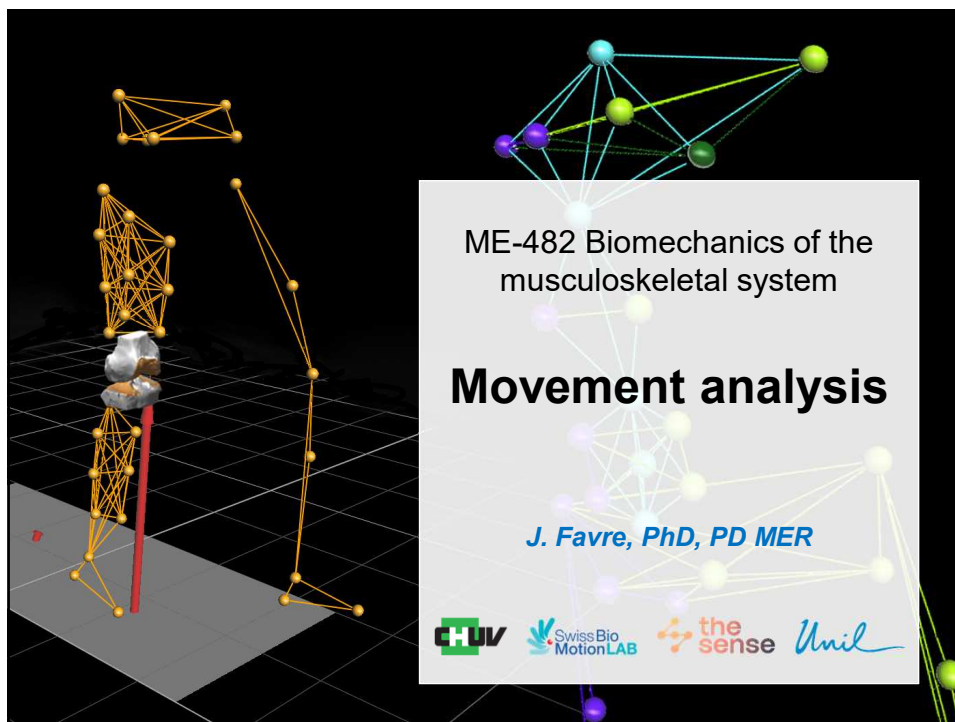




1

Objectives

- Review the tools to measure human movement
- Discuss some examples of use
- Outline possible future directions

Focus on walking



2

Subjective functional evaluation (KOOS)

Knee injury and Osteoarthritis Outcome Score (KOOS), English version LK1.0

1

KOOS KNEE SURVEY

Today's date: / / Date of birth: / /

Name:

INSTRUCTIONS: This survey asks for your view about your knee. This information will help us keep track of how you feel about your knee and how well you are able to perform your usual activities. Answer every question by ticking the appropriate box, only one box for each question. If you are unsure about how to answer a question, please give the best answer you can.

Function, daily living

The following questions concern your physical function. By this we mean your ability to move around and to look after yourself. For each of the following activities please indicate the degree of difficulty you have experienced in the **last week** due to your knee.

A1. Descending stairs

None☐

Mild☐

Moderate☐

Severe☐

Extreme☐

A2. Ascending stairs

None☐

Mild☐

Moderate☐

Severe☐

Extreme☐

⋮

A16. Heavy domestic duties (moving heavy boxes, scrubbing floors, etc)

None☐

Mild☐

Moderate☐

Severe☐

Extreme☐

A17. Light domestic duties (cooking, dusting, etc)

None☐

Mild☐

Moderate☐

Severe☐

Extreme☐



www.aaos.org 

3

Semi-objective gait evaluation (FGA)

Functional Gait Assessment

Name:

Age:

Gender:

Sex:

Date:

Signature:

Assessor:

Assessor Signature:

1. Gait Level Surface

Grading: Check the lowest category that applies.

Instructions: Walk at your normal speed from here to the next mark (20 ft./6m).

