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PUBLICATION N°6

45^e SESSION

CTS SCIENCES ET TECHNIQUES DES ACTIVITÉS PHYSIQUES
ET SPORTIVES – JEUNESSE ET LOISIRS (STAPS-JL)

SPÉCIALITÉ : PHYSIOLOGIE DE L'EFFORT

AGBODJOGBÉ KPÈDÉTIN WILFRID DIEU-DONNÉ

MAÎTRE-ASSISTANT

GSM : +229 97 33 73 00

E-mail : agbowil2002@yahoo.fr

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Journal Information

Title: International Journal of Sports and Exercise Medicine

ISSN: 2469-5718

Editor-in-chief: J.David Prologo, Dale Ding

NLM title abbreviation: Int J Sports Exerc Med

ICV: 91.84

ISO abbreviation: Int J Sports Exerc Med

Other titles: IJSEM

Category: Sports Medicine

DOI: 10.23937/2469-5718

Peer review: Double blind

Review speed: 3 weeks

Fast-track review: 10 days

Publication format (s): Electronic and print

Publication policy: Open Access; COPE guide

Publication type(s): Periodicals

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Raffaele Manni
National Institute of Neurology, IRCCS "C. Mondino Foundation", Via Mondino 2, 27100 Pavia, Italy

EDITOR-IN-CHIEF



J. David Prologo
Assistant Professor
Division of Interventional
Radiology and Image Guided
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Japan General Hospital

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Michael Y. Sha

Vice President of R&D

Senior Staff Scientist

DiaCarta, Inc

USA

Dr. Sha is a highly recognized R&D leader with more than 20 years experience in molecular diagnostics. Dr. Sha, as CTO, lead developing liquid biopsy NGS for cancer diagnostics in Dia Carta Inc. Dr. Sha worked as the R&D director to lead and develop functional screening uncultivable bacteria through microfluidic chip PCR at GALT Inc. His focus, work ethic, and drive has led multiple teams to receive numerous awards, over \$3million for CTC/ct DNA NGS and POC projects for the Intensity Innovation program during working at Thermo Fisher Inc. As a senior staff scientist, he leads developing Chip PCR for [view full biography](#)



Natalia Oiring de Castro Cezar

Professor

Department of Gerontology

Federal University of Sao Carlos

Brazil

Professor at the Department of Gerontology at the Federal University of São Carlos and PhD in Physical Therapy and Functional Performance. Research Interests are Aging, frailty syndrome, cognitive disorders, motor changes and body composition (muscle, fat and bone) in older people.



Marco Martins Lages

Head coordinator

Hospital Municipal Miguel Couto

HZM - Inga University

Brazil

I am an Orthopedic surgeon in 2011 and Sports Medicine in 2012. I also concluded a Master Degree in Medicine in 2020. Currently, I work at Hospital Municipal Miguel Couto, where I am the head coordinator of the medical residence in Orthopedics. I also work at the National Confederation of Volleyball as part of the staff doctors in the man's team, and teach orthopedics in the pos-graduation course of sports medicine at HZM - Inga University in Brazil. Usually, my interests in research regards Trauma Surgery [view full biography](#)



Guntug Batihan

Consultant Thoracic Surgeon

Department of Thoracic Surgery

University of Health Sciences

Turkey

Dr. Guntug Batihan is a Consultant Thoracic Surgeon at the University of Health Sciences Turkey Dr. SuatSeren Chest Diseases and Chest Surgery Education and Research Hospital. He received his medical degree from Dokuz Eylul University (Turkey) in 2015 and completed his Thoracic Surgery Residency training at the Dr. SuatSeren Chest Diseases and Chest Surgery Education and Research Hospital. He serves on several editorial boards, is a reviewer of many scientific journals, and is an author of more than 30 medical journal articles. His research interests include video-assisted thoracic surgery, lung cancer, mediastinal diseases, pleural diseases, and interventional bronchology. He is [view full biography](#)



Enrico M. Camporesi

Professor

Department of Physiology

University of South Florida

USA

Tel: 813-844-7170

Enrico M. Camporesi is Professor of of Surgery at University of South Florida College of Medicine Tampa, Florida, USA. He is Professor and Chairman of Anesthesiology. He got American Medical Association Physician Recognition Award in Continuing Medical Education. He is Resident for Department of Anesthesiology at Duke University Medical Center. Assistant Professor of Physiology at University of Milan, Italy. Research interests are Exercise in air, on O2, in water, and before surgery: preconditioning. Environmental altered exercise, as at altitude, in space and underwater; at increased and reduced total pressure.



Heinz Lohrer

Professor

University of Freiburg

Institute for Sports Medicine

Germany

Tel: +49-69-67800933

He is Honorary Professor and Lecturer at the University of Freiburg, Germany. He is Director of the Orthopaedic Department of the Institute for Sports Medicine. Since 1995 he is Medical Director of the Institute for Sports Medicine Frankfurt, Germany. He is Board member and Chair of the Scientific Committee of the European College of Sports and Exercise Physicians (ECOSEP). Reviewer for 25 different scientific journals. Board Member Olympischer Spitzensport German Gymnastics Federation. My research interests are Ankle ligament injuries, Achilles tendon injuries (acute and chronic).



Ciro Jose Brito

Department of Physical Education

Federal University of Juiz de Fora

Science Life Institute

Brazil

Graduate in Physical Education from the Federal University of Vicosa (2002). Master in Nutrition Science from the Federal University of Vicosa (2005). Doctor in Physical Education from the Catholic University of Brasilia (2010). Post-doctorate in Science of Physical Activity from the Polytechnic University of Madrid (2016). Adjunct professor at the Federal University of Juiz de Fora and advisor of the Postgraduate Program in Physical Education UFV/UJFF (Master's and Doctorate). He has experience in Physical Education, with emphasis on Exercise Physiology, working mainly on the following subjects: Sports nutrition, combat sports and training evaluation.

Zefang Ren



Professor

Department of Statistics & Epidemiology

Sun Yat-sen University

China

Tel: 0086-20-87332577

Dr. Zefang Ren received his M.S. and Ph.D. from Sun Yat-sen Medical University in preventive medicine. Since then, Dr. Ren has been working as a teacher and researcher in the School of Public Health. He once worked at Vanderbilt University as an epidemiologist (2002-2005). Dr. Ren currently focuses on cancer (breast and ovary) epidemiology, exploring the etiological and survival factors, such as environments (metals, virus, et al), exercise and other life styles. He is the PI for five projects funded by National Natural Science Foundations of China (NSFC), including a joint grant of NSFC and NIH. He has published more [view full biography](#)



Yves Henrotin

Professor

Rehabilitation department

Institute of Pathology

Co-chair of the National Council of Physiotherapy

University of Liege

Belgium

Tel: +32-4-2427797

HENROTIN Yves is Professor of Pathology, Physical Therapy and Rehabilitation and director of the Bone and Cartilage Research Unit at the University of Liege (Belgium). He is a member of the American College of Rheumatology, the Osteoarthritis Research Society International, the French Society of Rheumatology and the International Cartilage Repair Society. Between 2006 and 2013, he was a member of the board of directors of the Osteoarthritis Research Society International (OARSI), the premier organization focused on the prevention, diagnosis and treatment of osteoarthritis. He was elected treasurer in 2010. He focused on the world BMJ debate and consensus congress in [view full biography](#)



Shi-Min Chang

Professor & Director

Department of Orthopedic Surgery

Tongji University School of Medicine

Yangpu Hospital

China

Dr. Chang is now a director doctor and Professor of Orthopedic Surgery, working at Yangpu Hospital, affiliated to Tongji University School of Medicine, Shanghai, China. Dr. Chang was educated in Second Military Medical College, Shanghai Medical University, and got his MD degree in 2000. In 2001-2003, he worked as a postdoctoral research fellow in Fudan University. Then he was associate professor and professor of Tongji University, Tongji Hospital. Dr. Chang is interested in Orthopedic Trauma and Reconstructive Microsurgery for musculoskeletal system. He has published 40 scientific papers in English and 200 papers and 7 books in

Chinese. He is good [view full biography](#)**Ketan Patel**

Professor
School of Biological Sciences
University of Reading
UK
Tel: 0118-378-8079

Ketan Patel received his PhD from Imperial College London for his work on Duchenne Muscular Dystrophy and has maintained a research interest in muscle function ever since. He was awarded Medical Research Council Fellowship at Mill Hill London where he pioneered the cloning of muscle specific genes and thereafter, through a Wellcome Trust Career Development Award held at the Department of Anatomy and University College London, under the mentorship of Professor Cheryl Tickle (FRS) and Professor Lewis Wolpert (FRS) developed the muscle default model. He holds the Chair in Developmental Biology and Regenerative Medicine at the University of Reading [view full biography](#)

**Yonatan Kaplan**

Director
Sports Medicine Institute
Hebrew University
Lerner Sports Center
Israel

Yonatan Kaplan is Director, Sports Medicine Institute, Lerner Sports Center, Hebrew University, Jerusalem, Israel. He is Part-time Lecturer, Diploma in Sports Medicine, Tel-Aviv University, Senior Lecturer, Kiryat Ono School of Physiotherapy, Physiotherapy Editor, Israeli Journal of Arthroscopy Orthopedic & Related Sports Injuries. Reviewer of Journal of Knee Surgery Sports Traumatology Arthroscopy. His areas of research interests are Sport injury prevention, rehabilitation following ACL repair, Weight-bearing parameters on sports equipment.

