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Modern Functional Evaluation Methods for Muscle Strength and Gait Analysis

Springer

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ISSN 2191-530X ISSN 2191-5318 (electronic)
SpringerBriefs in Applied Sciences and Technology
ISBN 978-3-319-67436-0 ISBN 978-3-319-67437-7 (eBook)
https://doi.org/10.1007/978-3-319-67437-7

Library of Congress Control Number: 2017952519

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Auctoris Praefatio ad Lectorem

Measure what can be measured, and make measurable what cannot be measured.

Galileo Galilei

The study of movement has always fascinated artists, photographers, and researchers and, across the years, several notable attempts to capture, freeze, study, and reproduce motion have been made.

Nowadays, motion capture plays an important role within many fields, from graphical animation, filmmaking, and virtual reality to medicine. By movement analysis it is possible to measure kinematic and kinetic performance of the human body. Such quantitative data may support the diagnosis and treatment of motor pathologies, supporting clinical decisions and follow-up of treatments or rehabilitation. This approach is nowadays called *evidence-based medicine*.

Andrea Ancillao received the Master's degree in Clinical and Biomedical Engineering from "Sapienza" University of Rome, Italy, in 2010, and the Ph.D.—Doctor Europaeus degree, cum laude, in Industrial Production Engineering from the same university in 2017. He has years of experience in the field of functional evaluation, motion analysis, biomechanics and he is author of several international publications.

This work contains the description and the results of two research projects carried out by the author while he was a PhD candidate at the Faculty of Engineering of Sapienza University of Rome. Modern motion capture and signal-processing techniques are exploited to: (i) develop a protocol for the validation and quality assurance of clinical strength measurements, (ii) develop an algorithm for the interpretation of clinical gait analysis and quantification of the deviation from normality, and (iii) design user-friendly software tools to help clinicians use the novel data-processing algorithms and quickly report the results of measurements.

This book is meant for clinicians and biomedical engineers who deal with clinical motion analysis, gait analysis, and clinical strength measurements. The book is arranged in such a way to provide a thorough description of the methods implemented in the research projects, the issues encountered in the design of experiments, and the solution proposed. A thorough discussion of the results is also presented in a contextual view.

The work is divided into three chapters.

Chapter 1 contains a survey of the history of motion analysis including the earliest experiments in biomechanics. The review covers the first historical attempts that were mainly based on photography to the state-of-the-art technology in use today, that is, the optoelectronic system.

The working principle of the optoelectronic system is reviewed as well as its applications to modern setups in clinical practice.

Modern functional evaluation protocols, aimed at the quantitative evaluation of physical performance and clinical diagnosis of motor disorders, are also reviewed in this chapter. Special attention is paid to the most common motion analysis exam that is nowadays standardized worldwide: gait analysis. Examples of gait analysis studies on subjects with pathology and follow-up were reviewed, and the clinical interpretation of gait analysis and methods to quantify deviation from normality are discussed in Chap. 3.

Chapter 2 describes the design criteria of an experimental setup that applies motion analysis to the quality assurance of clinical strength measurements.

The chapter begins with a review of strength measurement methods that are popular in clinical practice for the evaluation of muscle weakness, health status of ligaments, and the effects of therapies. A variety of protocols is reviewed, implying the acquisition of forces, angles, and angular velocities when the maximum voluntary force is exerted.

Handheld dynamometry (HHD) is extensively used in clinical practice; however, several shortcomings are identified, the most relevant being related to the operator's abilities. Thus, a modern protocol has been designed in order to measure the inherent inaccuracy sources that occur when the HHD is used to measure knee and ankle strength.

The analysis has been conducted by gathering the output of a compact six-component load cell, comparable in dimension and mass to clinical HHDs, and an optoelectronic system, and the quality of measurements is investigated.

The main finding is that the use of a single-component HHD induces an overall inaccuracy of 5% in strength measurements when operated by a trained clinician; angular misplacements are kept within the values found in this work ($\leq 15°$) and with a knee ROM $\leq$ 22°. The most relevant source of inaccuracy was identified in the angular displacement of HHD on the horizontal plane.

Chapter 3 describes the development of a modern synthetic index applied to the gait analysis of subjects with pathology.

The chapter begins with a review of gait analysis data-processing techniques and synthetic descriptors aimed at simplifying gait analysis interpretation and quantifying improvements/variations in gait after a treatment.

In this work, synthetic descriptors are implemented and applied to: (i) quantify gait variations in subjects with cerebral palsy who underwent orthopaedic surgery;

(ii) test the effectiveness of a recently proposed index, the linear fit method, on such patients; and (iii) design and implement a novel index that overcomes the limitations observed in the previous methods.

The new index takes into account the effects due to offset and allows computing the deviation from normality on tracks purified by the offset. As for the subjects studied in this work, offset plays an important role in gait deviation; the new proposed method is recommended to study gait pattern of subjects with cerebral palsy.

The design of dedicated software, with graphical user interface, is described. Such software is aimed: (i) to compute the synthetic descriptors on a large amount of data, (ii) to speed up data processing, and (iii) to provide clinicians with quick access to the results and reporting.

Rome, Italy Andrea Ancillao

Acknowledgements

This work is based on the result of the research projects that I carried out for my PhD defence that took place at Sapienza, University of Rome on February the 24th, 2017. It cannot begin without my most sincere thanks to the people who made it possible and helped me along the way.

First and foremost, I sincerely acknowledge Prof. Paolo Cappa, who gave me the opportunity to start this adventure and go through with it. The success of this work is mainly due to his help. I would sincerely acknowledge Prof. Jaap Harlaar for giving me the opportunity to spend some pleasant months at the VUmc, University of Amsterdam and for helping me out on the gait analysis project. A heartfelt thanks goes also to Prof. Giorgio Albertini and Prof. Manuela Galli that, in the years gone by, taught me the basis of functional evaluation and motion analysis. Finally, the biggest thank you goes to all the colleagues from Sapienza and from VUmc who gave me helpful support along this journey.

Contents

Abbreviations

CP	Cerebral Palsy
CS	Coordinate System
CV	Coefficient of Variation
D/A	Digital-to-Analog converter
DDST	Denver Developmental Screening Test
EDS-HT	Ehlers–Danlos Syndrome, Hypermobility Type
EMG	Electromyography
GA	Gait Analysis
GDI	Gait Deviation Index
GGI	Gillette Gait Index
GMFCS	Gross Motor Function Classification System
GPS	Gait Profile Score
GUI	Graphical User Interface
GVS	Gait Variable Score
HFI	Hip Flexor Index
HHD	Handheld Dynamometer
ICC	Intraclass Correlation Coefficient
IR	Infrared Radiation
LFM	Linear Fit Method
LRS	Local Reference System
MAP	Movement Analysis Profile
MCID	Minimally Clinical Important Difference for GPS
MoCap	Motion Capture
OC-GPS	Offset Corrected—Gait Profile Score
OC-GVS	Offset Corrected—Gait Variable Score
OC-MAP	Offset Corrected—Movement Analysis Profile
OS	Optoelectronic System
PD	Parkinson's Disease
PIG	Plug-in-Gait Marker Protocol
R	Pearson's Coefficient of Correlation

RMS	Root Mean Square
RMSE	Root Mean Square Error
RoM	Range of Motion
RS	Reference System
SD	Standard Deviation
SEMLS	Single-Event Multilevel Surgery
TD	Typically Developing Children