Score	Level of Function	Description
☐ 0	Severe impairment	• Cannot walk 20 ft./6m without assistance. • Has severe gait deviations or imbalance. • Reaches and touches the wall.
☐ 1	Moderate impairment	• Walks 20 ft./6m at slow speed. • Has an abnormal gait pattern. • There's evidence for imbalance.
☐ 2	Mild Impairment	• Walks 20 ft./6m with assistive devices at a slower speed. • Has mild gait deviations.
☐ 3	Normal	• Walks 20 ft./6m without aids at a good speed and with a normal gait pattern. • No evidence for imbalance.



www.carepatron.com 

4

Julien Favre, CHUV Swiss BioMotion Lab,
julien.favre@chuv.ch

2

Semi-objective gait evaluation (TUG)

Time Up and Go test

www.freepik.com

Ortega-Bastidas et al. 2023

5

Semi-objective gait evaluation (SGT)

Salford Gait Tool

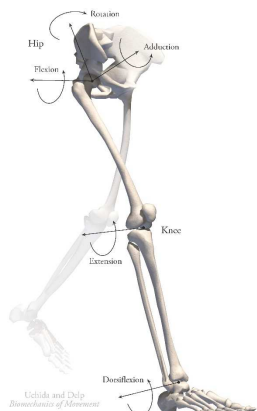
Enter the observed degrees of ranges of movement in the spaces below. Then assign a CATEGORY from the list on the left for each joint.

	Initial Contact												End Double Support												Mid Stance												Start Double Support												Toe off												Mid Swing												Sum of Category Scores																									
Name:																																																																																																		
Date:																																																																																																		
Diagnosis:																																																																																																		
TRUNK																																																																																																		
Circle observation:	normal												normal												normal												normal												normal												normal												Overall: normal																									
	backwards												backwards												backwards												backwards												backwards												backwards												backwards																									
	forwards												forwards												forwards												forwards												forwards												forwards												forwards																									
HP	degrees												category												degrees												category												degrees												category												degrees												category												(1)*	
CATEGORY:	-2° to -21° or more extension												-1° to -6° or more extension												0° to -5° ext to 15° flexion												1° to 16° or more flexion												2° to 46° or more flexion																																																	
KNEE	degrees												category												degrees												category												degrees												category												degrees												category												(5)*	
CATEGORY:	-2° to -16° or more extension												-1° to -6° or more extension												0° to -5° ext to 15° flexion												1° to 11° or more flexion												2° to 46° or more flexion																																																	
ANKLE	degrees												category												degrees												category												degrees												category												degrees												category												(0)*	
CATEGORY:	2° to 21° or more DF												1° to 11° or more DF												0° to -5° or more PF												-1° to -16° or more PF												-2° to -46° or more PF																																																	
toe strike	PF												PF												PF												PF												PF												PF																																					
heel strike	PF												PF												PF												PF												PF												PF																																					
heel off the floor?	Yes												Yes												Yes												Yes												Yes												Yes																																					
heel strike	No												No												No												No												No												No																																					

Toro et al. 2007

6

Objective gait evaluation



Spatio-temporal parameters

- Speed
- Foot events
- Stride length
- ...

Kinematics

- Joint angle
- Segment angular velocity
- ...

Kinetics

- Joint moment
- Trajectory of the center of mass
- ...

Electromyography

- Contraction magnitude
- Activation period
- ...

7

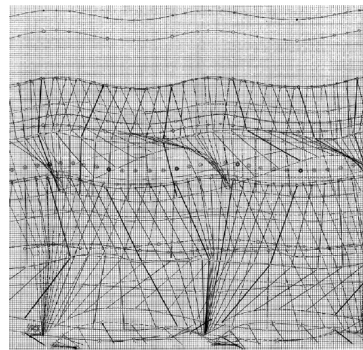
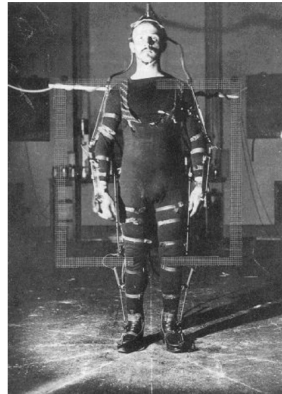
Image-based motion capture



Muybridge (1830-1904)

8

Image-based motion capture



Fisher (1861-1917)