**Christina Tsitsimpikou**

Directorate
Department of Hazardous Substances
Division of Environment
Greece

Christina Tsitsimpikou, Ministry of Finance, General Secretariat of Public Revenue, General Directorate of General Chemical State Laboratory, Division of Environment, Department of Hazardous Substances, Mixtures and Articles: Senior officer, toxicological assessment REACH/CLP enforcement. She has completed her Bachelor of Science in Chemistry, Master Degrees on Pharmacognosy and Sports Medicine. She is General Secretary of the Hellenic Society of Toxicology and member of the National ERT Committee, Member of the WADA Ethics and Education Committee (2003 - 2004), Member of the Monitoring Group of the Anti-Doping Convention (T-DO), representative of Greece 1999-2003). Her area of expertise are Toxicology,

Pharmacognosy, Biochemistry, Analytical [view full biography](#)**Daniel J. Lee**

Director of Traumatic Brain Injury Clinic
Department of Behavioral Health
University of the Health Sciences School of Medicine
USA
Tel: 337-531-3026

Daniel Lee completed his bachelors degree at DeSales University with foci in biology, psychology, and neuroscience. In his spare time, Daniel competed as an amateur power lifter. He obtained a direct commission as a second lieutenant in the US Army and completed his doctorate of medicine at the Uniformed Services University of the Health Sciences. Dr. Lee was promoted to Captain and completed his residency in psychiatry at Walter Reed National Military Medical Center. During residency, he developed keen interests in pharmacology, psychopharmacology, athletic and dietary supplements, research methodology, meta-analysis, bias in research, and PTSD screening. Dr. Lee is currently [view full biography](#)

**Hainan Yu**

Adjunct Professor
Centre for the Study of Disability Prevention and Rehabilitation
University of Ontario Institute of Technology
Faculty of Health Sciences
Canada

Tel: 416 482 2340

Hainan Yu completed his medical degree in 1998 from Capital Medical University and residency training in ophthalmology in 2003 from Beijing Gongtan General Hospital. In 2005, Dr. Yu was awarded a Masters degree in public health with a focus on health promotion and health education from the University of Southampton. He is a research associate for the development of the Minor Injury Treatment Protocol Project at the UOIT-CMCC Center for the Study of Disability Prevention and Rehabilitation, University of Ontario Institute of Technology (UOIT) and Canadian Memorial Chiropractic College (CMCC). He is responsible for infrastructure development, critical appraisal of the [view full biography](#)

**Subhash Juneja**

Research Associate
Division of Orthopedics
Toronto Western Hospital
University Health Network
University of Toronto

Canada

Tel: 416-422-0438

I have PhD in Animal Biochemistry and post-doctoral research in endocrinology, cancer, cell cycle, development, musculoskeletal research (bone, tendon and cartilage, osteoarthritis, spine, IVD). I have authored or co-authored more than 40 research papers including Science, Nature Genetics and JNCI. In musculoskeletal research area, I have published papers in journals like: Arthritis and Rheumatism, Connective Tissue Research, Bone, PLoS etc. My current and long-term research interests are: Arthritis, Entheses repair, Tendon, Ligament, Stem cell therapy, Chondrogenesis, Spine and IVD. Currently I am working as a Research Associate in Arthritis Program in the division of Orthopedics at Toronto Western Hospital, Toronto, [view full biography](#)

**Robert J. Manasse**

Clinical Associate Professor
Department of Orthodontics
University of Illinois
UIC College of Dentistry
USA

Tel: 312/996-7138

Dr. Robert Manasse is a Clinical Associate Professor in the Department of Orthodontics at the University of Illinois at Chicago and in the private practice of orthodontics in the South Suburbs of Chicago. He is involved in teaching the orthodontic residents both the clinical and laboratory courses of the orthodontic curriculum. He is also an advisor for several research projects for the Masters thesis of residents in the UIC Orthodontic Residency Program. Dr. Manasse received both his dental training and orthodontic residency program at the University of Illinois at Chicago. Dr. Manasse received his Diplomate status on the American Board [view full biography](#)

**Federico Carpi**

Associate Professor
Queen Mary University of London
School of Engineering & Materials Science
UK
Tel: +44 (0)20 7882 6087

Federico Carpi was born in Pisa in 1975. He received the Laurea degree in Electronic Engineering, the Ph.D. degree in Bioengineering and a second Laurea degree in Biomedical Engineering from the University of Pisa, Italy, in 2001, 2005 and 2008, respectively. From 2000 to 2012, he has been with the University of Pisa, Interdepartmental Research Centre 'E. Piaggio', School of Engineering, Italy. Since 2012, he serves as a Reader in Biomedical Engineering and Biomaterials at Queen Mary University of London, School of Engineering and Materials Science. His main research activities deal with the following topics Man-machine Interfaces, Bioinspired and Biomimetic [view full biography](#)

Weina Liu

Associate Professor
School of Physical Education & Health Care Director Assistant

East China Normal University
China

Tel: +86 13764927525



Weina Liu is a Principal Investigator and Assistant Director of the Key Laboratory of Adolescent Health Assessment and Exercise Intervention of the Ministry of Education of China and an Associate Professor in Human Kinesiology at School of Physical Education & Health Care in East China Normal University. She obtained her Ph.D.

degree in Human Kinesiology from East China Normal University. She completed her postdoctoral research at Department of Physiology in the Second Military Medical University. Dr. Liu has been the recipient of several awards including the National Natural Science Foundation of China, the Key Laboratory Construction Project of Adolescent Health [view full biography](#)

**Andrea Biscarini**

Associate Professor
Department of Experimental Medicine
University of Perugia
Italy
Tel: 39-075-585-8135

Andrea Biscarini received a degree in Physics (110/110 summa cum laude) in 1990 from the University of Perugia (Italy), and the Ph.D. degree in Engineering in 1994 from the University of L'Aquila (Italy). He has been the scientific coordinator of the Medical Physics Section within the Department of Surgical, Radiologic and Odontostomatologic Science of Perugia University. He is currently Associate Professor of Biomechanics at the Department of Experimental Medicine (University of Perugia), and director of the Laboratory of Movement and Sport Activities (LAMS) of the University of Perugia. As a consultant, he supervises the biomechanical and sport activities within the [view full biography](#)

**Omid Alizadehkhayati**

Associate Professor
School of Health Sciences
Liverpool Hope University
Liverpool
UK

Tel: +44 151 2913262

Omid Alizadehkhayati received his MD from the Tabriz University of Medical Science, Iran in 1995, and his PhD in Musculoskeletal Sciences/ Sports Medicine from the University of Liverpool, UK in 2006. Following a 7-year clinical research work at the Musculoskeletal Science Research Group at the University of Liverpool and Orthopaedic and Trauma Department at the Royal Liverpool and Broadgreen University Hospitals, he joined Liverpool Hope University in 2013, where he is an Associate Professor in School of Health Sciences (Sport and Exercise Science). His main research interests include evaluation of Neuromuscular Function in healthy population, sporting activities, and patients with [view full biography](#)

**Domenico Testa**

Associate Professor

Department of Anesthesiology and Surgical Science and Emergency

Second University of Naples

Italy

Born in Caserta (Italy) on 22 April 1967, achieved Medicine Degree with highest honors, in July 1992. Authorized to practice medicine with honors, it was enrolled in 1992, as Fellow, at the School of Specialization in Otorhinolaryngology and Cervico-Facial Surgery, University of Naples Federico II'. The specialist in Otorhinolaryngology and Cervico-Facial Surgery, October 1997, with highest honors. In 1997 is the winner of Scholarship for PhD at the University of Catania. From 03/07/2000 to 30/09/2005 has worked at the University of Naples 'Federico II' as a Consultant for High Skills in ENT and Cervico-Facial Surgery. In October 2005 he won [view full biography](#)

**Sandra Wallner-Liebmann**

Associate Professor

Medical University Graz

Institute of Pathophysiology and Immunology

Austria

Tel: +43-316-380-4292

Sandra Wallner-Liebmann is an Austrian Citizen. she is Associate Professor at Medical University of Graz. Surrogate-Dean of the Institute of Pathophysiology & Immunology. Her research interests include Lifestyle assessment, anthropometrical measurements, indirect calorimetry, stress tests and endocrine monitoring, physical performance, proinflammatory gene expression in PBMC, markers of nutrient intake, psychometry, genetic markers for addiction, atherosclerosis, dysfunctional eating behaviours.

**Sujay Saphire Galen**

Assistant Professor

Department of Health Care Sciences

Wayne State University

USA

Sujay Galen is a Physical Therapist, and he received his PhD in Bioengineering from University of Strathclyde, Glasgow, United Kingdom. His research interests bring together the disciplines of Bioengineering and Physical Therapy in promoting function and mobility in individuals with various neurological disorders. His PhD work focused on improving walking in children with Cerebral Palsy through a combined intervention of Functional Electrical Stimulation and Botulinum Toxin A Therapy. His post-doctoral research was in studying recovery in individuals with incomplete spinal cord injury and was funded by the spinal research trust in the UK. He currently is a Clinical Assistant Professor [view full biography](#)

Lisa K. Sprod

Assistant Professor



University of North Carolina

School of Health & Applied Human Sciences

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USA

Tel: 910-962-2583

Dr. Lisa K. Sprod is an Assistant Professor in School of Health and Applied Human Sciences, College of Health and Human Services at University of North Carolina Wilmington, North Carolina. She got her Ph.D from University of Northern Colorado, Greeley, Colorado. She has completed M.P.H. at University of Rochester School of Medicine and Dentistry-Rochester, New York. Dr. Sprod has published more than 30 peer reviewed articles. Research Interest are Sport and Exercise Science, yoga, Cancer-Related Fatigue, Breast Cancer, Human Performance and Wellness.

