favor of lateral location in the preoperative period and changed to 5.17% in favor of medial side Results from Şentürk I. et al 2017.

II. BIOMECHANICAL GAIT IMPAIRMENT IN JOINT REPLACEMENT

Clinical reasoning

Do patients walk slower because of pain? Or are they afraid to walk normally with a prosthesis?

Do patients have less joint range of motion due to the characteristics of the prosthesis? Or because exist a muscle deficiency after surgery? Or for pain?

Do the patients present alterations in the ground reaction force due to the fact that the load is not supported normally on the operated leg or only because the speed decreases?

Do patients after surgery have a higher plantar pressure because they support the leg normally on the side with joint replacement?

D.3 How do I interpret a biomechanics instrumented analysis' report in a case of gait pathology?

III. Biomechanical gait impairment in people after a stroke

III. BIOMECHANICAL GAIT IMPAIRMENT AFTER STROKE

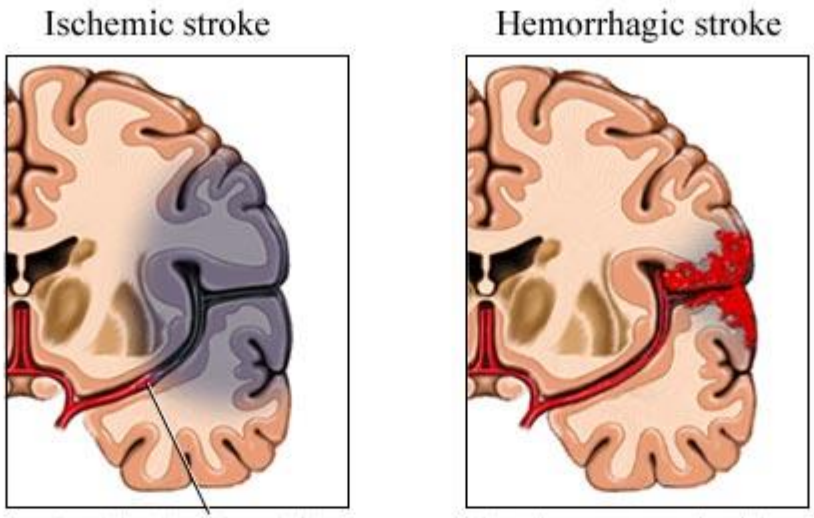


Figure 1 – Types of brain stroke. In ischemic stroke, a clot blocks blood flow to an area of the brain. In hemorrhagic stroke, bleeding occurs inside or around brain tissue. Image from www.braingait.com

- Brain stroke is a leading cause of serious long-term disability.
- Walking dysfunction occurs in more than 80% of stroke survivors.
- 25% of all stroke survivors have residual gait impairments.
- Gait impairments cause difficulties in performing activities of daily living and mobility.

III. BIOMECHANICAL GAIT IMPAIRMENT AFTER STROKE

Spatiotemporal parameters

Table 1 – Mean value of spatiotemporal parameters in chronic hemiplejic patients (stroke > 6 months) and healthy controls. Results from Boudarham J. et al. 2013.

Table 1: Spatiotemporal parameters

	Hemiplejic (*n* = 42)	**Healthy**
Velocity (m.s-1)	0.82	1.25
Stride length (m)	1.03	1.31
Step length (m)	0.52	0.65
Step width (s)	19.3	15.2
Cadence	93.1	114.3
Stride time (s)	1.32	1.06
Stance phase duration (%GC)	59.8	60.4
Swing pase duration (%GC)	40.2	39.6
Double support duration (%GC)	27.1	20.6