Baker 2006 

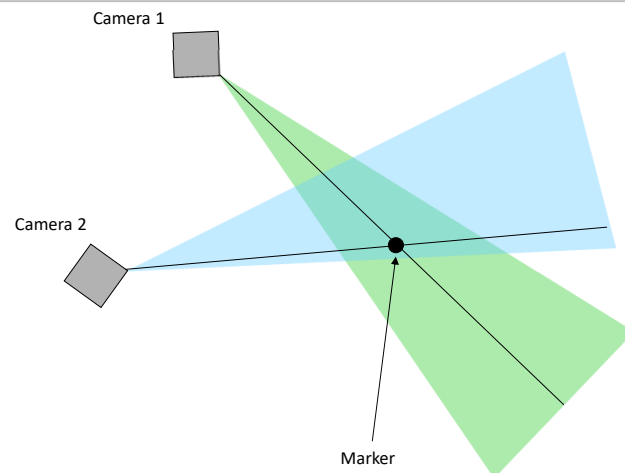
9

Passive marker-based motion capture



10

Passive marker-based motion capture



11

Passive marker-based motion capture



www.logemas.com

- Measure: marker positions
- Large number of markers possible
- Capture volume of up to 5 x 10 x 2 m
- Sampling frequency of 100 Hz and above
- Accuracy ~1 mm
- Drawbacks: calibration, line of sight, tracking & ambient light



12

Active marker-based motion capture



www.logemas.com



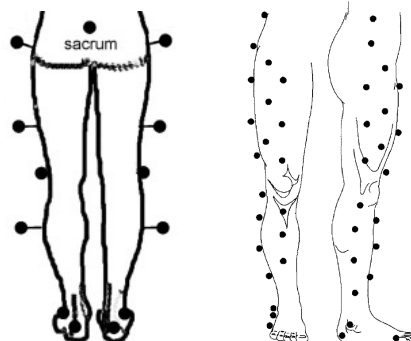
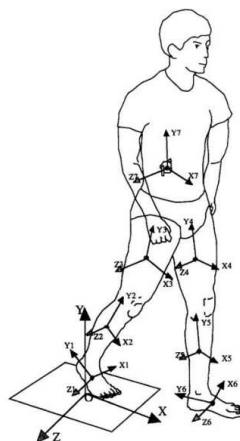
www.ndigital.com

- Automatic marker labelling
- Require some electronics



13

Marker sets and anatomical frames

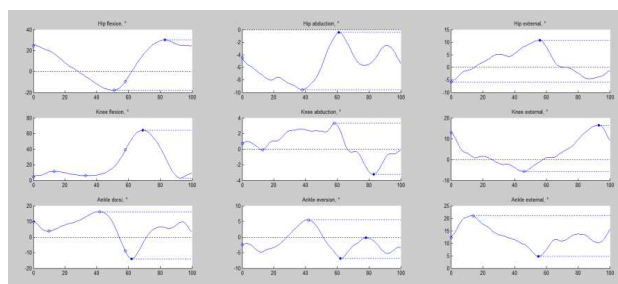
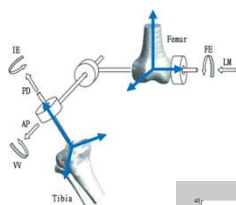


Nuesch et al. 2016, Chehab et al. 2017, Wu et Cavanagh 1995



14

Joint coordinate system



EPFL
F. VAUD

Hong-Jun et al. 2016, Grood et Sunday 1983



15

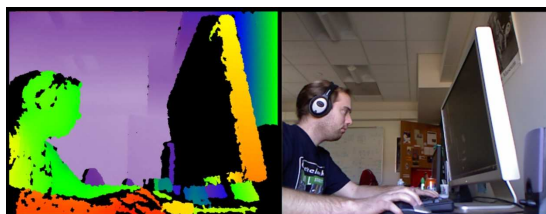
Markerless motion capture (depth camera)



www.Microsoft.com



www.graphics.Stanford.edu



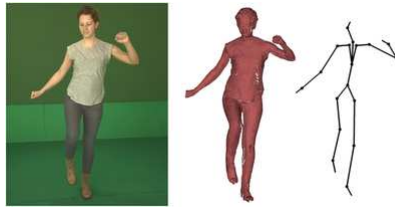
www.graphics.Stanford.edu

EPFL
F. VAUD



16

Markerless motion capture (depth camera)