**Christopher J. Roach**

Assistant Professor

Department of Orthopaedics & Rehabilitation

San Antonio Military Medical Center

University of the Health Sciences

USA

Tel: 210-916-1242

Dr. Roach completed his undergraduate degree at the United States Military Academy at West Point in 1995. He attended the Ohio State University College of Medicine and subsequently completed his Orthopaedic Residency training at Brooke Army Medical Center in San Antonio, TX in 2005. He obtained his American Board of Orthopaedic Surgery Certification in 2007 and Subspecialty Certification in Orthopaedic Sports Medicine in 2008. After 6 years in general orthopaedic practice at Fort Eustis, VA, Dr. Roach went on to complete fellowship training in Orthopaedic Medicine at West Point, NY in 2012. Dr. Roach specializes in arthroscopic knee, shoulder, [view full biography](#)

**Adam L. Schreiber**

Assistant Professor

Thomas Jefferson University

Department of Rehabilitation Medicine

The Sidney Kimmel Medical College

Director Rehabilitation Medicine Ambulatory Services

USA

Tel: 855-727-2465

Dr. Adam L. Schreiber graduated from the A.T. Still University of Health Sciences/ Kirksville College of Osteopathic Medicine in 2003. He works in Philadelphia, PA and specializes in Physical Medicine & Rehabilitation. Dr. Schreiber is affiliated with Thomas Jefferson University Hospital. Dr. Adam Schreiber, DO is board certified in Physical Medicine & Rehabilitation. He has special expertise in 2 areas: Musculoskeletal Diseases, Osteopathic Manipulation.

**Tarang Jain**

Assistant Professor

Department of Physical Therapy and Athletic Training

Northern Arizona University

College of Health and Human Services

USA

Tel: 928-523-7305

Tarang is an Assistant Professor in the Department of Physical Therapy and Athletic Training, Northern Arizona University at Flagstaff with a PhD in Rehabilitation Science from the University of Kansas Medical Center. His professional experience and training have been primarily in orthopedic and sports physical therapy. His research interests include biomechanical movement analysis/neural control of movement and performance-based outcome measures. Specifically, his research is focused on understanding the pathophysiological mechanisms underlying chronic ankle instability using objective outcome measures. He is particularly looking to develop innovative and clinically viable rehabilitation strategies to optimize biomechanical and clinical outcomes following chronic ankle instability. [view full biography](#)

**Tim Miller**

Assistant Professor

Department of Orthopaedic Surgery

Ohio State University

Columbus

USA

Tel: (614) 366-2716

Timothy Miller, MD Ohio State Orthopaedic Sports Medicine. Assistant Professor of Clinical Orthopaedics. Dr. Miller received his medical degree from the Wright State University School of Medicine. He completed his residency in orthopaedic surgery at The Ohio State University, after which he completed a fellowship in Sports Medicine at the University of Pittsburgh Medical Center. He currently serves as a team physician for the Ohio State Buckeyes and medical director of Capital University Athletics. His research interests are endurance athletes, treatment and prevention of stress fractures and overuse injuries of the upper and lower extremity, gait analysis, dance injuries, [view full biography](#)

**Lan Yao**

Assistant Professor

College of Nursing

Michigan State University

USA

Tel: 517-353-4769

Lan Yao received her Ph.D. in nursing from University of Michigan in 2004. Dr. Yao's program of research focuses on utilizing residual emotional and procedural learning reserves in the dementia patients to tailor physical exercise interventions that affect functional ability, fall risks, and quality of life in patients with

Alzheimers disease and their caregivers. Physical activities and exercise intervention are particularly important when involving older adults with Alzheimers disease and other dementias. Inactivity exacerbates physical and cognitive deficits through the loss of motivation and efficiency in performing activities which leads to further deterioration and decline in function among these patients. [view full biography](#)

**Patrick Sadoghi**

Assistant Professor

Department of Orthopaedic Surgery

Medical University of Graz

Austria

Tel: +43 316 385 80971

He is Assistant Professor in Orthopaedic Surgery, Senior Resident in Orthopaedic Surgery, MBA in Healthcare and Hospital Management. He is Executive Board Member of the Austrian Society of Orthopaedic Surgeons. Scientific Expertise and Interest include Joint Replacement / Adult Reconstructive Surgery / Orthopaedic Sports Medicine / Knee Surgery.

**Wang wenru**

Assistant Professor Alice Lee Centre for Nursing Studies

Yong Loo Lin School of Medicine

Singapore

Tel: 65-6601-1761

Dr Wangs major interests include cardiovascular nursing and cardiac rehabilitation, developing psychometric measurement tools, chronic disease management, and nursing education. Over the past years, she has been awarded over 10 grants. Her research expertise covers quantitative, qualitative and mix-design methods. Dr Wang has authored two books, eight book chapters and has published over 50 peer-reviewed papers in international refereed journals and over 30 papers in local and regional scientific journals. She has presented her research at over 30 international conferences and has been recognised with several national and international awards for the achievement in her research endeavours. Dr Wang [view full biography](#)

**Alessandra di Cagno**

Assistant Professor

University of Roffeme

Department of Sport and Health Sciences

Italy

Tel: 3388511016

Alessandra di Cagno, PhD in 'Sport and Health Sciences', is currently Assistant Professor of 'Theory and methodology of Sport training' at the Department of Movement, Human and Health Sciences, Division of Health Sciences, of the University of Rome 'Foro Italico'. She is included in the Internal Medicine research group, where the Rector Prof. Fabio Pigozzi is the President. She was a National Gymnast of Italian Gymnastics Federation and National Coach. She was also International Judge of International Gymnastics Federation (FIG). From 2008 to 2012 has carried out her activities at the Department of Health Sciences of

the [view full biography](#)



J. David Prologo

Assistant Professor

Division of Interventional Radiology and Image Guided Medicine

Emory University Hospital

USA

I attended John Carroll University in Cleveland, Ohio where I earned a Bachelor of Science degree in Human Biology, after which I attended The Ohio State University College of Medicine, graduating in 2001. I completed my residency training at University Hospitals Case Medical Center where I served as chief resident, then went on to fellowship training in at Metrohealth Medical Center in Cleveland. I am currently an Assistant Professor in the Division of Interventional Radiology and Image Guided Medicine at Emory University School of Medicine. The epicenter of my research interests is the image guided transplantation of stem cells for [view full biography](#)



Peter Pribis

Assistant professor

Department of Individual, Family & Community Education

University of New Mexico

College of Education

USA

Tel: 505-277-5566

Dr. Pribis is a native of Slovakia, a small country in central Europe. He graduated from School of Medicine at King Charles University in Prague, Czech Republic and from Loma Linda University, School of Public Health with Dr.P.H. in nutrition and epidemiology. He worked as medical advisor and health consultant in Czech Republic and Germany. He was the director of the IMS program in Nutrition and Wellness at Andrews University in Michigan. He presently works as assistant professor of nutrition and dietetics at the University of Albuquerque. The all-encompassing concept of his research is the information to develop practical diagnostic and treatment methods that improve wellbeing and increase longevity. He currently holds an [view full biography](#)



Eric Braverman

Assistant Professor

Department of Psychiatry

University of Florida College

McKnight Brain Institute

USA

Tel: 212-213-6155

Eric R. Braverman, M.D. is the founder and president of PATH Foundation NY, a non-profit research organization devoted to establishing how the brain functions and using that information to develop practical diagnostic and treatment methods that improve wellbeing and increase longevity. He currently holds an

appointment as Courtesy Assistant Professor at the University of Florida College of Medicine and the McKnight Brain Institute. Dr. Braverman graduated from NYU School of Medicine with honors and completed his residency at Greenwich Hospital, a Yale University School of Medicine affiliate. He assisted with folic acid studies at Harvard Medical School and contributed to [view full biography](#)



Roy T.H. Cheung

Assistant Professor

Department of Rehabilitation Sciences

The Hong Kong Polytechnic University

Hong Kong

Tel: 852-2766-6739

Dr. Cheung received his Bachelors degree in Physiotherapy from the Hong Kong Polytechnic University. He worked as a frontline clinician in both public and private settings for years. After earning his PhD in the area of sports biomechanics from the same university, Dr. Cheung completed a postdoctoral fellowship at the Department of Physical Medicine & Rehabilitation, Harvard Medical School, where he studied the relationship between running biomechanics and injury, and methods to examine real time kinematics of foot structures and patella. His current areas of study include biomechanics in runners, efficacy of prophylactic device for sportsmen, and gait retraining for [view full biography](#)



Sandy Jack

Consultant Clinician Scientist

University College London

Department of Musculoskeletal Biology

Institute of Ageing and Chronic Disease

UK

Tel: 02381205308

Sandy Jack PhD is currently a Consultant Clinician Scientist at University Hospital Southampton NHS Foundation Trust (UHS), Southampton and NIHR Southampton Respiratory Biomedical Research Unit and Integrated Physiology and Critical Illness Group, Clinical and Experimental Sciences, Faculty of Medicine, University of Southampton (Uos). She is also Honorary Senior Lecturer at the Universities of Southampton, Liverpool and University College London. Sandy manages the Centre for Human Integrative Physiology in the Wellcome Trust Research Facility at UHS, she leads on the Fit-4-Surgery Group (Uos-UHS). She is a member of faculty on numerous courses including the European Practicum in Exercise Testing and Interpretation. [view full biography](#)