III. BIOMECHANICAL GAIT IMPAIRMENT AFTER STROKE

Spatiotemporal parameters

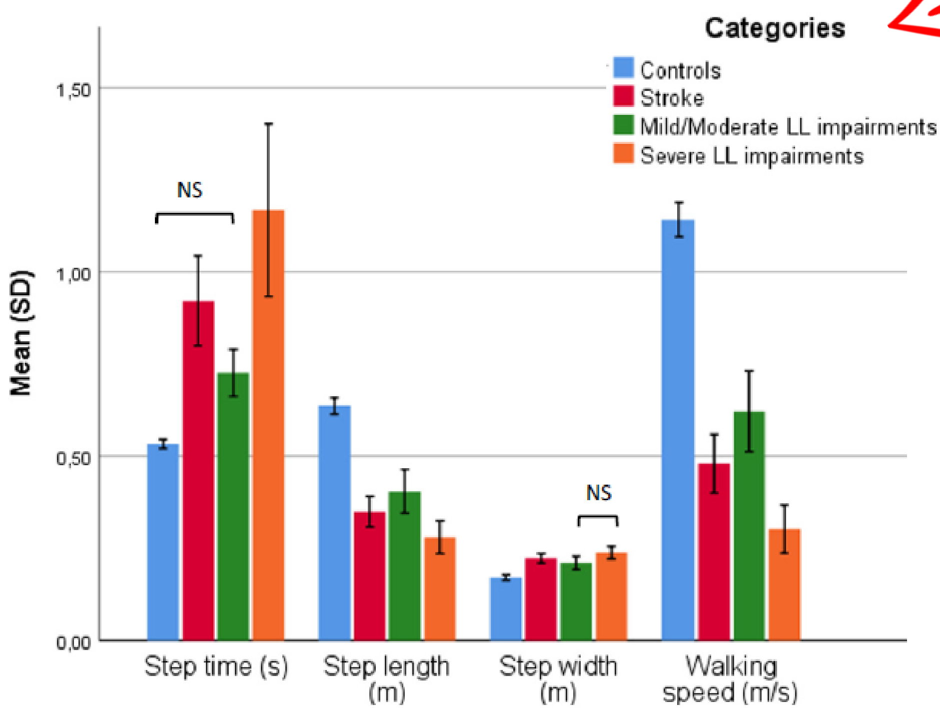


Figure 2 – Spatiotemporal parameters with respect to lower limb impairment (based on muscle strength, muscle tone and mobility). Results from Tamaya V.C. et al. 2020.

Lower limb impairments.

Strength			
5	Complete RoM, max resistance		Normal
4	Complete RoM, min resistance		
3	Complete RoM, against gravity		Moderate
2	Complete RoM, no gravity		
1	Palpable contraction		Severe
0	No contraction		
Tone			
0	No increase in resistance		Normal
1	Slight increase, catch and release		Moderate
2	Marked increase, easily moved		
3	Considerable increase, difficult to move		Severe
4	No movement possible		
Mobility			
0	Total RoM		Normal
1	Decrease of less than ½ of RoM		Moderate
2	Decrease of more than ½ of RoM		Severe
Lower limb impairments: total score of strength, tone and mobility			
	Normal		Mild
	Normal		
	Moderate		
	Normal		Moderate
	Moderate		
	Moderate		
Severe	Severe	Severe	Severe
Normal	Moderate	Normal	
Normal	Moderate	Moderate	

III. BIOMECHANICAL GAIT IMPAIRMENT AFTER STROKE

Spatiotemporal parameters

Decrease step length and walking speed.

Step time and step width increase.

Decrease stance phase and prolong swing phase in the paretic side.

III. BIOMECHANICAL GAIT IMPAIRMENT AFTER STROKE

Asymmetry of spatiotemporal parameters

- The difference between sides is a simple way to quantify symmetry, where difference of 0 represents perfect symmetry.
- **Raw value of symmetry index:** the sign of the value indicates the direction of the asymmetry.
- **Absolute values of symmetry index:** provided the amplitude of asymmetry.
- **Coefficient of variation**