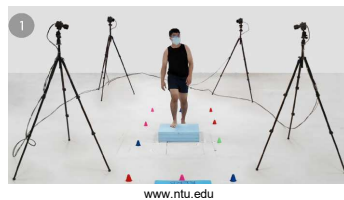
- Measure: joint position
- Limited capture volume
- Rather low sampling frequency (<100 Hz)
- Less accurate than marker-based
- Drawbacks: dependent on the built-in AI (cloud computing)



Fechteler et al. 2019 

17

Markerless motion capture (video camera)



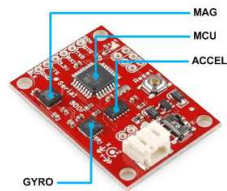
- Measure: joint position
- Multiple or single camera
- Large capture volume possible
- Sampling frequency of 100 Hz and above
- Less accurate than marker-based
- Drawbacks: dependent on the built-in AI (cloud computing)



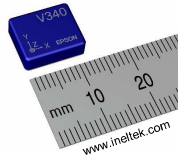
Serranoli et al. 2020 

18

Inertial measurement unit (IMU) -based motion capture



Zheng et al 2014



www.btsbioengineering.com

- Measure (3D): acceleration, angular velocity and magnetic field
- Can provide orientation



19

Inertial measurement unit (IMU) -based motion capture

- Measure (3D): acceleration, angular velocity and magnetic field
- Can provide orientation
- Unlimited number of units and unlimited capture volume
- Sampling frequency over 100 Hz
- Different approach than stationary devices
- Application-specific algorithms, variable accuracy
- Drawbacks: attachment, anatomical calibration