Sanjeev U. Nair

Senior Fellow in Cardiovascular Medicine

Lehigh Valley Health Network

University of S Florida College of Medicine

USA

Tel: +39-0472-767650

DDr. Daniel Dalla Torre holds a D.D.S and a M.D. degree, both awarded at the Medical University of Innsbruck. After his residency in oral and maxillofacial surgery he worked as consultant at the University Clinic for Craniomaxillofacial and Oral Surgery in Innsbruck. In 2014 he established the dental clinic Dalla Torre in Sterzing, Italy, a private clinic specialized in advanced oral and maxillofacial surgery as well as traumatology, with a special regard to facial sports injuries. To date, DDr. Dalla Torre is still involved in research at the Medical University of Innsbruck, with a special focus on head and face [view full biography](#)



Dale Ding

Associate Professor of Neurosurgery

Department of Neurological Surgery

University of Louisville School of Medicine

USA

Tel: 1-434-924-2203

Dale Ding obtained his M.D. from Duke University and is currently a senior neurosurgical resident at the University of Virginia. He has published over 100 articles, primarily in the field of cerebrovascular disease and in top subspecialty journals, such as the Journal of Neurosurgery, Neurosurgery, American Journal of Neuroradiology, Cerebrovascular Diseases, and Journal of Cerebral Blood Flow and Metabolism, and has presented over 40 abstracts at national and regional meetings. He serves as the Associate Editor of Neuroimmunology and Neuroinflammation and presides on the editorial boards of JSciMed Neurosurgery and Spine, Journal of Cerebrovascular Disease, Austin Journal of Cerebrovascular Disease [view full biography](#)



Chad A Krueger

Executive chief resident

Orthopaedic Surgery Resident

San Antonio Military Medical Center

USA

Tel: (210) 216-8538

I grew up in Wells, ME and graduated Summa Cum Laude from the University of Delaware with an Honors Degree in exercise physiology and minors in chemistry and medical humanities. I received my M.D from the University of Medicine and Dentistry New Jersey- Robert Wood Johnson Medical School and am currently completing my Orthopaedic Surgery Residency at San Antonio Military Medical Center in San Antonio, TX. As an active duty Officer in the United States Army. I look forward to continuing to care for injured service men and women as an Orthopaedic Surgeon when I have completed my residency. [view full biography](#)

Jorma Sormunen

Resident

Department of Oncology

Tampere University

Finland

Sanjeev U. Nair did his formal training in Internal Medicine and Cardiovascular Critical Care in India and was awarded a Doctorate in Medicine. He thereafter received training in the United Kingdom prior to migrating to the United States where he is presently located as a senior fellow in cardiovascular medicine at Lehigh Valley Health Network, one of the nations top 50 centers in cardiology. His primary research interests include sudden cardiac death and cardiac arrest, therapeutic hypothermia and cardiovascular interventions especially related to structural heart disease. He is widely published and has multiple peer-reviewed publications to his name. He has [view full biography](#)



Karen Hind

Senior Research Fellow

Institute of Sport, Physical Activity and Leisure (ISPAL)

Leeds Beckett University

UK

Karen Hind received her Doctorate from the School of Medicine, University of Leeds UK in 2005. She has been leading and managing research into bone and body composition at the Institute of Sport, Physical Activity and Leisure, Leeds Beckett University UK since 2007. She is also a Visiting Fellow at the University of Newcastle upon Tyne UK, an ISCD certified clinical densitometrist, and an active member of the European Innovative Partnership on Active and Healthy Ageing. Dr Hind has served as a reviewer for many scientific journals and funding bodies. Her expertise is in musculoskeletal health across the lifespan, including [view full biography](#)



Joshua Vincent

Doctoral research assistant

Roth|McFarlane Hand and Upper Limb Center

St. Josephs Healthcare London

Canada

Tel: 519 694 6222

Joshua Vincent, PhD is a young investigator based at the Roth MacFarlane Hand and Upper Limb Center, at St. Josephs Healthcare London, London ON Canada. His background is in Physiotherapy. He is interested in outcomes research especially of the upper limb in conditions related to sports injuries and trauma like fractures, nerve injuries etc. His areas of research interest include evidence based practice, clinical measurement properties of impairment and self-report measures of the upper limb, interpretation of change, translation and cross-cultural adaptation; and outcome evaluation after surgeries for conditions of the upper limb.



Daniel Dalla Torre

Researcher

Head of the dental clinic

University of Innsbruck

Institution of dental clinic

Austria



Tel: +32 491 728 137

Jorma Sormunen received his Doctorate of Medicine from University of Kuopio, Finland. He is a specialist in Occupational Medicine. He also has a special competence in Military Medicine as well as certificate of Global Health from the University of Philippines, Manila. In addition to medical degrees he has a Masters degree in Business Administration from the University of Wales, UK. Currently Dr Sormunen is involved in research and publishes on the effects of physical condition and exercise on the incidence of cancers.

**Gherardo Finocchiaro**

Post-doctoral research fellow

Cardiovascular Sciences Research Centre

St Georges University of London

UK

Tel: 39-95-641157

Dr Finocchiaro completed his undergraduate training and qualified from Trieste University (Italy) in 2007. He completed his fellowship in Cardiology in Trieste in April 2012, with particular interest in cardiomyopathies. He then spent one year at Stanford University (CA, US), focusing on hypertrophic cardiomyopathy and athletes heart, gaining a post-doctoral diploma in 2013. Subsequently he worked for seven months at The Heart Hospital imaging center (London) learning cardiac MRI. He is now undertaking research at St Georges University Hospital, London in the field of sudden cardiac death, cardiomyopathies and athletic cardiac adaptation. My main interests are sports cardiology, cardiomyopathies, sudden [view full biography](#)

**A Barبران Garcia**

Faculty of Medicine

University of Barcelona

Institute for Biomedical Research

Spain

Tel: +34 932 275 540

Anael Barبران-Garcia is a respiratory physiotherapist at the Hospital Clinic de Barcelona - IDIBAPS. His career has developed in the field of research in pulmonary rehabilitation, the use of technology to support physical activity in chronic patients and exercise physiology. His PhD thesis has been developed within the NEXES European project (FP7-CIP-ICT-PSP-2007-1-225025), awarded by the European Union with three stars excel Excellence Award Reference. NEXES aims to validate and promote the adoption of innovative integrated care services supported by Information and Communications Technology for chronic patients. Anael Barبران has been also contributor to several national projects for the scalability [view full biography](#)

Georg Ebersbach

Head of Department

Humboldt University

Movement Disorder Clinic



Germany

Tel: 0049-33204-22781

Georg Ebersbach, M.D. is director of the Movement Disorders Clinic Beelitz-Heilstatten, Germany, since 1998. He is lecturing clinical neurology at the University Hospital Charite, Berlin and Sports Neurology at the University Potsdam. He is secretary of the German Parkinsons disease Society (Deutsche Parkinson Gesellschaft).

He has published numerous peer-reviewed articles and reviews on different clinical aspects of Parkinsons disease and other movement disorders. Main topics of his research are disturbances of gait and posture in PD, exercise and physical therapy in PD and non-motor symptoms in PD.

**Christian Brinkmann**

Leader of the Cardiovascular group

Institute of Cardiovascular Research and Sport Medicine

German Sport University Cologne

Germany

Tel: +49 (0)221-4982-6176

Dr. Christian Brinkmann studied sports science and biology. He works at the Institute of Cardiovascular Research and Sport Medicine (Department of Molecular and Cellular Sport Medicine) at the German Sport University Cologne. His research interests focus in particular on exercise physiology in patients with metabolic syndrome. He wrote his doctoral thesis on the influence of physical exercise on oxidative stress and the antioxidative defense system in type 2 diabetic patients. Christian Brinkmann has authored many peer-reviewed articles in internationally referenced journals.

**Roger Ramsbottom**

Senior Lecturer

Department of Sport and Health Sciences Oxford Brookes University

Uk

Tel: +44 (0)1865 483265

Roger Ramsbottom is currently a Senior Lecturer in the Department of Sport and Health Sciences at Oxford Brookes University. Roger gained his PhD in Exercise Physiology at the University of Loughborough, United Kingdom investigating accumulated oxygen deficit as a non-invasive measure of the anaerobic capacity. He was the lead scientist in the development of the 20-m shuttle run test for the assessment of aerobic fitness. He is a Fellow of the British Association of Sport and Exercise Sciences (BASES), member of the Physiological Society and Associate Editor for the Journal of Sports Science and Medicine and on the Editorial Board [view full biography](#)

**Hugh H K Fullagar**

Researcher

Saarland University

Institute of Sport and Preventive Medicine

Germany

Tel: +4915170802127

Hugh has a passionate drive to further the performance of athletes with a strong focus on maximizing his contributions to organizations in the disciplines of both science and sport. Currently, he is undertaking a combined role as a doctoral candidate and sport scientist at the Institute of Sports and Preventative Medicine. In addition, Hugh is involved in research projects which focus on optimal regeneration techniques to enhance recovery and performance, the cumulative effect of fatigue on performance in and out of competition, identifying and monitoring valid performance indicators in elite footballers and training periodisation and recovery planning. Specifically, his doctorate [view full biography](#)

**Abeer M. Mahmoud**

Research Assistant Professor

School of Applied Health Sciences

University of Illinois at Chicago

USA

Dr. Abeer M. Mahmoud received her doctorate of Medicine from Assiut University, Egypt. She has continued her training in Pathology while performing her residency in the Department of Pathology in Egypt. Following this she worked as a pathologist for two years at South Egypt, Cancer Institute, before realizing her true passion was in biomedical research. This interest led her to the University of Illinois at Chicago, where she completed her Ph.D. in Pathology in 2013. Since then she has performed very successful research and has been very productive. During her postdoctoral training, Dr. Mahmoud received training on the principals and [view full biography](#)