$$\frac{V\ paretic - V\ nonparetic}{0.5\ (V\ paretic + V\ nonparetic)}\ x\ 100$$

$$\frac{Standar\ desviation}{Average}$$

III. BIOMECHANICAL GAIT IMPAIRMENT AFTER STROKE

Asymmetry of spatiotemporal parameters

Table 2: Absolute symmetry index of spatiotemporal outcomes

Speed groups	Step length		Stance time		Swing time		Double support	
	Patients	Controls	Patients	Controls	Patients	Controls	Patients	Controls
0.5–1.4	29.27	7.99	14.14	2.51	43.94	6.96	27.52	9.78
1.5–2.4	17.38	4.55	12.55	2.28	29.09	4.39	16.95	9.80
2.5–3.4	13.41	4.08	10.44	2.35	20.21	5.33	17.69	8.93
3.5–4.4	6.56	3.06	4.30	1.93	9.81	2.28	13.46	10.99
4.5–5.5	6.21	3.49	4.35	2.43	7.92	1.91	13.40	10.74

Table 2 – Absolute value of symmetrical index of principal spatiotemporal gait outcomes in people after stroke (*n*=130) and healthy controls (*n*=130). Results from Wang Y. et al. 2019.

III. BIOMECHANICAL GAIT IMPAIRMENT AFTER STROKE

Kinematics parameters: thorax

Stroke versus Healthy controls

Stroke with severe impairment, stroke with mild/moderate impairment and Healthy controls

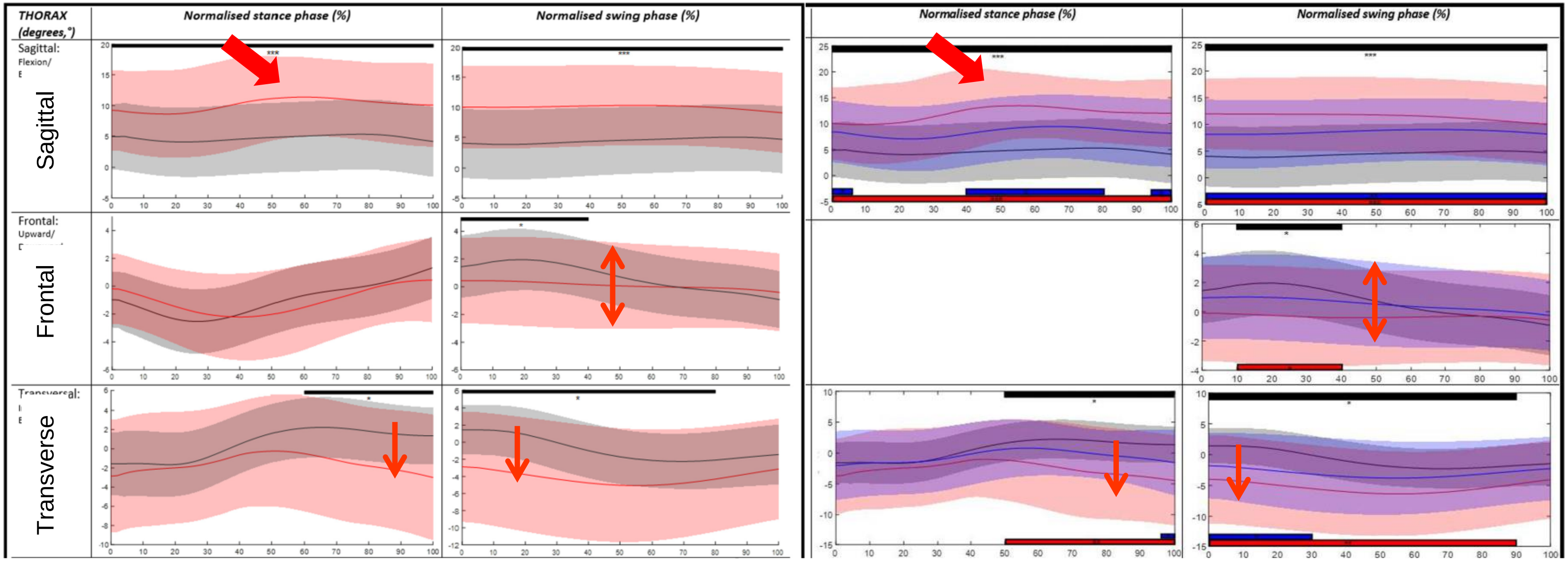
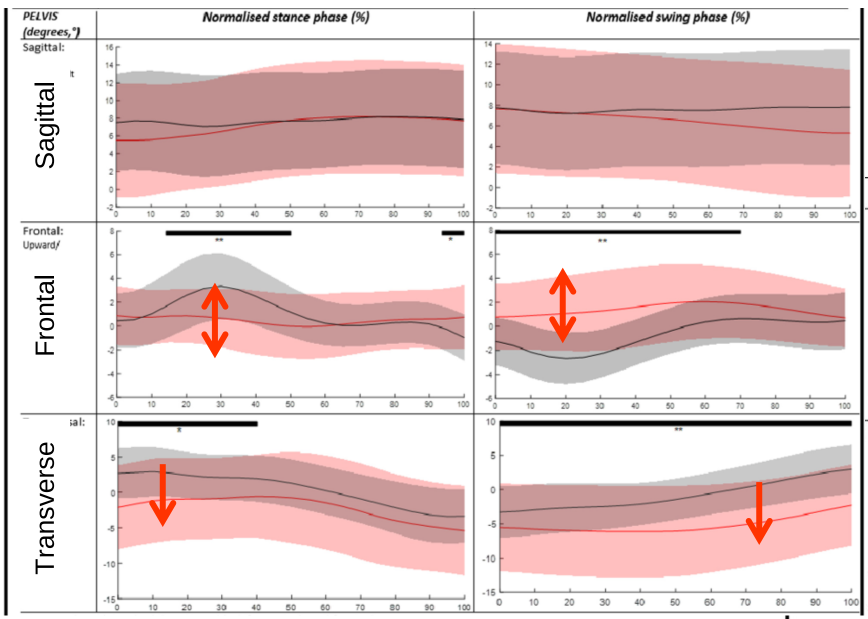


