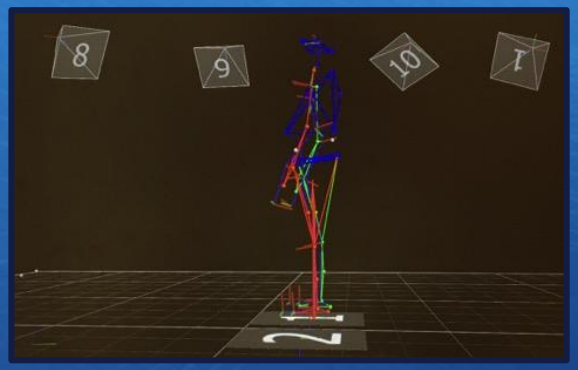
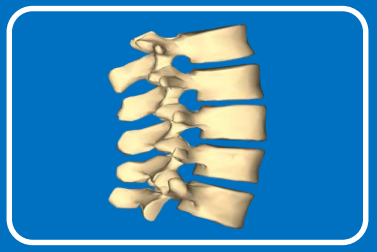
An Innovative Measurement in Musculoskeletal Rehabilitation Using 3D Motion Analysis



Caroline Wong 1
Leo Kam 1
Sharon Tsang 2
1. Physiotherapist I, Prince of Wales Hospital, Hong Kong
2. Assistant Professor, The Hong Kong Polytechnic University, Hong Kong

Background

LBP
- musculoskeletal dysfunction
- high prevalence & demand on medical care / rehabilitation



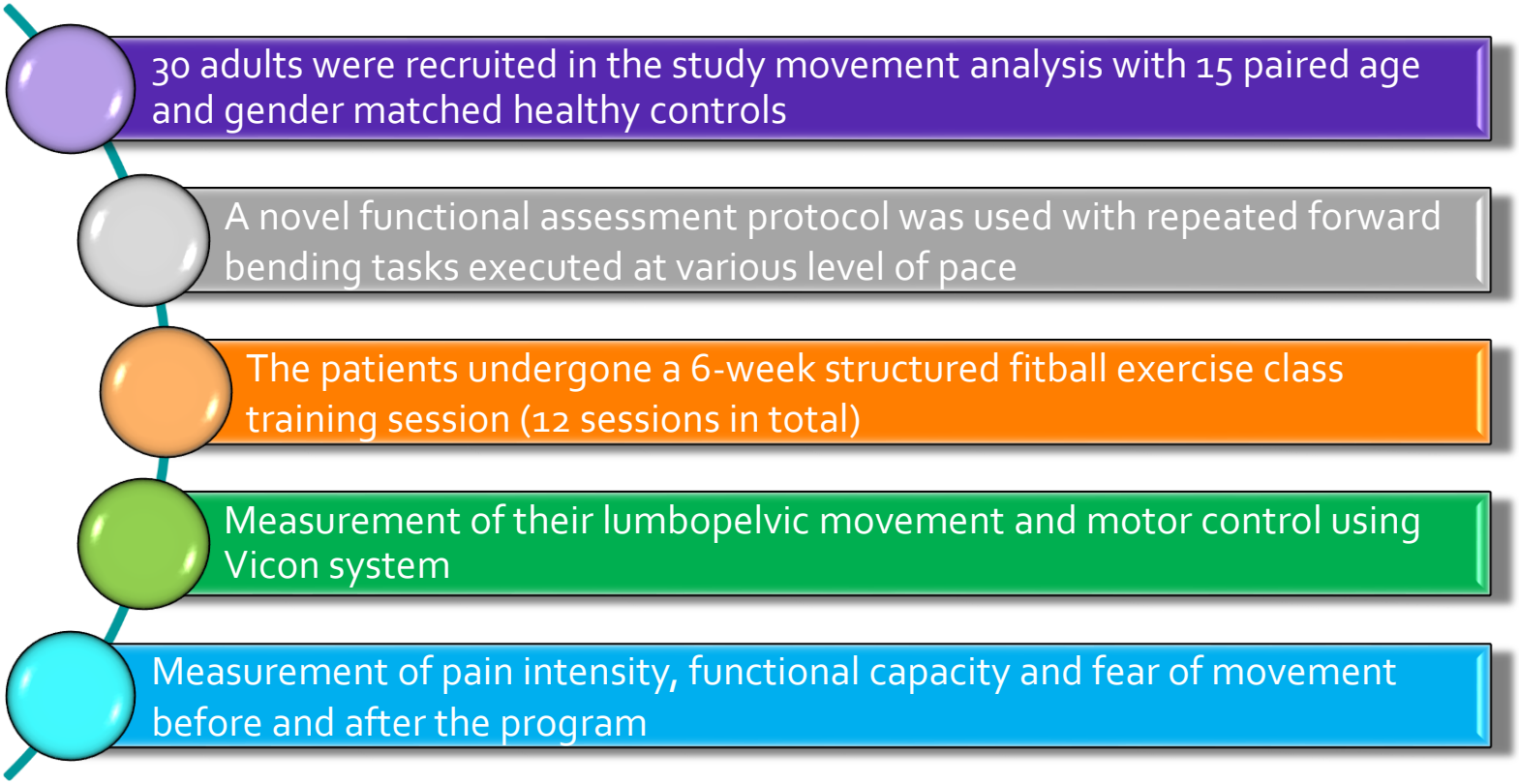
People with CLBP
- various forms of impaired movement pattern / motor control of the lumbopelvic and hip region

Extent of such impairments and their recovery
- associated with the clinical outcomes
  e.g. pain intensity, functional capability …

Kinematics of Spine During Lumbar Flexion

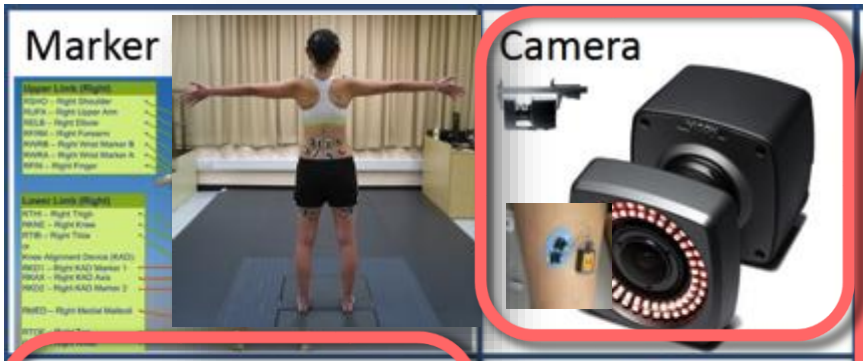
- For healthy individuals, the spine maintains a neutral posture and the lower spine rounds forward
- For low back pain patients, movement occurs from the hip joint