EDITOR-IN-CHIEF

**J. David Prologo**

Assistant Professor

Division of Interventional Radiology and Image Guided Medicine

Emory University Hospital USA

**Dale Ding**

Resident Physician

Department of Neurosurgery
University of Virginia
USA

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International Journal of
Sports and Exercise Medicine

ISSN: 2469-5718

(International Journal of Sports and Exercise Medicine, php)

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Dave Clark Senior Lecturer in Strength and Conditioning, School of Sport and Exercise Sciences, Room No. TR8 1.18, Tom Reilly Building, Byrom Street, Liverpool, L3 4AF, UK
Dawn T Gulick Widener University, One University Place, 126 Coffee Hall, Chester, PA 19013, USA
Ce Yang Research Institute of Surgery, Daping Hospital, Third Military Medical University, Changjiang Zhilu, Daping, Chongqing, 400042, China
Danièle Ranoux Department of Neurosurgery, Centre Hospitalier Universitaire de Limoges, Limoges, France
Andy Waldheim

Maria Teresa Colomina Department of Psychology and Research Center for Behavior Assessment (CRAMC), Universitat Rovira i Virgili, Tarragona, Spain
E. Marini Unit of Internal Medicine, Department of Medicine, University of Perugia, Perugia, Italy
Rebecca Pratt McLaren HealthCare, G-3245 Beecher Rd, Flint, MI, 48332, USA
Katsuhiko Suzuki Faculty of Sport Sciences, Waseda University, Tokorozawa 359-1192, Japan
Carla Harkness-Armstrong Post-Doctoral Research Associate in Biomechanics, Dept. of Sport and Exercise Sciences Faculty of Science and Engineering, Manchester Metropolitan University, Institute of Sport, Manchester, M1 7EL, UK
Ettore Marini Unit of Internal Medicine, Department of Medicine, University of Perugia, Perugia, Italy
NOOR AZIZAH OMAR Department of Biomedical Sciences, School of Medicine and Veterinary Medicine, University of Edinburgh, Old Medical School, Teviot Place, Edinburgh EH8 9AG, United Kingdom

Dong Pan School of Information Science and Engineering, Central South University, Changsha 410083, China
Michael Doarn Assistant Professor, Department of Orthopedics and Sports Medicine, University of South Florida, USA
Nada Salhab School of Nutrition and Translational Research in Metabolism, Faculty of Health Medicine and Life Sciences, Maastricht University, Maastricht, The Netherlands
Kristen Renner Research Assistant Professor, Orthopaedic Research, Joint Appointment, Biomedical Engineering, The University of Arizona, Office: (520) 626-8229, 655 N. Alvernon Way, Room 104A, Tucson, AZ, USA
Nancy L. Malcom Associate Professor of Sociology, USA
Katharina Department of Sport Science, University of Innsbruck, 6020 Innsbruck, Austria
Shanta Bantia Nirx Therapeutics, 689, Highland Lakes Cove, Birmingham, AL-35242, USA
Mazdak Ghajari Imperial College London, Department of Aeronautics, South Kensington Campus, London, SW7 2AZ, UK

Pei Jean LIM Waseda Bioscience Research Institute in Singapore, Waseda University, Singapore 138667, Singapore
Shinya Aoyama Organization for University Research Initiatives, Waseda University, Tokyo 1628480, Japan
Andrew Hatchett Department of Exercise and Sport Sciences, University of South Carolina Aiken, Aiken, SC 29801, USA
Joshua Zadro Institute for Musculoskeletal Health, Sydney School of Public Health, Faculty of Medicine and Health, University of Sydney, Sydney, New South Wales, Australia
Christine Dalsjö AnyBody Technology, A/S Niels Jensen Vej 10, DK 9220 Aalborg, Denmark; Department of Materials and Production, Aalborg University, Fibigerstræde 16, DK-9220 Aalborg, Denmark
Farman Ali Fujian Provincial Key Laboratory of Agroecological Processing and Safety Monitoring, College of Life Sciences, Fujian Agriculture and Forestry University, Fuzhou 35002, China
Preston Wiley Faculty of Kinesiology, The University of Calgary, 2500 University Dr. N.W., Calgary, Alberta, Canada
Odette Laneuville Department of Biology, Faculty of Science, University of Ottawa, Bone and Joint Research Laboratory, Faculty of Medicine, University of Ottawa, 451 Smyth Road, Ottawa, ON K1H 8N5, Canada

ShuZhe Ding Department of Orthopaedic Oncology, Changzheng Hospital, 415 Fenyang Road, Shanghai, China
Caroline Heckman Institute for Molecular Medicine Finland FIMM, HILIFE, University of Helsinki, Helsinki, Finland
Daniel Marinho Department of Sport Sciences, University of Beira Interior, Portugal
Nico Kolokythas Department of Nutrition and Dietetics, University of Thessaly, UK
Maria Rosaria Tumolo National Research Council Institute, for Research on Population and Social Policies, Research Unit of Brindisi, c/o ex Osp. Di Summa, Piazza Di Summa, 72100 Brindisi, Italy
Oladipo O Eddo Assistant Professor, School of Kinesiology, George Mason University, 10890 George Mason Circle, Katherine Johnson Hall 2018, MS 4E5, Manassas, VA 20110, Tel: (703) 993-7183, USA
Ceri Diss Department of Life Sciences, University of Roehampton, London, UK
Huang Hongshi Institute of Sports Medicine, Peking University Third Hospital, Beijing Key Laboratory of Sports Injuries, Beijing,

Devin Wahl Charles Perkins Centre, University of Sydney, Sydney 2006, Australia; Aging and Alzheimers Institute, ANZAC Research Institute, Concord Clinical School/Sydney Medical School, Concord 2139, Australia
Markus Gesslein Department of Orthopedics and Trauma Surgery, Nuremberg General Hospital, Paracelsus Medical University, Nuremberg, Breslauer Strasse 201, 90471 Nuremberg, Germany
Morganne Reid Department of Psychology, Catholic University of America, 620 Michigan Ave NE, Washington DC, 20064, USA
Huang Xiao School of Sports and Health Science, Tongren University, Tongren 554300, China
Qiang Xu Guangzhou University of Chinese Medicine, Guangzhou, Guangdong, China
Jocelyn Bowden Institute of Bone and Joint Research, Kolling Institute, The University of Sydney, St Leonards, New South Wales, Australia
Daniela Iucini University of Milan, BIOMETRA Department, Milan, Italy; Exercise Medicine Unit, Humanitas Clinical and Research Center, Rozzano, Italy
Anastassios Philippou

Department of Physiology, Faculty of Medicine, National and Kapodistrian University of Athens, Greece
Pengcheng Xie Department of Anesthesiology, Shanghai Pudong Hospital, Fudan University Pudong Medical Center, 2800 Gongwei Road, Huinan Town, Pudong, Shanghai, 201399, China
Mark L. Vickers Faculty of Medicine, The University of Queensland, Brisbane, Queensland, Australia
Liu Xiao Ning Department of Sports Medicine, Orthopaedic Center, the Second Hospital of Jilin University, Changchun 130041, Jilin, China
Claire Kenneally-Dabrowski ANU Medical School, Australian National University, Australian Institute of Sport, Canberra, ACT, Australia
Tao Xiao College of Mathematics and Statistics, Shenzhen University, Shenzhen 518060, China
Guillaume Py Université de Montpellier, INRA, UMR866 Dynamique Musculaire et Métabolisme, Montpellier, France
John O. Osborne School of Exercise and Nutrition Sciences, Queensland University of Technology, Brisbane, QLD, Australia

Shotaro Naganawa Department of Radiology, Graduate School of Medicine, The University of Tokyo, 7-3-1, Hongo, Bunkyo-ku, Tokyo 113-8655, Japan
Jonathan Eskander Department of Anesthesiology, Portsmouth Anesthesia Associates, Portsmouth, VA, USA
Ruiz-Moreno, Carlos Exercise Physiology Laboratory, Camilo José Cela University, 28692 Madrid, Spain
Jorge Gutiérrez-Hellín Exercise Physiology Laboratory, Camilo José Cela University, 28692 Madrid, Spain
Myles W. O'Brien Division of Kinesiology, School of Health and Human Performance, Dalhousie University, Halifax, Canada
Yu Lun Tai Department of Health and Human Performance, University of Texas Rio Grande Valley, Brownsville, TX, USA
Ambra Antonioni Unit of Biology and Genetics, Department of Movement, Human and Health Sciences, University of Rome "Foro Italico", Piazza Lauro de Bosis 15, 00135, Rome, Italy
Yusuke Graduate School of Health Management, Keio University, Kanagawa, Japan; Sports Medicine Research Center, Keio University, Kanagawa, Japan