Figure 3 – Mean angle and standard deviations of thorax movement in sagittal, frontal and transverse plane. Black line: controls, blue: stroke mild/moderate lower limb impairment, red: stroke with severe lower limb impairment. Results from Tamaya V.C. et al. 2020.

III. BIOMECHANICAL GAIT IMPAIRMENT AFTER STROKE

Kinematics parameters: pelvis

Stroke versus Healthy controls



Stroke with severe impairment, stroke with mild/moderate impairment and Healthy controls

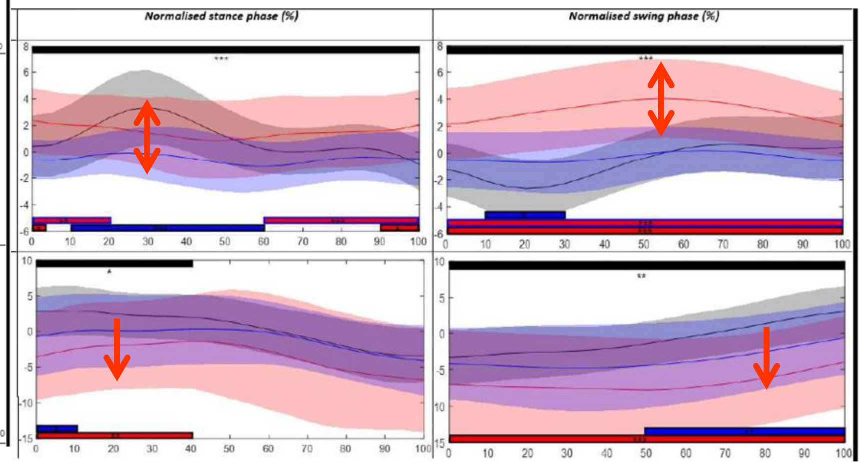


Figure 4 – Mean angle and standard deviations of pelvis movement in sagittal, frontal and transverse plane. Black line: controls, blue: stroke mild/moderate lower limb impairment, red: stroke with severe lower limb impairment. Results from Tamaya V.C. et al. 2020.