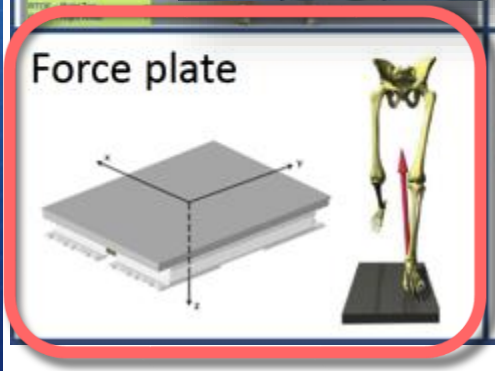
Evaluation of Low Back Pain Patients

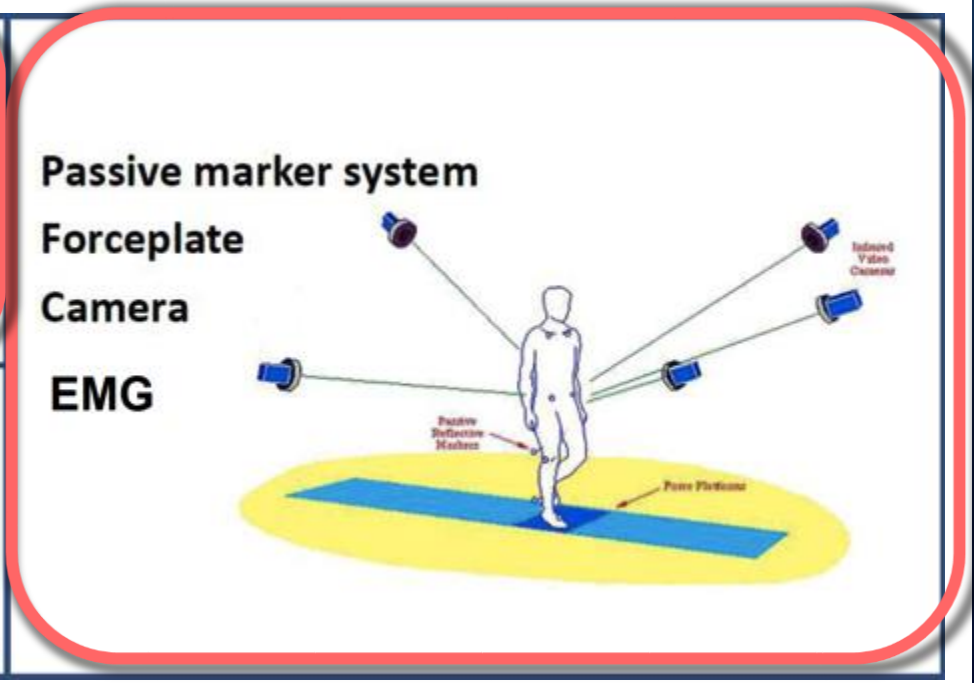


- A clinical study conducted at our centre in 2016-2017 in evaluating the recovery of lumbopelvic movement and motor control of individuals with nonspecific LBP