W.R. Walsh Surgical and Orthopaedic Research Laboratories, Prince of Wales Clinical School, University of New South Wales, Prince of Wales Hospital, Gate 6, Avoca St, Randwick, Sydney, NSW 2031, Australia
Leejay Tan Hospital Raja Permaisuri Bainun, Department of Forensic Medicine, Ipoh, Perak Darul Rizuan, Malaysia
Alba Pasini Department of Biomedical and Specialty Surgical Sciences, University of Ferrara, corso Ercole I d'Este 32, Ferrara, 44121, Italy
Pushpa Joshi Department of Neurology, Martin-Luther-University Halle-Wittenberg, Germany
Liu Xiaoning Department of Sports Medicine, Orthopaedic Center, the Second Hospital of Jilin University, Changchun 130041, Jilin, China
Beate Klein Abteilung für Psychiatrie und Psychotherapeutische Medizin, Salzkammergut Klinikum Vöcklabruck, Dr.-Wilhelm-Bock-Straße 1, 4840, Vöcklabruck, Österreich, Austria
Gary Smith Department of Pediatrics, The Ohio State University College of Medicine, Columbus, OH, USA
Michael Tarpey Department of Human Nutrition, Foods and Exercise, Virginia Tech, 338 Wallace Hall, 295 West Campus Drive, Blacksburg, VA 24061, USA

Hiroki Fukuhara Department of Urology, Faculty of Medicine, Yamagata University, 2-2-2 Iida-Nishi, Yamagata, Japan
Washmuth Associate Professor, School of Health Professions, Department of Physical Therapy, USA
Ben Lee Occupational and Environmental Physiology Group, Coventry University, UK
Yuan zuobiao American Academy of Acupuncture and Oriental Medicine. 1925 W County Rd 82, Roseville, MN 55113, USA
Melinda Connor CAM, Akamai University, 110 Hawaii; Arizona School of Acupuncture and Oriental Medicine, Earthsongs Holistic Consulting, 31907 South Davis Ranch Rd., Marana, AZ 85658, USA
Ghasemikaram Mansour Institute of Medical Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Henkestr. 91, 91052, Erlangen, Germany
Eduard Isenmann Institute for Cardiovascular Research and Sports Medicine, Department of Molecular and Cellular Sports Medicine, German Sports University, 50333 Cologne, Germany
Daher Antonio Queiroz Visiting Professor, Division of Restorative and Prosthetic Dentistry, The Ohio State University College of

Dentistry , Columbus, Ohio, USA
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International Journal of **Sports and Exercise Medicine**

ISSN: 2469-5718

([International-Journal-of-Sports-and-Exercise-Medicine.php?jid=ijsem](https://clinmedjournals.org/early_Online.php?jid=ijsem))

Early Online

Open Access DOI:10.23937/2469-5718/1510234 (<http://doi.org/10.23937/2469-5718/1510234>)

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Article Type: Research Article | First Published: October 21, 2022

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RESEACRH ARTICLE

Influence of the Menstrual Cycle on the Performance of Different Physical Tests Specific to Handball

MOUSSOUAMI Simplicie Innocent^{1,2*}, AGBODJOGBE Kpedetin Wilfrid Dieu Donné³, BOUSSANA Alain Marc², LOUNIONGO God², ALONGO Yvon Rock Ghislain² and BIO NIGAN Issiako¹

¹Sport, Health and Evaluation Research Unit (UR/SSE), National Institute for Youth, Physical Education and Sport (INJEPS), University of Abomey-Calavi (UAC), Benin

²Laboratory of Physiology of Effort and Biomechanics (LPB), Higher Institute of Physical Education and Sport (ISEPS), University Marien Ngouabi, Congo

³Laboratory of Physiology of Effort, National Institute for Youth, Physical Education and Sport (INJEPS), University of Abomey-Calavi (UAC), Benin

***Corresponding author:** Simplicie Innocent Moussouami, Sport, Health and Evaluation Research Unit (UR/SSE), National Institute for Youth, Physical Education and Sport (INJEPS), University of Abomey-Calavi (UAC), 01 BP: 169, Porto-Novo, Benin, Tel: 00242-06-636-66-97/00229-90-23-67-60



Abstract

Nowadays, several scientific studies focus women's the menstrual cycle and its impact on sports performance. However, the results of these studies are controversial. In This regard, the aim of this study is to evaluate the effects of the menstrual cycle on physiological responses, intermittent Yo-Yo test performance, repeated sprints and medicine-ball in elite women handball players. The sample of this study is 18.71 ± 0.72 years older female players. The following handball specific physical tests were performed: intermittent Yo-Yo test, repeated sprints and medicine-ball whose lactate concentration was also measured. Endurance capacity ($\dot{V}O_{2\max}$) was lower in the luteal phase ($p < 0.001$). In contrast, medicine-ball performance, and repeated sprinting ability are better in the Follicular Phase (FP). The menstrual cycle affected performance on the Yo-Yo IET, exercise HRmax and muscle strength. Better performance is observed during the follicular phase.

Keywords

Performance, Menstrual cycle, Sport, Congo

Introduction

Handball is a team sport characterized by intense and intermittent efforts, it involves, among other things, acceleration, changes of direction, sprinting,

jumping, shooting, slow running, walking, dueling with wrestling-like paces [1,2]. In its current form, a handball match lasts 60 minutes, consisting of two halves of 30 minutes each separated by a 10-minute break. Intense efforts during the match are characterized by a heart rate above 85% of maximum [3], a maximum oxygen consumption ($\dot{V}O_{2\max}$) of up to $61 \text{ ml.kg}^{-1}.\text{min}^{-1}$ in men and $52 \text{ ml.kg}^{-1}.\text{min}^{-1}$ in women [2].

Recent changes in handball rules make the game much faster, with less time loss between phases [4] and require players to make maximum physical efforts during matches. To achieve the best performance, teams must, therefore, through consistent physical preparation meet these physical and physiological demands [5]. To this end, several physiological, environmental and hormonal parameters during a match have to be taken into account. These parameters are dependent on several factors including gender, circulating blood volume, heart rate, serum lactic acid level, body temperature, scapular limb strength, pelvic limb power and maximum oxygen consumption ($\dot{V}O_{2\max}$) which are important physiological characteristics for optimal handball performance. The rules of the game, the training methods are identical for both sexes. But in the

training process, the menstrual cycle in women, must be an important factor that must be taken into account.

The menstrual cycle is mainly divided into two phases: a follicular phase, which begins with the bleeding phase, and a luteal phase. These phases of the menstrual cycle are associated with hormonal fluctuations and can affect the physiology of the woman's body. Furthermore, it is assumed that the menstrual cycle affects women's physiological indices when compared in the luteal and follicular phases. Indeed, estrogen and progesterone receptors have been identified in skeletal muscle. As skeletal muscles are organs that play a very important role in movement and in HB racing, cyclical fluctuations of these hormones can directly influence training results.

Recently several studies have reported that women with a normal menstrual cycle may be more prone to decreased performance and post-exercise muscle soreness in the early follicular phase. Shahidi, et al. [6] showed that some physiological parameters such as ($\dot{V}O_{2\max}$) and body temperature are influenced by menstrual cycles. In contrast, Guler, et al. [7] concluded that menstrual cycles in female futsal players do not affect flexibility, power, speed, anaerobic and aerobic performance. Blanca Romero-Moraleda, et al. [8] report that resistance-trained eumenorrhoeic women have similar speed, strength and power performance when exercising with loads equivalent to 20, 40, 60 and 80% of 1RM during the Smith machine half-exercise during exercise in different phases of the menstrual cycle.

The effects of the menstrual cycle on body composition, physical capacity and physiological parameters during and after exercise have been studied in the literature, but the results remain incomplete and contradictory. Further studies on this topic are therefore needed. Furthermore, the literature lacks studies on the relationship between the different phases of the menstrual cycle and physical performance in female handball players. Therefore, the aim of this study is to evaluate the effects of the menstrual cycle on physiological responses and performance to repeated sprints in elite women handball players.

Material & Methods

Participants

A total of 43 elite female players in the junior and senior age group in Brazzaville with a normal menstrual cycle (between 25 and 28 days) took part in this research. The sample for this study was selected by reasoned choice and consisted of 22 players in the luteal phase and 21 in the follicular phase. These athletes are selected for their experience in national and international competitions. To be included in the sample for this research, each player had to meet the following inclusion criteria: be licensed during the 2018 season. In addition to the general criteria, athletes had

to participate in at least one national champion and had never used oral contraceptives. The purpose and risks of this study are explained and each participant signed a written consent. The study was validated by the ethics committee of the Higher Institute of Physical Education and Sport in accordance with the Helsinki recommendations.

Data collection protocol

Before the start of the experiment and the beginning of each phase of the menstrual cycle, anthropometric, physiological, urine and blood samples are taken. Heart rate, core temperature and serum lactate levels are also measured. Urine collection was used to measure urine density to determine water status. The heat stress index is calculated. During this study, field tests such as the Yo-Yo IRT2 (9) and medicine-ball are performed for the respective calculation of $\dot{V}O_{2\max}$ and scapular limb strength. Subjects are also subjected to a capacity test of repeated sprints. These tests are used on day 6 and 10 of the follicular phase and day 20 and 24 of the luteal phase (10). All measurements are repeated at the end of each phase, at the same times of day. Subjects continued training during the follicular (FP) and luteal (LP) phases except on the days of the experiment. They are forbidden to drink caffeine, alcohol or any other drug.

Measurements and tests

Anthropometric measurements

Height: The equipment used to measure height is a two-metre-high ZT-150A toise (Perlong Medical with Equipment, China). The height measurement is consisted of determining the stature of the subjects. It determines the structure measured from the foot to the top of the skull. The subject is asked to stand barefoot on a flat, compact surface in an upright position (arms at the side of the body, heels together, head upright, looking towards the horizon). The reference point being the feet and the vertex (top of the head), the researcher placed the graduated scale behind the subject, and compressed the subject's hair using a square (point) fixed to the scale, graduated to the nearest centimeter.