III. BIOMECHANICAL GAIT IMPAIRMENT AFTER STROKE

Kinematics parameters: hip, knee and ankle

Hip flexion-extension | **Knee flexion-extension** | **Ankle flexion-extension**

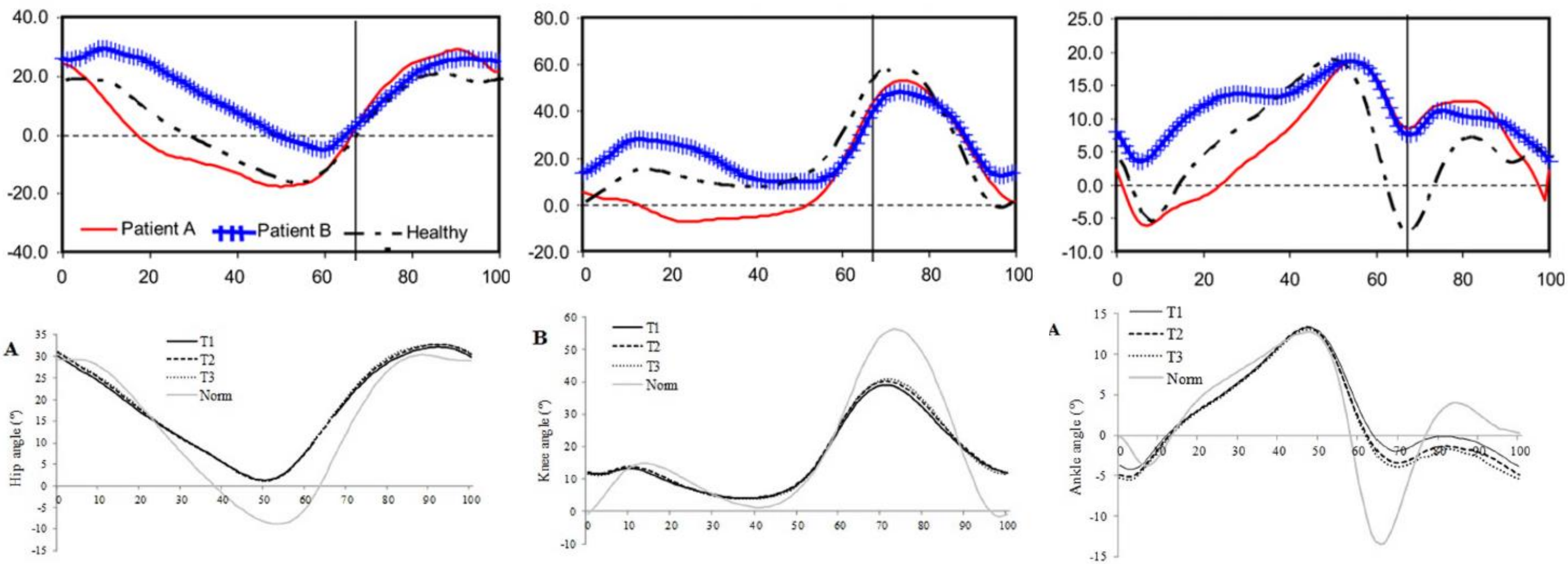
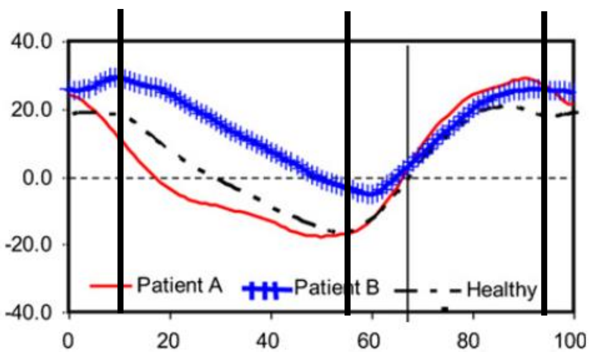


Figure 5 –Upper curves corresponds to results from Nadeau S. et al. 2013. Lower curves corresponds to results from Boudarham J. et al. 2013.