Measurement of Kinematics Using Vicon System

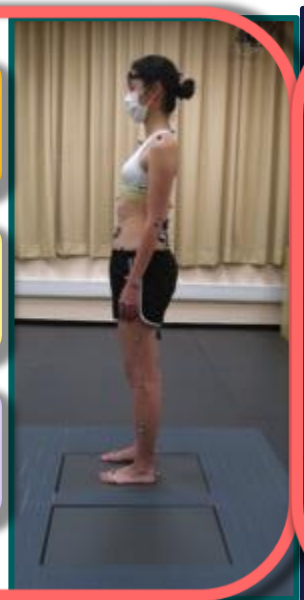


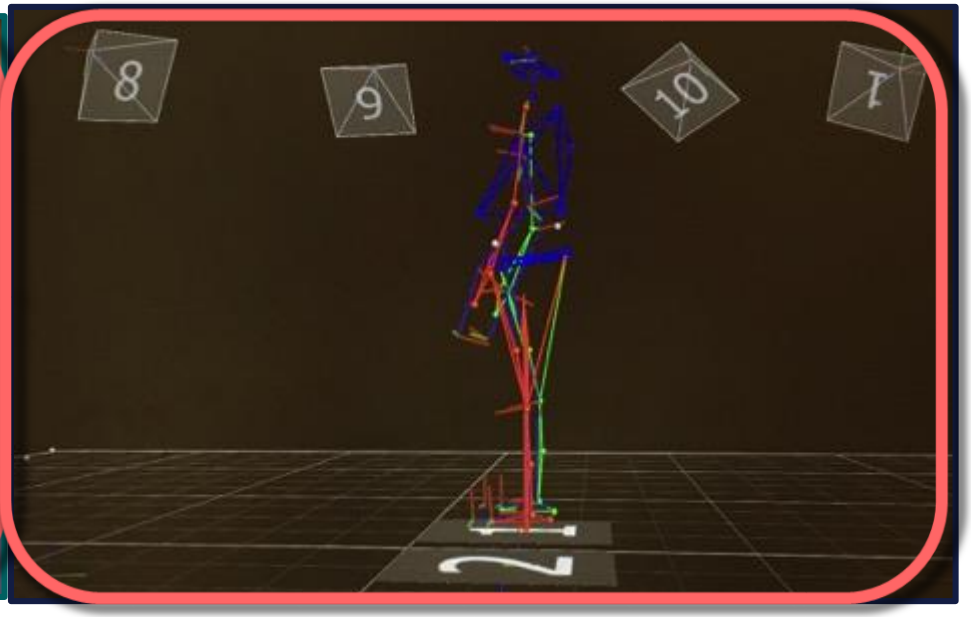




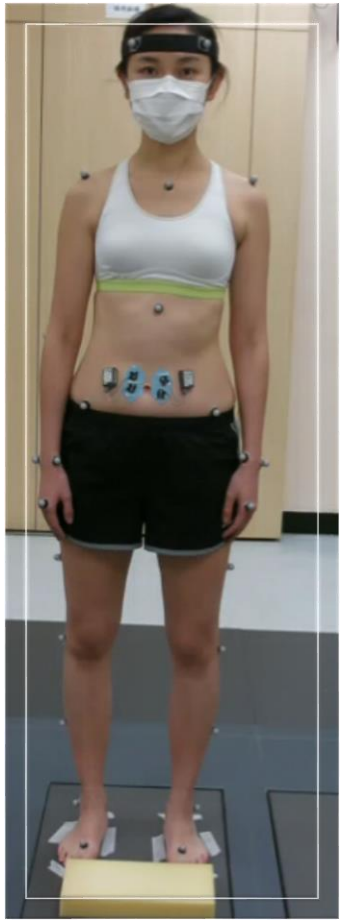
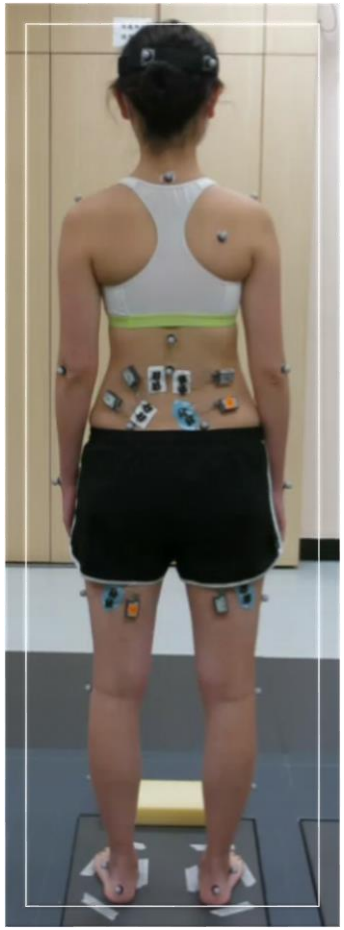
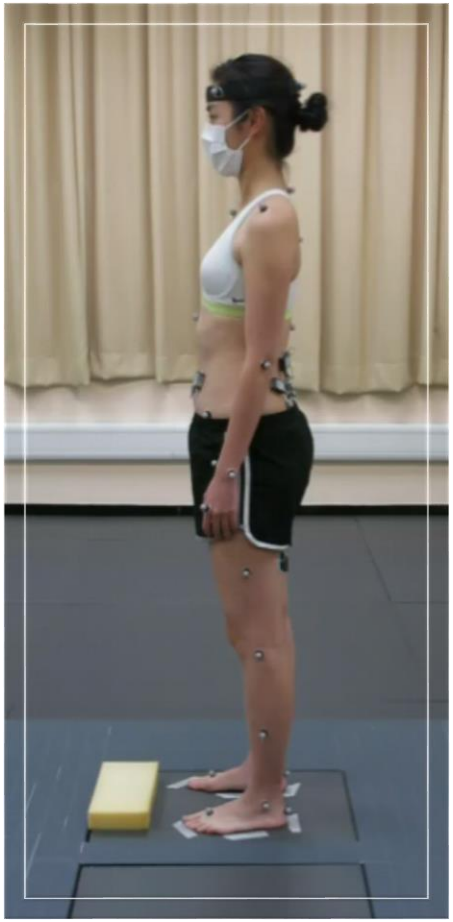
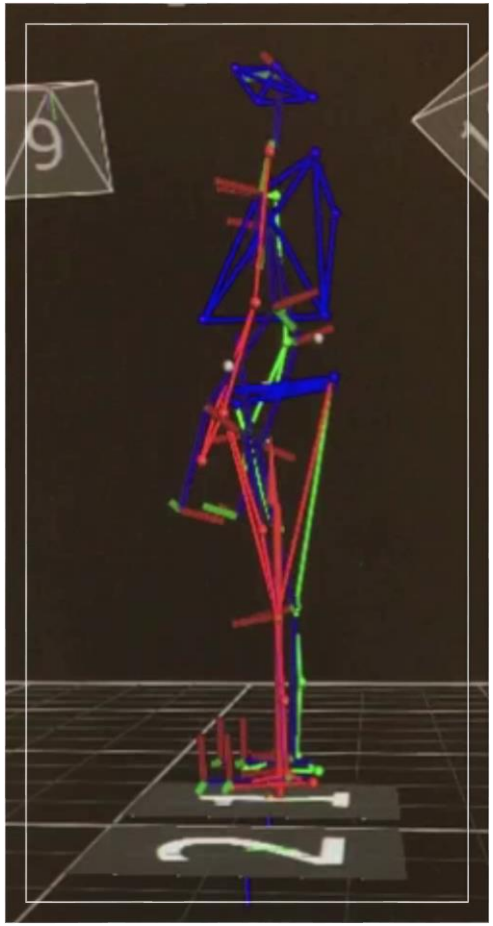
Measurement of Kinematics Using Vicon System

- Direct Linear Transformation from 10 Raw Cameras
- Identified Markers
- 3D Images
- Reconstruct Skeleton
- Kinematics & Kinetics