Body mass: A digital scale of the brand Personal Scale (model: 2003A; max weight: 180 kg, d = 0.1 kg) is used to measure weight. The weight measurement consisted of determining the subjects' body mass. The subject stood on the scale platform, upright with his or her hands at his or her sides, staring straight ahead and the body mass value was measured in kilograms from the reading on the scale. Height was measured using a stadiometer (to the nearest 1 cm) with a participant standing upright against a vertical surface, and weight was measured using a weighing machine to the nearest 1 kg with subjects standing still, with their feet approximately 15 cm apart and the weight evenly distributed on each leg. Participants were instructed to

wear light clothing (culturally appropriate) and not to wear shoes when measuring body weight. BMI in kg/m² was calculated by the Quetelet index.

Biometric measurements: Core body temperature: The equipment used to determine rectal temperature (Tr) was MT 101R automatic thermometers (Hangzhou Sejoy, China) for personal and individual use. Before and after each use, the administrator cleaned the probe with alcohol-soaked cotton wool for disinfection. The researcher switches on the thermometer and this will cause a beep to be heard indicating that the device is actually working. A display test is then performed and the last measurement in memory is displayed. This was measured in the rectum using a Biopac MP100 system with a 1.7 mm diameter SKT100C transducer module. To insert this system into the rectum we wrapped the thermistor probe in a plastic film lubricated with gel before inserting it.

Heart rate: A Geonote heart rate monitor (Decathlon, France) is used to measure heart rate. The subject wore a belt with heart activity sensors which were transmitted to a watch worn on the wrist. The subject is instructed to turn on the heart rate monitor and then press the “effort indicator” button until the heart appeared, marking the heart activity. After a few minutes of rest, the administrator, having noted the stability of the heart rate value, took and recorded this value. This measurement is consisted of determining the heart rate in its value.

Samples: Serum lactic acid level: The equipment used to measure the serum lactic acid level is the lactate pro II. This measurement is consisted of the determination of lactic acid in blood. The blood is taken from the earlobe by a needle and collected on a slide for examination.

Water status: The equipment used to determine water status is the PEN-Urine clinical refractometer, brand name Atago (Japan). The water status is determined from the urine density. Thus, an athlete is considered normo-hydrated when his urine density (UD) < 1.020. He was dehydrated when 1.020 < UD < 1.030. The athlete was severely dehydrated when the UD > 1.030.

Menstrual cycle information: The materials used to obtain information about the participants’ menstrual cycle were the mobile application mycalendar, period-Tracker, US and a menstrual diary. The length of the menstrual cycle and the start of each phase were determined using a mobile application (Mycalendar®, Period-Tracker, US) and a menstrual diary indicating the date of menstruation, the duration of menstruation and the discomfort experienced in the days before and during menstruation. Participants collected these data for a complete menstrual cycle, starting with the randomly allocated phase.

Physical effort tests

Repeated sprint capacity: This test is made of six

sprints at maximum speed interspersed with 10s of recovery. This test consists a assessing an individual’s ability to repeat effort intervals over a prolonged period. On a flat surface the researcher measured a distance of 35 m where he placed two image sensors at the beginning and end of the journey. Using a stopwatch, the researcher starts a 35 m shuttle run at maximum speed.

To assess the CSR or anaerobic sprinting in running, the 6 × 35 m test of was used. The test consists of six repeated 35m sprints at full speed with a 10 second recovery time between each sprint. The time performance will be used to calculate the power of each sprint, as follows:

Yo-yo Intermittent Recovery test (Yo-yo IRT2): Yo-yo Intermittent Recovery test (Yo-yo IRT2) was used to calculate $\dot{V}O_{2\max}$ [9,10]. This test is based on an intermittent shuttle run performed over a distance of 20m with an active recovery zone of 5 m. At the signal of the audio recording that serves as a guide to the test, the athlete runs the distance back and forth and then pauses for 10s in active recovery. From the level reached by the athlete, the distance covered was determined and the $\dot{V}O_{2\max}$ was calculated according to the following equation:

Yo-Yo IRT2: $\dot{V}O_{2\max}$ (mL/min/kg) = IRT2 distance (m) × 0.0136 + 45.3

Medicine-ball eccentric throw test: This test is a valid tool to measure the strength and power of the scapular limbs. Using a 2 kg ball, the subject throws it as far as possible with a flexion-extension movement of the arms above the head. The subject maintains a standing posture for the throws, and must not bend his or her legs, arch backwards, or bend the torso over the legs. After three trials with a 60-second break in between, the examiner selects the best of the three for analysis.

Statistical analysis

The data from this study were processed with Statistica software (Stat. Soft. Inc., version 12.0). The normality of the distribution of the variables was checked with the Kolmogorov Smirnov test and the homogeneity of variances was tested with the Levene test. The two-factor ANOVA (Time × cycle periods) are used to test for interactions between measurement times and groups. The Wilcoxon rank test was used to test the measurement time effect in each period. Comparisons between the two periods of the cycle were made with the Man Whitney U test. The significance level of the statistical tests was set at $p < 0.05$.

Results

Players in the PF and PL groups were 18.36 ± 0.84 and 18.71 ± 0.72 years-old, respectively. Height, body mass and BMI were similar in both groups ($p > 0.05$). HR recorded in the PF group was on average significantly

Table 1: Anthropometric and physiological characteristics of the players.

	Effectif total (n = 43)	FP Group (n = 22)	LP Group (n = 21)	p-value
Age (years)	18.53 ± 0.79	18.36 ± 0.84	18.71 ± 0.72	1.15
Height (cm)	165.80 ± 4.60	160.61 ± 5.41	165.09 ± 3.73	0.09
BM (kg)	58.48 ± 7.12	59.88 ± 8.09	57.01 ± 5.76	0.13
BMI (kg/m ²)	21.33 ± 2.87	21.61 ± 3.00	21.03 ± 2.77	0.72
HR (bpm)	85 ± 6	83 ± 4	87 ± 5 ^{**}	0.004
Trec (C°)	37.57 ± 0.58	37.26 ± 0.50	37.90 ± 0.48 ^{***}	0.001

The numbers in the boxes represent the means ± standard deviations (Mean ± SD); FP: Follicular Phase; LP: Luteal Phase; BM: Body Mass; BMI: Body Mass Index; HR: resting heart rate; Trec: core temperature; ^{**}: difference between FP group and LP group, significant at p < 0.01; ^{***}: difference between FP group and LP group, significant at p < 0.001

Table 2: Variation in anthropometric parameters of female players (n = 43).

	PF Group (n = 22)		LP Group (n = 21)	
	Before	After	Before	After
BM (kg)	59.88 ± 8.09	59.33 ± 8.03 ^{**}	57.01 ± 5.76	56.61 ± 5.59 ^{***}
BMI (kg/m ²)	21.61 ± 3.00	21.40 ± 2.94 ^{***}	21.03 ± 2.77	20.83 ± 2.46 ^{**}

Numbers in boxes represent means ± standard deviations (Mean ± SD); FP: Follicular Phase; LP: Luteal Phase; ^{*}: difference between FP group and LP group, significant at p < 0.05; ^{**}: difference between FP group and LP group, significant at p < 0.01; ^{***}: difference between FP group and LP group, significant at p < 0.001

Table 3: Assessment of physiological parameters and performance during the different phases of the menstrual cycle in the women handballers studied.

	FP Group (n = 22)	LP Group (n = 21)	p-value
	$\bar{x} \pm \sigma$	$\bar{x} \pm \sigma$	
HRre (bpm)	79.3 ± 3.4	85.7 ± 4.6	0.12
HRmaxthéo (bpm)	202 ± 1	202 ± 1	-
HRmax (bpm)	161 ± 3	174 ± 5	< 0.001
Trec (C°)	38.81 ± 0.28	38.85 ± 0.51	0.41
Densité Urinaire (DU)	1.01 ± 0.008	1.01 ± 0.10	0.32
% PP (%)	1.30 ± 0.45	1.73 ± 0.62 [*]	0.03
IPCT	6.48 ± 0.56	6.44 ± 1.01	0.76
$\dot{V}O_{2max}$ (mL/min/kg)	49.28 ± 1.07 ^{***}	47.40 ± 0.76	< 0.001
PMB	7.28 ± 0.35 ^{**}	6.73 ± 1.01	0.01
CSR (min)	6.81 ± 0.38	7.01 ± 0.32	0.08
Pmoy	240.87 ± 58.30 [*]	209.47 ± 25.81	0.01
Pmax	308.02 ± 68.63 [*]	269.34 ± 16.09	0.02
IF	40.88 ± 7.23	40.44 ± 12.57	0.89

Numbers in boxes represent mean values ± standard deviations; HRre: exercise heart rate; HRmaxthéo: maximum heart rate; Trec: core temperature; % PP: percentage weight loss; IPCT: heat stress index; $\dot{V}O_{2max}$: maximal oxygen consumption; PMB: medicineball performance; CSR: repeated sprint capacity; Pmoy: mean power; Pmax: maximum power; ^{*}: difference between PF group and PL group, significant at p < 0.05; ^{**}: difference between PF group and PL group, significant at p < 0.01; ^{***}: difference between PF group and PL group, significant at p < 0.001

higher than that recorded in the PL group (83 ± 4 versus 87 ± 5 bpm; p = 0, 004). Core temperature was significantly lower (37.26 ± 05 °C; p < 0.001) in the FP group than in the PL group (Table 1).

The body parameters recorded at the beginning of the repeated sprints were identical between the PF and PL groups. However, significant changes were noted in both groups after the repeated sprints. But no significant

differences were found between the two groups at the end of the program (Table 2).