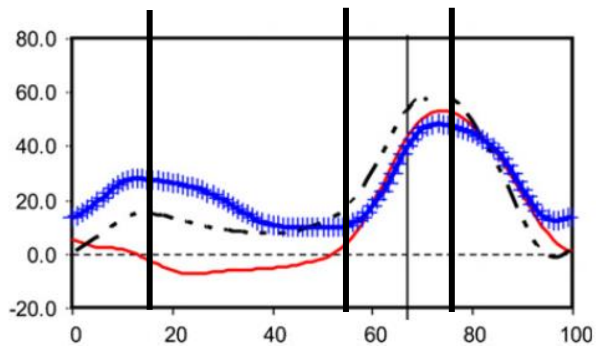
III. BIOMECHANICAL GAIT IMPAIRMENT AFTER STROKE

Kinematics parameters: hip, knee and ankle

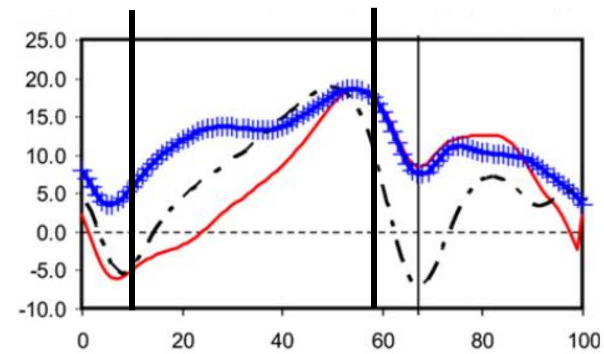
Hip flexion-extension



Knee flexion-extension



Ankle flexion-extension



Decrease hip flexion

Increase hip flexion

Increase hip extension

Increase knee flexion

Knee hiperextension

Decrease knee flexion

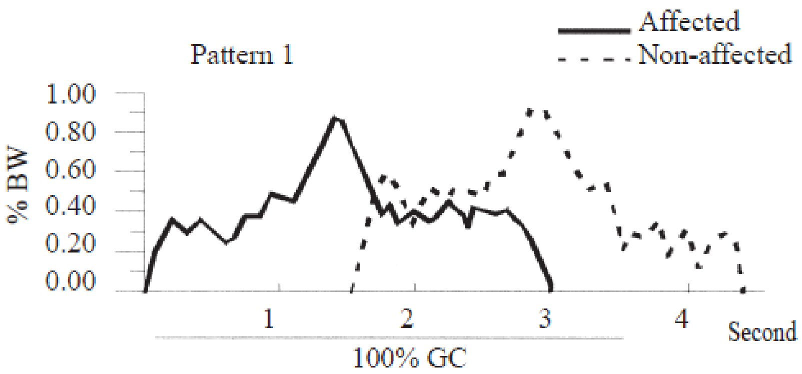
Increase plantarflexion

Lack of plantar-flexion

III. BIOMECHANICAL GAIT IMPAIRMENT AFTER STROKE

Kinetic parameters: ground reaction force

Pattern I with an irregular shape



Pattern II with an irregular inverted-V shape

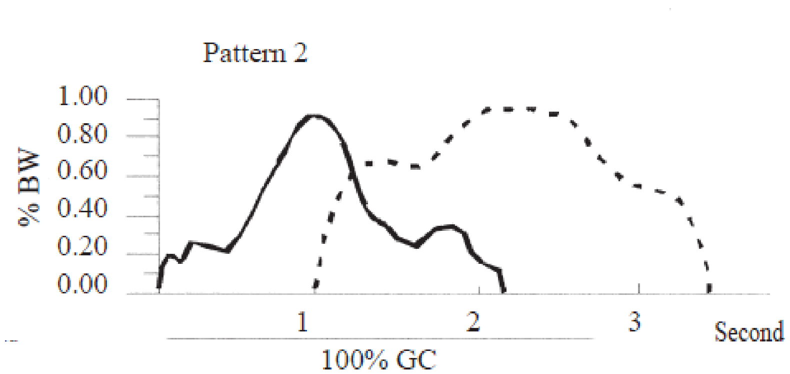