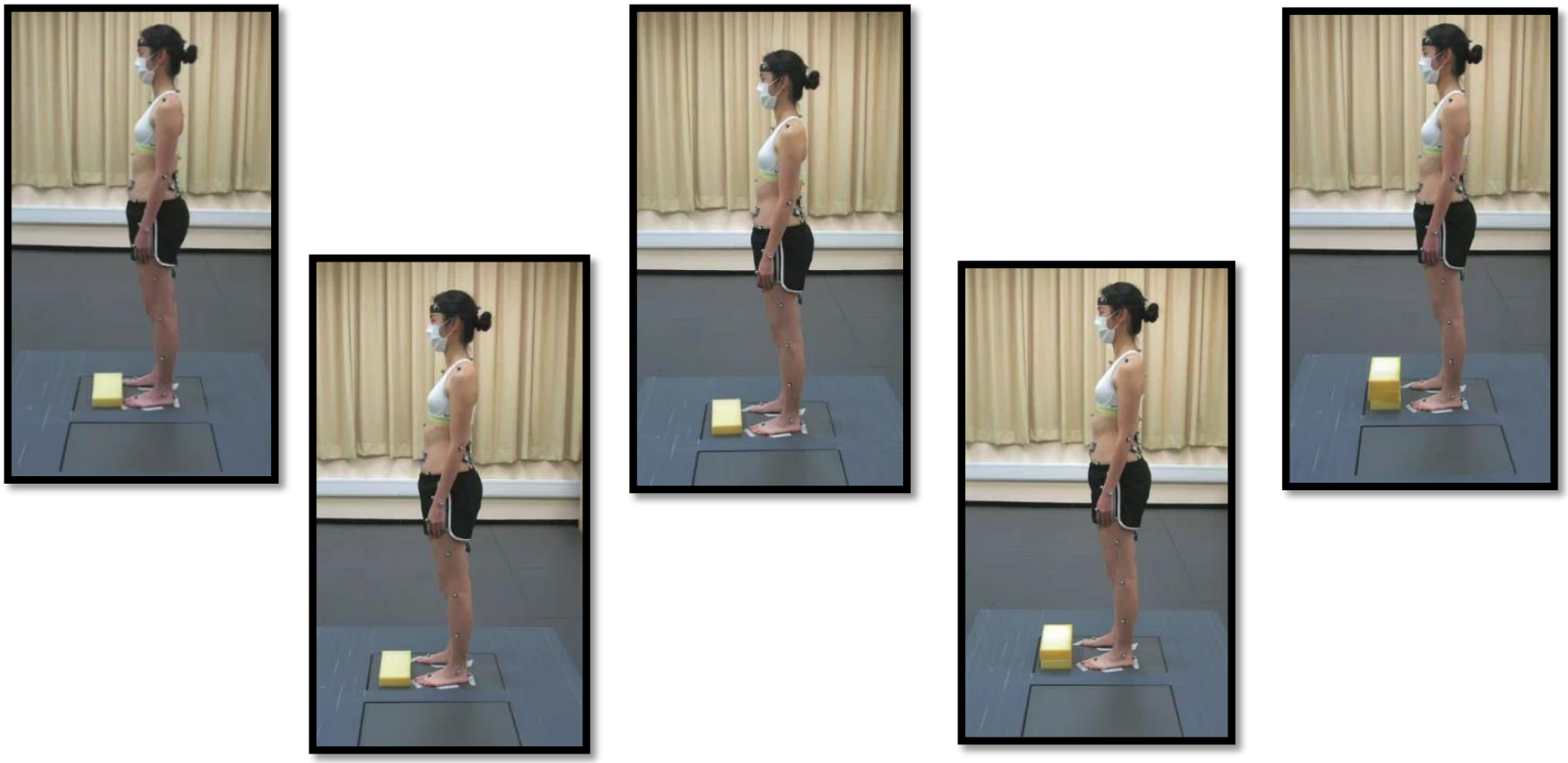




Novel Evaluation Protocol at a Self Preferred Speed

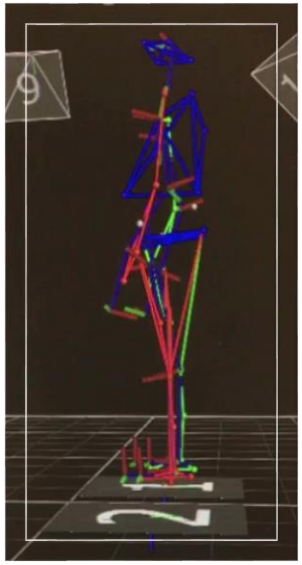





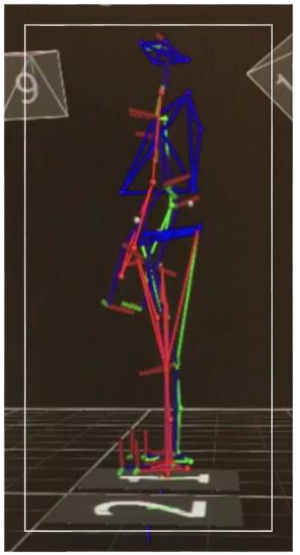
Novel Evaluation Protocol at Five Different Speeds



Novel evaluation protocol randomized from 20 to 60 bpm

Intervention and Evaluation with Vicon System





Baseline Evaluation → Exercise Training → Post Exercise Training Evaluation

Main Findings of the Clinical Study

* significant difference between healthy & LBP (pre: baseline difference)
§ significant difference between LBP (pre & post: intervention effect)