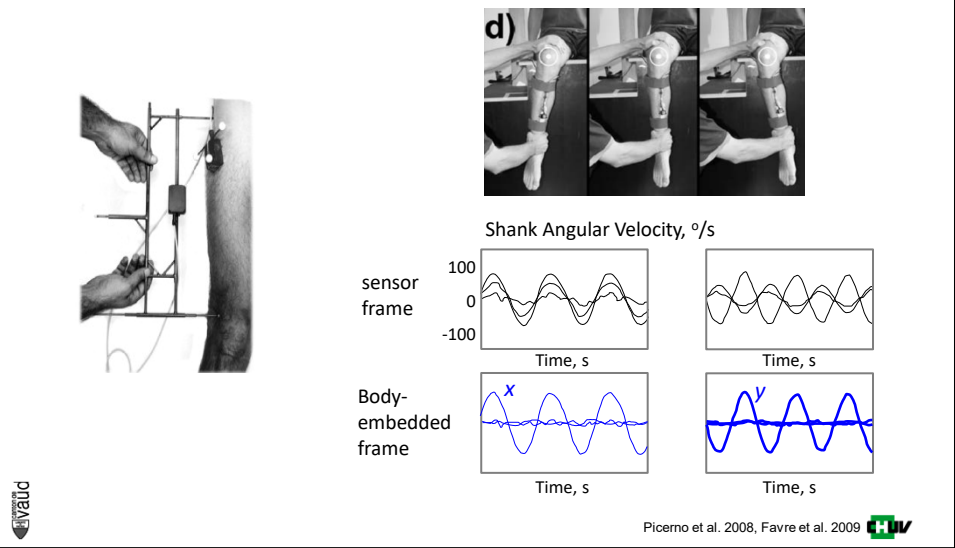


www.utwente.nl



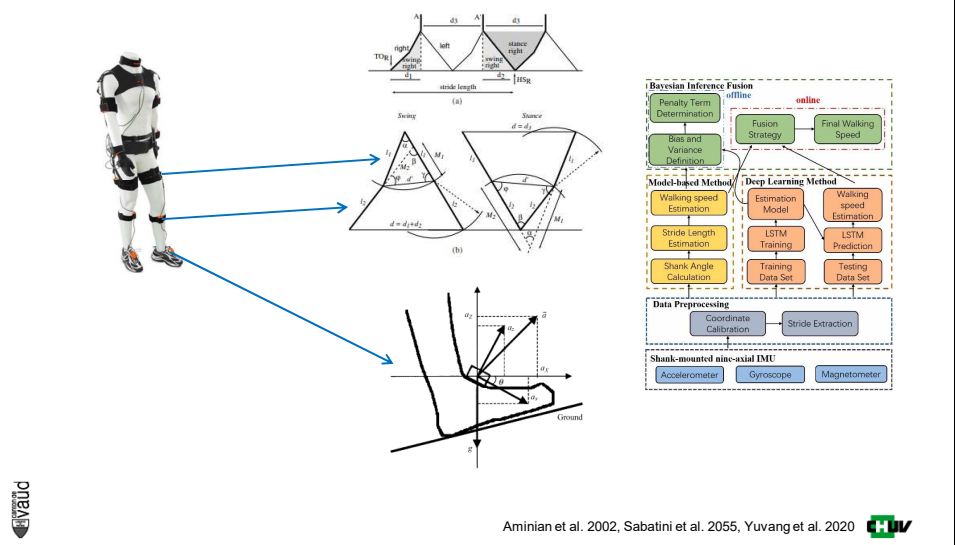
20

IMU anatomical calibration



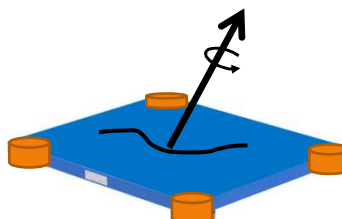
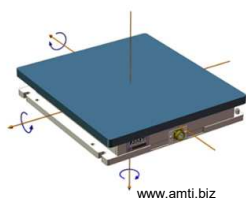
21

Estimating walking speed using IMU

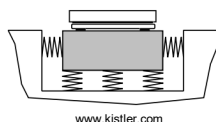


22

Force plate



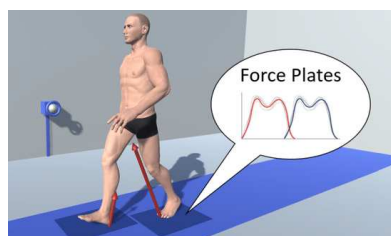
- Measure: 3D force, 3D moment, center of pressure
- High sampling frequency
- Mounting could be an issue