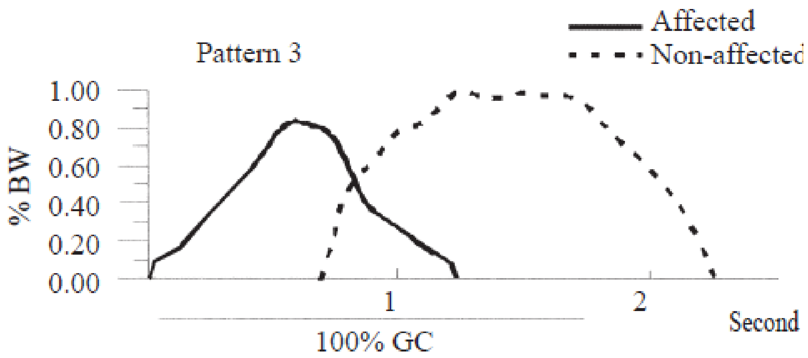


Figure 6 – Vertical ground reaction force pattern of people with unilateral hemiplegia caused by cerebral hemisphere stroke (the average duration after stroke onset was 10.3 months). Results from Chung-Yao Chen et al. 2007. Pattern I correspond to curves with irregular shape. Pattern II correspond to curves with an irregular inverted-V shape.

III. BIOMECHANICAL GAIT IMPAIRMENT AFTER STROKE

Kinetic parameters: ground reaction force

Pattern III with an inverted-V or inverted-U shape



Pattern IV with a bimodal M shape

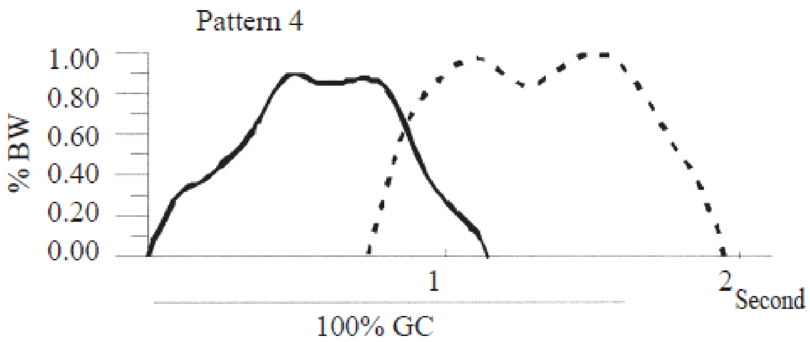
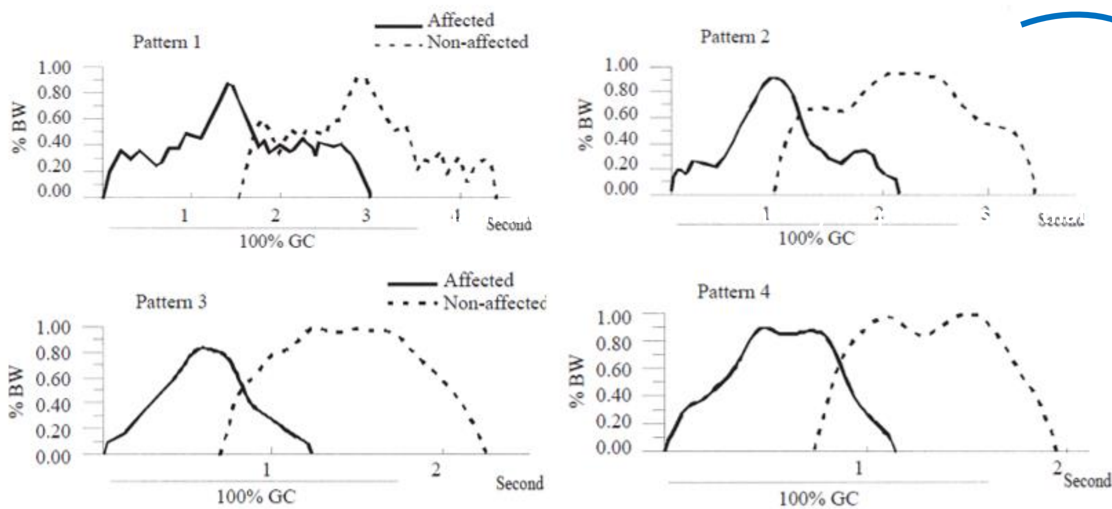
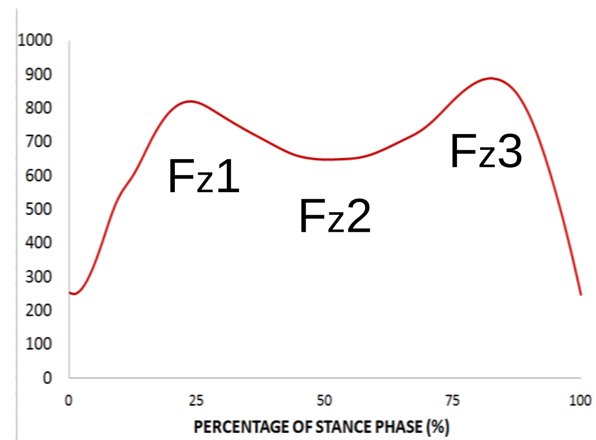