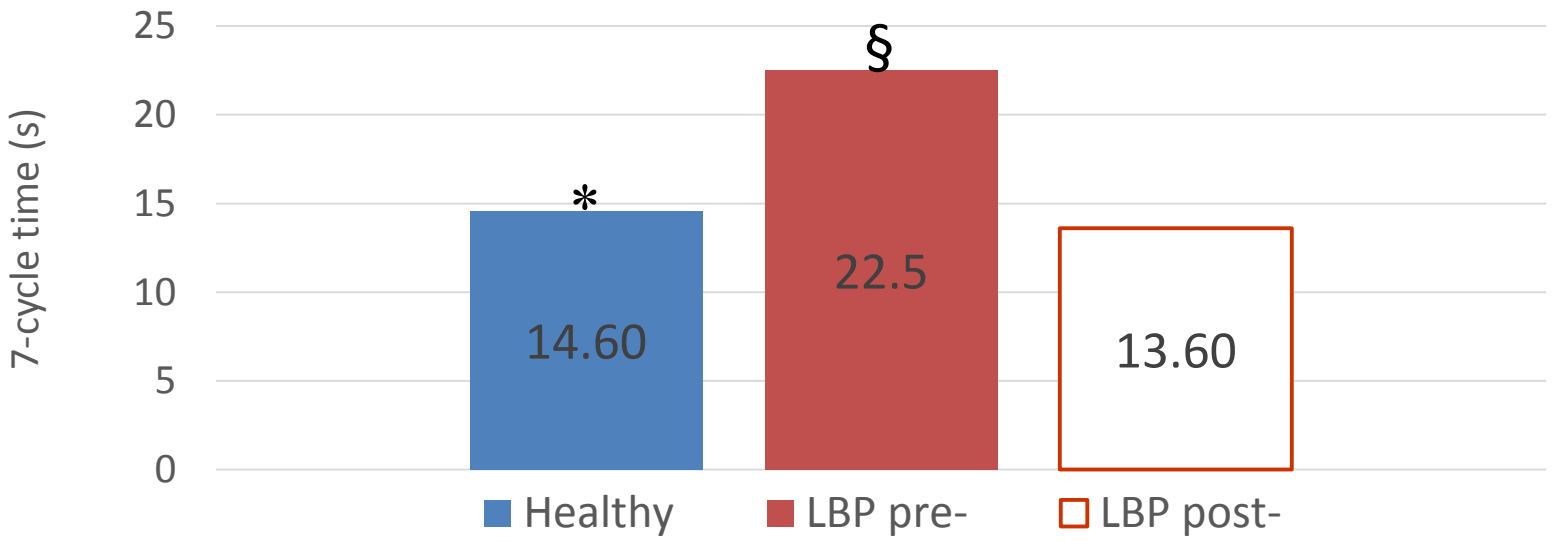


Fig 1. Time required for completing 7 repeated cycles of forward bending task

Main Findings of the Clinical Study

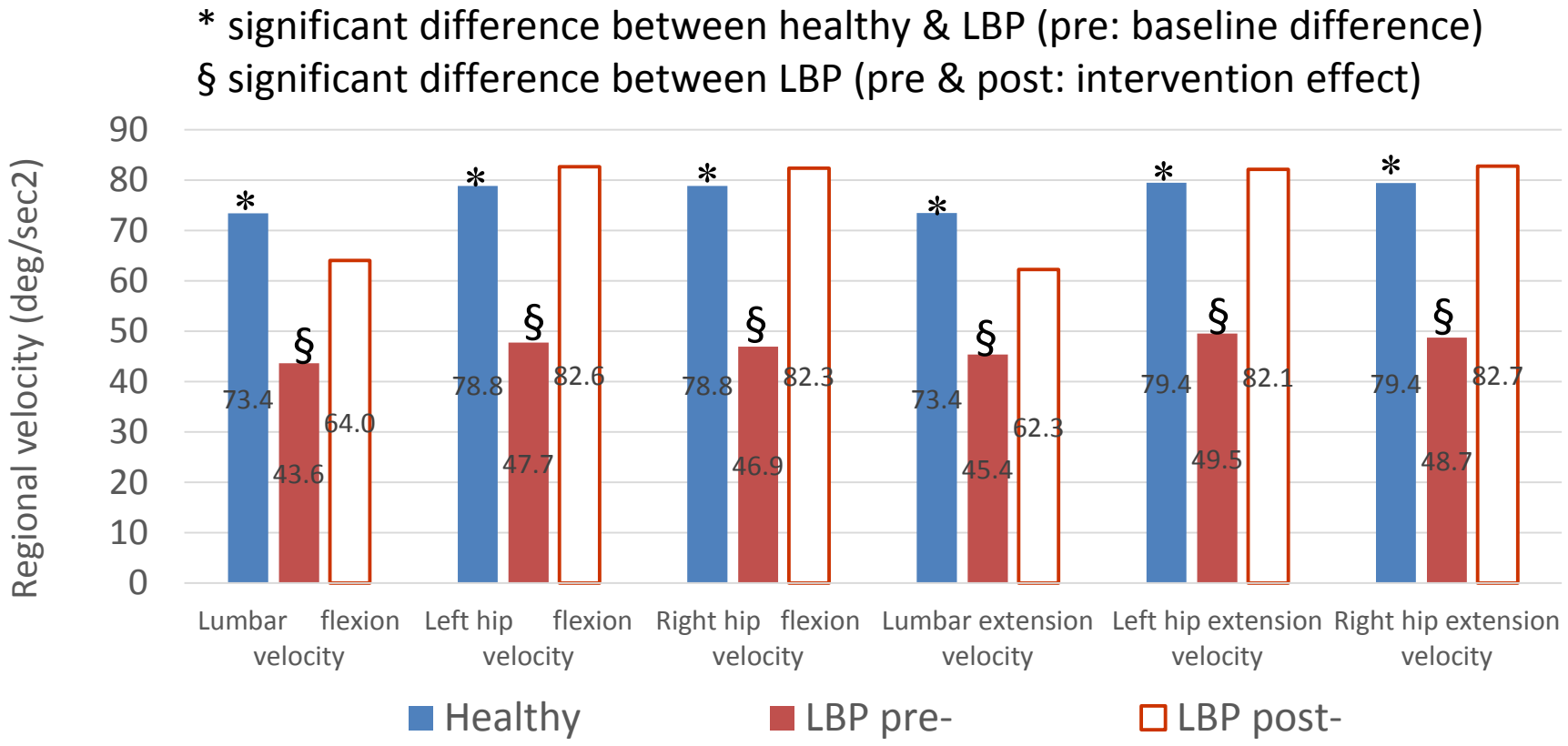


Fig 2. Mean velocity at lumbar spine and hip joints during forward bending

Limitations of the Vicon System in Clinical Application

- Routine application using Vicon system for objective movement analysis has limitations
  - practically difficult in demanding clinical settings (take 1-2 hours in measuring one single subject)
  - limitation of marker-based optical tracking system in daily monitoring & outdoor measurement

To Overcome This Challenge

- Our centre explored the applicability of a handy & portable, commercially available industrial-grade tri-axial inertial sensors (the LORD micro-strain 3DM-GX5-25)
- Each sensor contains tri-axial gyroscopes, accelerometers and magnetometers
- Dimension: 44mm (h) x 25mm (w) x 11mm (d) and weights 19g each
- Accuracy of $\pm 0.5^{\circ}$ (static testing) and $\pm 2.0^{\circ}$ (dynamic testing)

Application of Inertial Sensors in Various Field

Exploration of the inertial sensor in the medical field for clinical use (e.g. assessment and treatment evaluation)

Objectives of the Study

- Validate the Inertial system with the golden standard 3D motion analysis system (Vicon system)
  - kinematics (full body model of plug-in-gait)
- Examine the reliability of this Inertial system in clinical use for measuring
  - range of motion
  - angular velocities

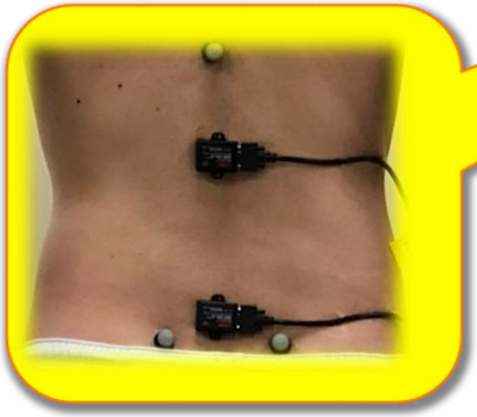
Methodology

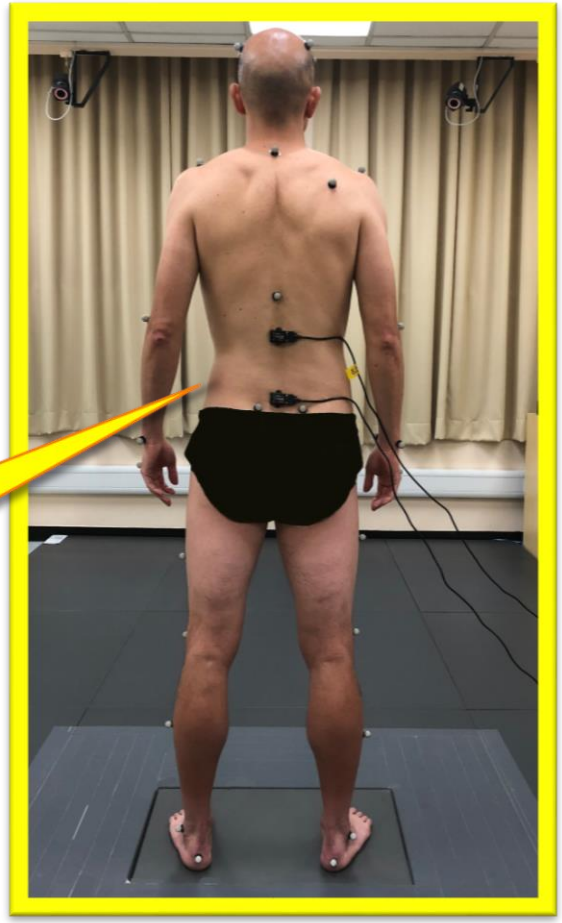
- The healthy subjects and LBP patients perform forward bending in self preferred speed, 20 and 40 bpm
- The kinematics and kinetics of the subjects were analyzed using both the Vicon system and Inertial system
- The sensors were connected to a purpose built data logger and software
- Baseline & post exercise training evaluation with the Inertial system

Acquisition of 3D Kinematics with Inertial Sensors

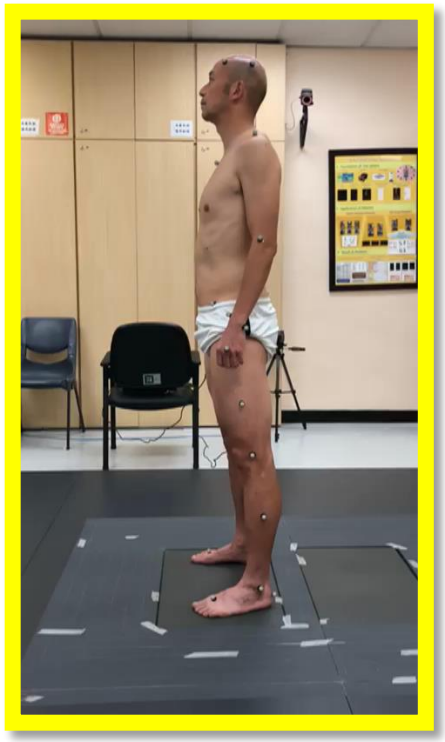
- Sensors placement of the inertial sensors for the lumbar spine:
  - One over spinous process of L1
  - Another over spinous process of S1

(Williams JM et al, 2013)