23

Force plate

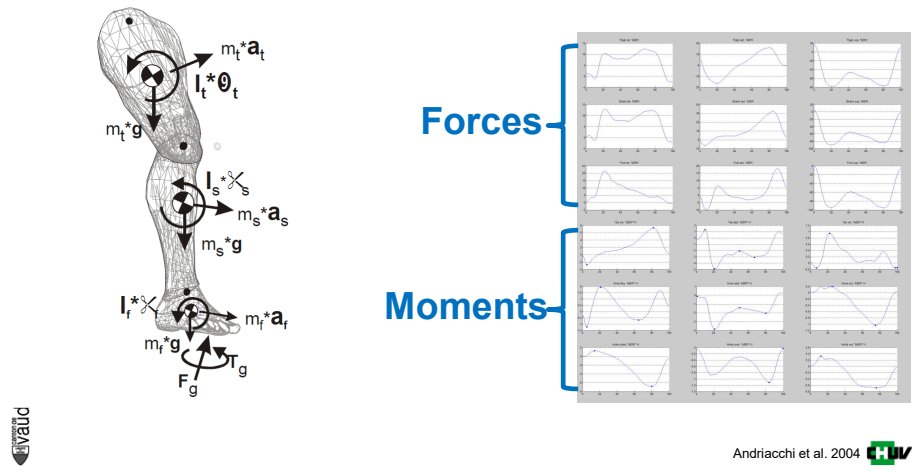
- Embedded in the ground or portable



Wagner 2017

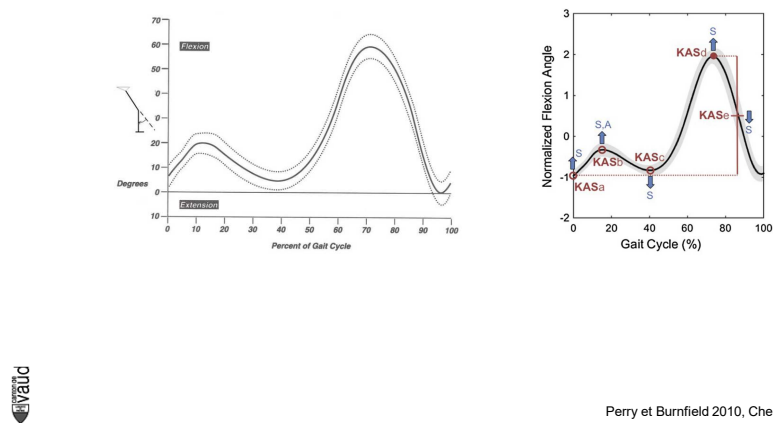
24

Inverse dynamics



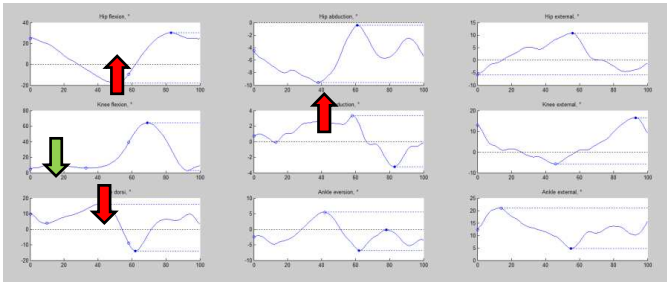
25

Description by discrete features



26

Description by discrete features



Angle, but also angular velocity, displacement, ...

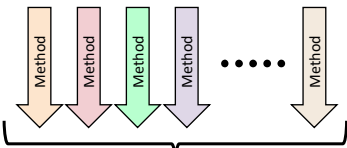
→ Movement scores



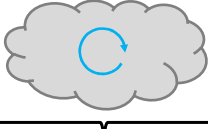
27

Current status

Gait assessment methods



Knowledge

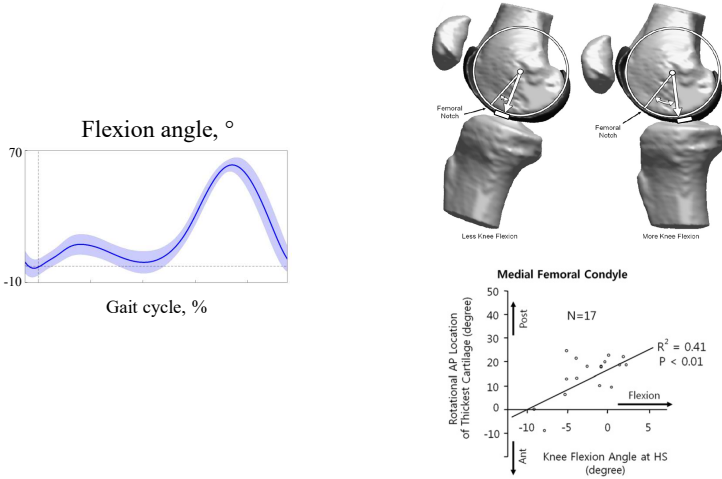


Used in clinic



28

'Ideal' walking mechanics ?