Figure 7 – Vertical ground reaction force pattern of people with unilateral hemiplegia caused by cerebral hemisphere stroke (the average duration after stroke onset was 10.3 months). Results from Chung-Yao Chen et al. 2007. Pattern III correspond to curves with an inverted-V or inverted-U shape. Pattern IV correspond to curves with a bimodal M shape.

III. BIOMECHANICAL GAIT IMPAIRMENT AFTER STROKE

Kinetic parameters: ground reaction force





The stroke patients do not have a typical morphology of ground reaction forces on the z-axis during the gait cycle

The magnitude of the forces reached by the patients is not that observed in a healthy pattern either

Fz 1: 1.2 force/bodyweight

Fz 2: 0.7 force/bodyweight

Fz 3: 1.2 force/bodyweight

III. BIOMECHANICAL GAIT IMPAIRMENT AFTER STROKE

Kinetic parameters: ground reaction force

Moreover, patients with patterns I and II have poor motor control with poor stability, resulting in the application of irregular forces. Furthermore, patients with pattern I may need supervised ambulation due to unstable gait, especially when walking on uneven ground or when walking long distances

Patients with pattern III have fair motor control, associated with a poor capacity to roll over the affected foot because of emerging forces (inverted "V"- or "U"-shaped forces pattern) in the heel-strike, mid-stance and push-off phases.

Patients with pattern IV have good motor control associated with grading forces ("M"-shaped vertical forces) in the heel-strike, mid-stance and push-off phases, similar to that in normal subjects.

D.3 How do I interpret a biomechanics instrumented analysis' report in a case of gait pathology?

IV. Key Ideas

IV. KEY IDEAS

1. When we analyze the biomechanical profile of gait in a pathology, we compare the performance of patients with the performance of healthy subjects matched on characteristics such as height, gender and weight. On the other hand, we can base this comparison on the normality values given by the literature.

2. The interpretation of an abnormal gait pattern is based on a series of criteria that we must observe: measured mean values, morphologies of the data curves recorded throughout the gait cycle, peak values reached at key points or milestones of the walking cycle and time at which milestones are reached.

3. In populations with a pathology, the study and analysis of the biomechanical record will be conditioned by the degree of severity of the pathology under study. This subclassification can include the analysis by gait speed ranges, differentiating the performance between hemi-bodies, or the stages of deterioration typical of the pathology.

4. Biomechanical information supports clinical evaluation and helps to understand and define gait performance in patients from several pathologies, and therefore helps the medical professionals make treatment-decisions.

D.3 How do I interpret a biomechanics instrumented analysis' report in a case of gait pathology?

V. References

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