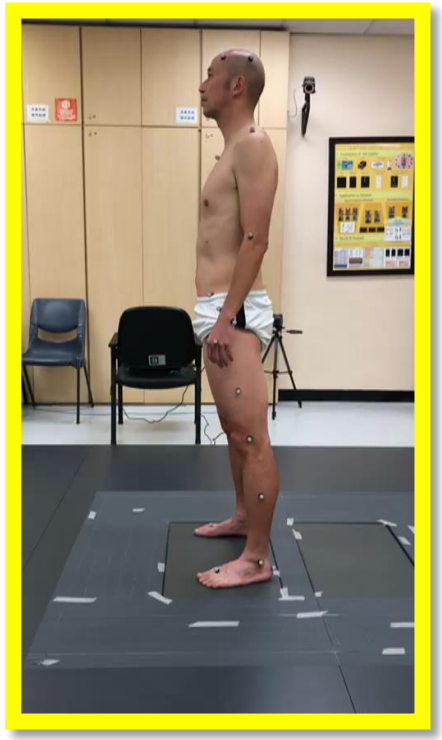


Motion Capture and Movement Analysis with Vicon and Inertial System



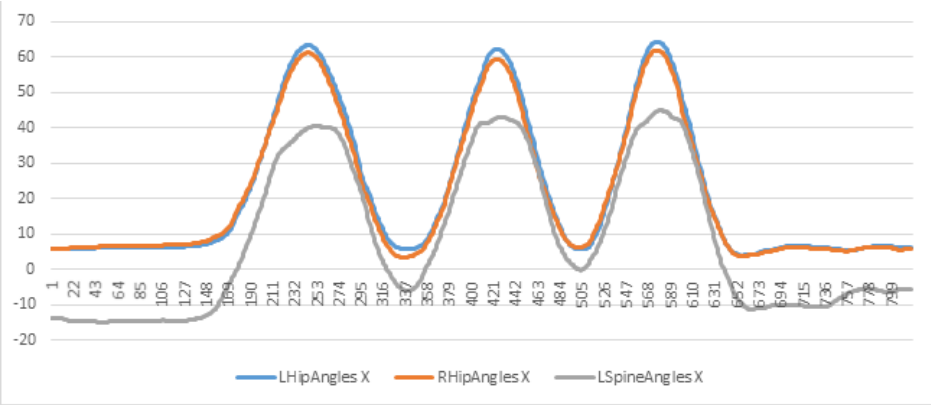
Preferred Speed

20bpm

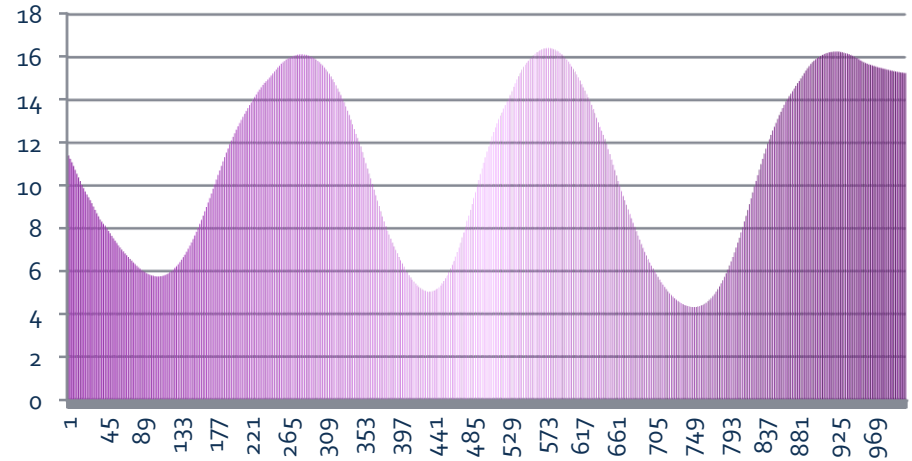


40bpm

Validation between Vicon and Inertial System



The tri-axial trajectory of the lumbar spine during repeated forward bending task **(captured by Vicon system)**



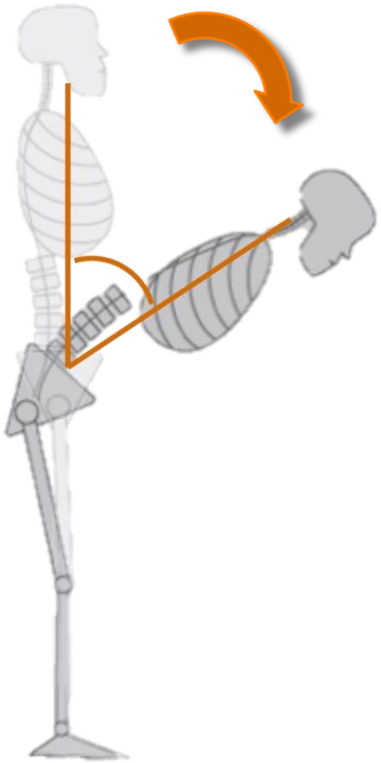
The trajectory of L1 during repeated forward bending task **(captured by Inertial system)**

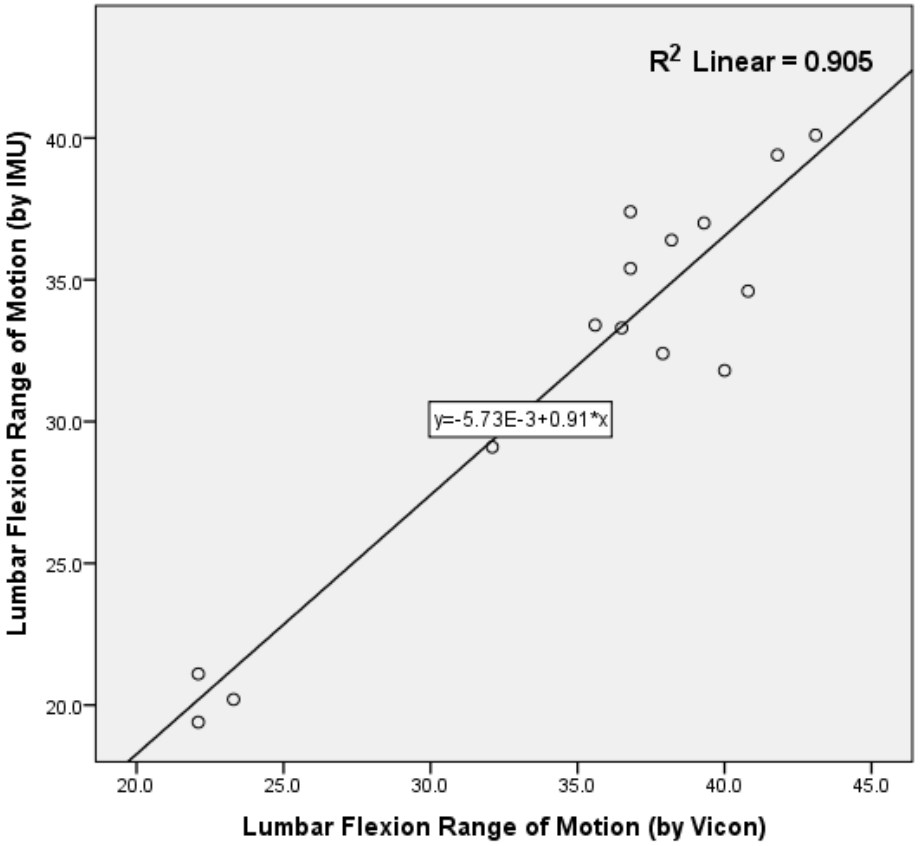
Summary Table of the Lumbar Flexion Range and Mean Velocity (During Flexion and Extension Phase)