Table 3 shows the variation of physiological parameters and performance during the different phases of the menstrual cycle in female handball players. In the Luteal Phase (LP) the players had a higher exercise heart rate compared to the follicular phase (174 ± 5 bpm versus 161 ± 3 bpm; p < 0.001). Consequently,

they achieved significantly lower endurance capacity performance ($\dot{V}O_{2\max}$) (47.40 ± 0.76 mL/min/kg versus 49.28 ± 1.07 mL/min/kg; $p < 0.001$). In contrast, the best medicine-ball performance, repeated sprint ability was recorded in the follicular phase compared to the luteal phase.

During repeated sprints, [La] increased by after post-exercise [La] increased but is significantly lower than that observed in the follicular phase (7.28 ± 0.35 mmol/L versus 6.73 ± 1.01 mmol/L; $p < 0.001$ and 308.02 ± 68.63 mmol/L versus 269.34 ± 16.09 mmol/L; $p = 0.02$) (Figure 1).

Discussion

The aim of the study is to determine whether each phase of the menstrual cycle had an influence on the physical performance of women handball players. The main findings of the study are: 1) Female handball players performed better in the Yo-Yo IET test, and muscle strength. 2) Exercise HRmax was affected in the luteal phase.

Available data on the effect of the menstrual cycle on performance are contradictory in nature. Although many studies have shown that the menstrual cycle has an influence on physical performance [11], a decent number of studies have concluded that there is no variation in performance between periods of the menstrual cycle [12]. In the literature, and to our knowledge, this is the first study to evaluate the effects of menstrual cycle

phase on the performance of different physical tests in handball. In this study, the phase of the cycle affected the endurance capabilities of the players in the Yo-Yo test. Physical performance in handball is considered to be attributed to the training status and aerobic capacity of athletes. The results of the present study are in agreement with those of Bandyopadhyay, et al. [13] who in a cross-sectional survey of 55 women with a normal cycle suggested that endurance capacity is significantly low in the follicular phase. In this investigation, $\dot{V}O_{2\max}$ is assessed directly by the Brude treadmill test method. Shahidi, et al. [6] reached the same conclusion in a study of older adolescent girls with a normal menstrual cycle of 25-35 days [14].

The most plausible explanation for the differences in endurance performance observed during the different phases of the menstrual cycle would certainly be the fluctuation in the concentration of ovarian hormones. The latter could have consequences on performance due to changes in core temperature. Indeed, body temperature is slightly higher by 0.3 to 0.5 °C during the luteal phase compared to the follicular phase [15]. Therefore, it can be postulated that elevated temperature during the luteal phase alters physiological responses during exercise. Several studies have suggested that elevated basal body temperature is associated with increased fatigue and impaired aerobic performance.

These results suggest that progesterone-induced temperature elevation may explain the variation in

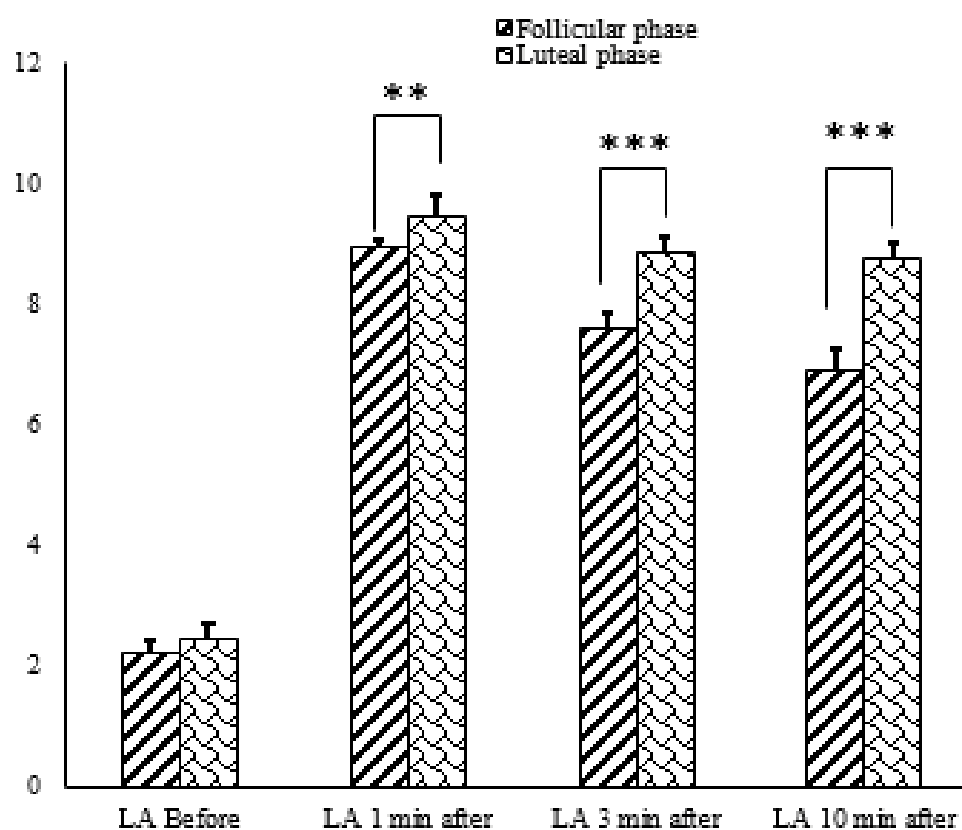


Figure 1: Changes in lactate concentration induced by repeated sprints.

endurance performance. However, other observations suggesting an association between endurance performance and menstrual cycle phase are not consistent with this hypothesis. In addition, numerous studies have shown that endurance performance is more reduced in the luteal phase compared to the follicular phase under hot and humid conditions (32 °C, 62% relative humidity) [16,17].

Regarding lactate concentrations between the 3- and 5-minute post-exercise phases, significant differences are observed in this study. Consistent with the results of the present study, Osthuyse, et al. [12] suggested that during the luteal phase, lactate concentration was reduced due to a low demand on aerobic glycolysis during this phase. Interestingly, however, the data from this study did not indicate any difference in lactate production at rest or at peak lactate concentration. These results are in agreement with those of Vaiksaar, et al. [18], who found no difference in lactate production in the same way in female rowers completing a one-hour row at 70% of $\dot{V}O_{2\max}$. When we compare the results of different studies on the effect of the menstrual cycle on performance seems difficult due to the specificities and physical and physiological demands of each sport discipline and the tests used.

The data from this study show no significant difference in sprint performance between the follicular and luteal phases. This result is in agreement with Julian, et al. [19] who reports that repeated sprint performance showed no difference in female footballers.

Another finding of this study is the lack of effect of cycling on muscle strength in the medicine-ball throwing test. Our results are consistent with those of previous studies [17] in which the authors reported no significant differences in muscle strength between phases of the menstrual cycle. However, in these previous studies, the handgrip test and the isometric test of the knee flexors and extensors are the most commonly used to determine muscle strength in athletes. In this study, we have selected the medicine-ball throw test to determine whether the menstrual cycle affected pelvic limb muscle performance. In contrast, another study examined the effects of training during the follicular and luteal phases on muscle strength, muscle volume and microscopic parameters. The results of this study have shown that the follicular phase results in an increase in muscle strength and muscle diameter compared to the luteal phase due to the high concentrations of free testosterone during this phase [20]. These observed differences could certainly be due to alterations in estradiol and progesterone related to the menstrual cycle. Indeed, several studies have shown that ovarian hormones fluctuate during the menstrual cycle [12,21].

Some limitations of this study deserve to be mentioned and discussed. The sample size of the study makes it impossible to reliably generalize the results to the

whole population of female handball players. Tracking of menstruation is used to determine the start of the menstrual cycle. Therefore, the menstrual calendar run alone does not provide all relevant information regarding the phase of the menstrual cycle [22]. Female serum sex hormones are also measured to determine the length of the cycle and the beginning/end of each cycle. No data on the exact amount of blood lost during the menstrual period is obtained. There are a few limitations to this study that are worth noting despite its strengths. This study only looked at two phases of the cycle in female handball players and female serum hormones were not measured to confirm cycle length, phase onset and phase end. The number of participants is small and does not allow for the generalization of these results to all female handball players. Studies with larger numbers are needed to validate these results. Nevertheless, athletes and coaches need to be consoled on the menstrual cycle, its relationship to performance, and the wide variability that exists between individuals. Many athletes are currently self-managing and should report menstrual concerns to both their GP and sports staff.

Perspectives

Further studies should consider: 1) Monitoring the evolution of physical parameters throughout the menstrual cycle and assessing the actual duration of the menstrual cycle with serum hormone measurements; 2) Analyzing the differences between the variation of these physical parameters in players with a regular cycle and those with an irregular cycle.

Conclusion

This study has assessed the influence of the different phases of the menstrual cycle on physiological responses, performance in the intermittent Yo-Yo test, repeated sprints and medicine-ball in elite women handball players. The results obtained suggest that the follicular phase induced a decrease in performance in the Yo-Yo IET test, muscle strength as well as the ability to perform repeated sprints. Assessing performance on different physical tests in handball will help players and coaches understand the specific adaptations of the menstrual cycle phase to exercise and sports performance.

Conflicts of Interest

The authors declare no conflicts of interest.

Authors' Contributions

All authors have contributed to this article, agree with the content and have approved the final manuscript.

Acknowledgements

The authors would like to thank all the handball players for their participation in the study and all the team leaders who believed in this study. Thanks also to the colleagues in the laboratory for their valuable contribution.

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