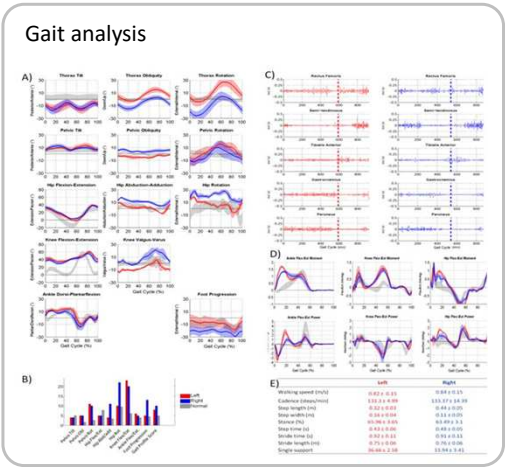
Koo et al. 2005

29

Support clinical decision making

Clinial evaluation

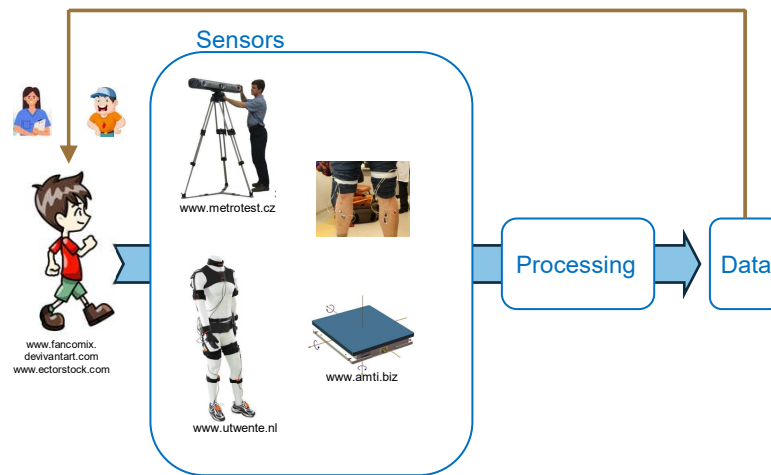
Questionnaires



Moissenet et Armand 2015

30

Gait retraining



31

Gait retraining - a running example

The American Journal of Sports Medicine
Volume 46, Issue 2, February 2018, Pages 388-395
© 2017 The Author(s). Article Reuse Guidelines
<https://doi.org/10.1177/0363546517736277>

SAGE
journals

Article - Epidemiology and Injury Prevention

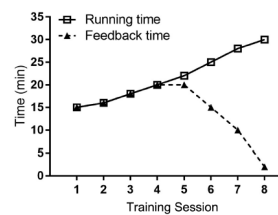
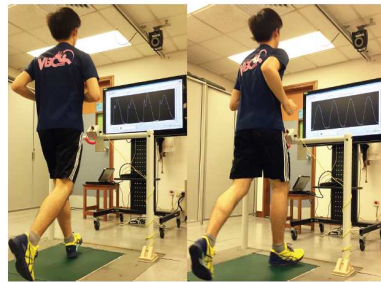
**Gait Retraining for the Reduction of Injury Occurrence in
Novice Distance Runners: 1-Year Follow-up of a Randomized
Controlled Trial**

Zoe Y.S. Chan, BEng^{†*}, Janet H. Zhang, MBBS[†], Ivan P.H. Au, BSc[†], Winko W. An, MEng[†],
Gary L.K. Shum, PT, PhD[§], Gabriel Y.F. Ng, PT, PhD[†], and Roy T.H. Cheung, PT, PhD[†]

32

Gait retraining - a running example

- 195 (166) runners with 8 biofeedback running sessions on a treadmill
- 195 (154) runners with 8 running on a treadmill sessions
- Participants with VARL less than 70 BW/s were excluded



- vGRF displayed
- Asked "to run softer", diminish the vertical impact



Chan et al. 2018

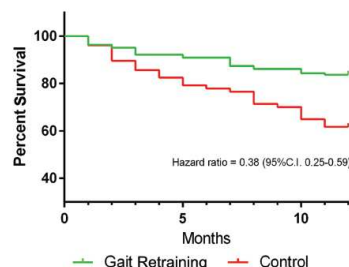
33

Gait retraining - a running example

- One year follow-up
- Injury incidence authenticated

Injury report:

- 16% in the experimental group
- 38% in the control group



62% lower injury occurrence in
gait-retrained runners
compared with controls



Chan et al. 2018

34

Gait retraining - a running example

No. (%) of Running-Related Injuries
in Gait Retraining and Control Groups

Condition	Gait Retraining Group		Control Group
Patellofemoral pain	4 (14)	<	18 (29)
Plantar fasciitis	2 (7)		23 (38)
Iliotibial band syndrome	3 (11)		8 (13)
Hamstrings strain	3 (11)		8 (13)
Achilles tendinitis	5 (18)	>	0 (0)
Calf strain	5 (18)		0 (0)
Shin splints	3 (11)		1 (2)
Patellar tendinitis	2 (7)		0 (0)
Meniscal injury	1 (3)		3 (5)



Chan et al. 2018

35

Swiss BioMotion Lab



36

Immersive instrumented treadmill

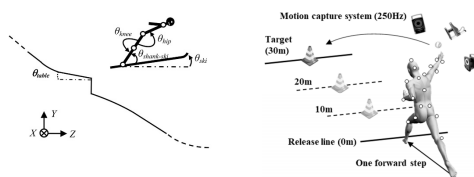
- Real-world tasks
- Environment
- Terrain
- Feedback
- Multisensory integration



37

Summary

- Tools exist to measure human movement
- We understood the basics
- Need larger (interventional) datasets
- AI-based analysis and personalization
- Mixed naturalistic settings
- Not limited to walking or the lower limbs



Chardonnes et al. 2012, Nishino et al. 2020

38