Trial		ROM			Angular Velocities					
		Lumbar flexion range (deg)			Mean lumbar flexion velocity (deg/sec)			Mean lumbar extension velocity (deg/sec)		
		PS	20bpm	40bpm	PS	20bpm	40bpm	PS	20bpm	40bpm
1	Vicon	22.1	23.3	22.1	10.6	11	34.7	13.9	13.8	25.4
	IMU	19.4	20.2	21.1	13	12.2	35.8	14.4	14.1	28.9
4	Vicon	36.5	40.8	32.1	21.3	29.1	32.5	21.3	17.5	46.6
	IMU	33.3	34.6	29.1	23	25.4	42.2	25	20.6	43.4
5	Vicon	22.1	23.3	22.1	10.6	11	34.7	13.9	13.8	25.4
	IMU	19.4	20.2	21.1	13	12.2	35.8	14.4	14.1	28.9

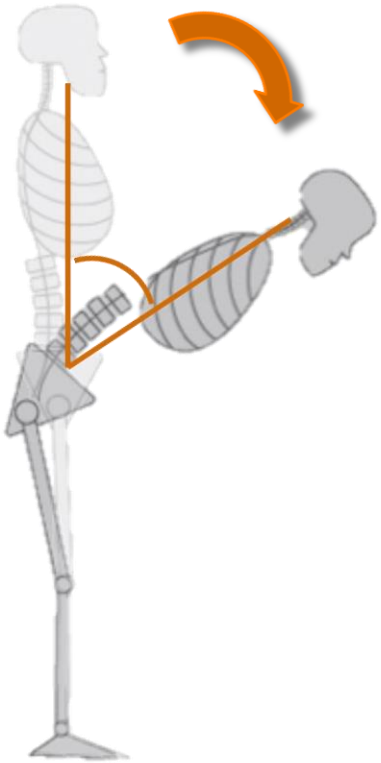
IMU: Inertial Measurement Unit

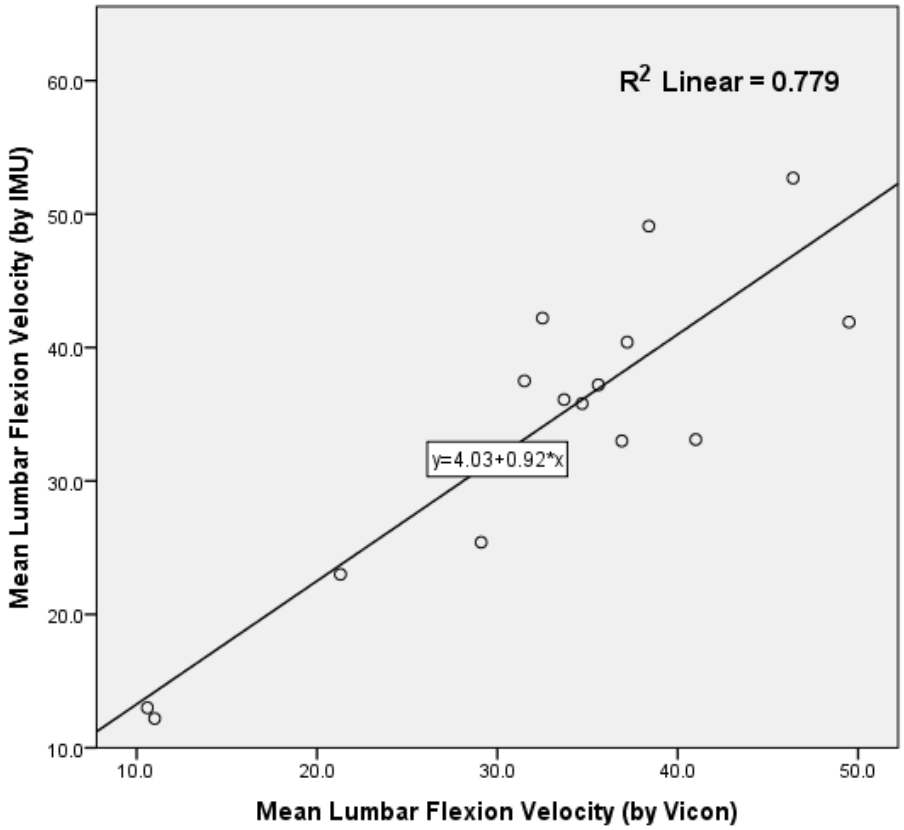
Validation of Lumbar Flexion Range of Motion Linear Regression: Coefficient of Determination



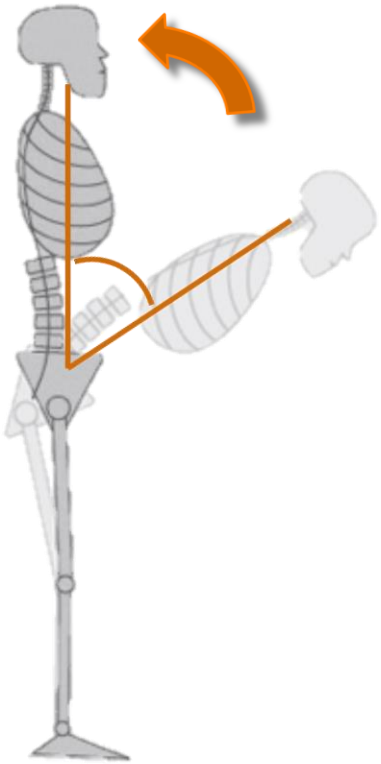


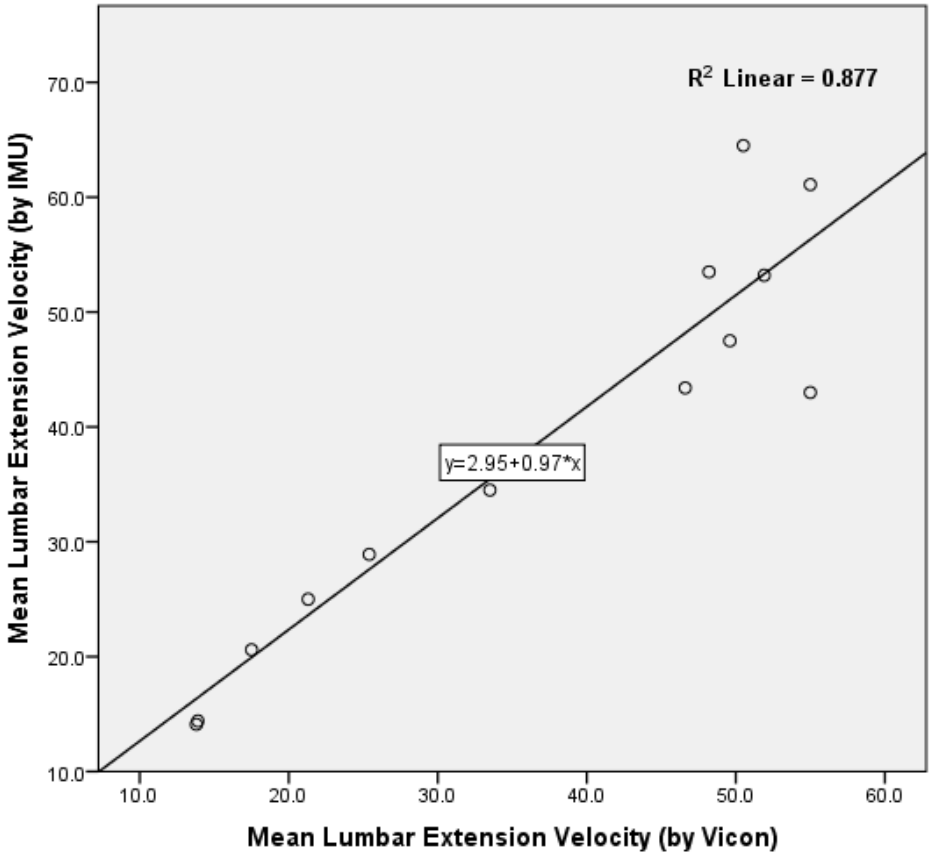
Validation of Mean Lumbar Flexion Velocity Linear Regression: Coefficient of Determination





Validation of Mean Lumbar Extension Velocity Linear Regression: Coefficient of Determination





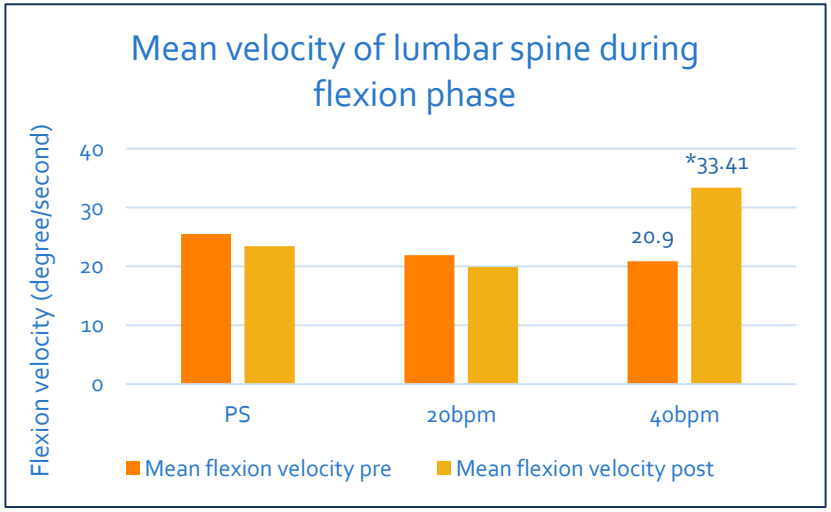
Intervention and Evaluation with Inertial System

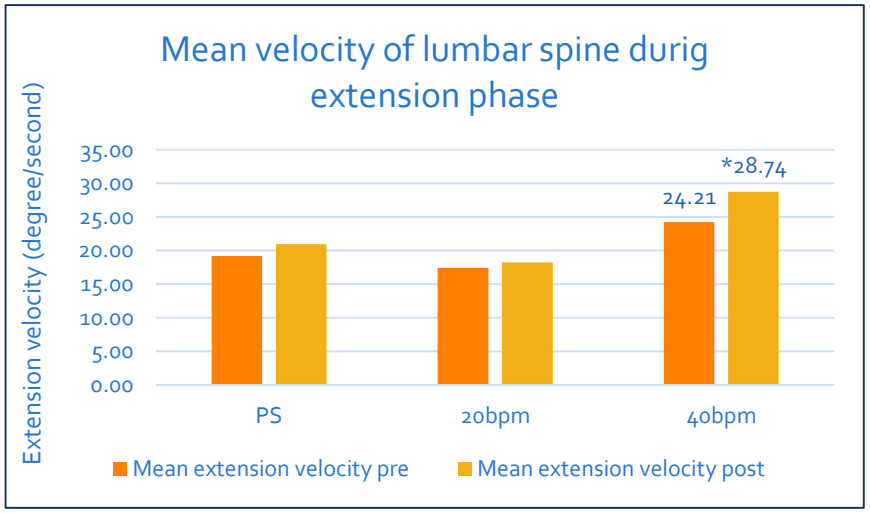
Baseline Evaluation

Exercise Training

Post Exercise Training Evaluation

Evaluation with Inertial System (Lumbar Spine Kinematics)





Both the mean velocity of lumbar spine (in the speed of 40bpm) during flexion and extension phase was significantly improved (* $p<0.05$)

Clinical Application and Significance

- Movement velocity
  - is a robust and sensitive parameter to identify and quantify movement and motor control impairment in patients with LBP

- The tri-axial inertial system is a highly practical tool
  - as handy and convenient to use
  - can use in both assessment and treatment evaluation
  - offers reliable and useful data for revealing the lumbo-pelvic movement impairments

Clinical Application and Significance

- Apart from LBP patients
  - Use of inertial system in the rehabilitation of various musculoskeletal conditions involving peripheral joints (e.g. shoulder or knee joints …)

- With the wearable sensor technology, movement analysis can be done outside the special room with Vicon cameras and force platform (e.g. gait analysis, agility evaluation …)

References

1. Adams MA, Bogduk N, Burton K, Dolan P. The biomechanics of back pain. Edinburgh, London, New York: Churchill Livingstone; 2002.
2. Bergmann JH, Mayagoitia RE, Smith IC. A portable system for collecting anatomical joint angles during stair ascent: a comparison with an optical tracking device. Dyn Med. 2009;8:3.
3. Cloete T, Scheffer C. Benchmarking of a full-body inertial motion capture system for clinical gait analysis. IEEE 2008.
4. Dagenais S, Caro J, Haldeman S. A systematic review of low back pain cost of illness studies in the United States and internationally. Spine J. 2008;8(1):8-20.
5. Esola MA, McClure PW, Fitzgerald GK, Siegler S. Analysis of lumbar spine and hip motion during forward bending in subjects with and without a history of low back pain. Spine . 1996;21(1):71-8.
6. McGill SM. Linking latest knowledge of injury mechanisms and spine function to the prevention of low back disorders. J Electromyogr Kinesiol. 2004;14(1):43-7.
7. O'Sullivan P. Diagnosis and classification of chronic low back pain disorders: maladaptive movement and motor control impairments as underlying mechanism. Man Ther. 2005;10(4):242-55.
8. Sahrmann S, Azevedo DC, Dillen LV. Diagnosis and treatment of movement system impairment syndromes. Braz J Phys Ther. 2017;21(6):391-9.
9. Shum GL, Crosbie J, Lee RY. Movement coordination of the lumbar spine and hip during a picking up activity in low back pain subjects. Eur Spine J. 2007;16(6):749-58.
10. Williams JM, Haq I, Lee RY. A novel approach to the clinical evaluation of differential kinematics of the lumbar spine. Man Ther. 2013;18(2):130-5.

Acknowledgement

- Dr. Sharon Tsang
- Dr. Eddy Siu
- Ms. Angelina Yeung
- Ms. Jamie Lau
- Mr. Johnson Pang
- Ms. Rachel Tsang
- Ms. Yana Wong
- Mr. Jay Dai
- Mr. Cheung Yat Man


THANK
YOU