CONSORTIAL MEMBER PROFILE:
The Human Performance Laboratory at the University of Calgary

The CCCRC now has 12 members and is a network of Canadian researchers designed to foster cross-disciplinary research collaboration on a variety of issues that will advance the CCA's Research Agenda. Each issue of the JCCA will feature a Consortial Member profile and clinicians and researchers are invited to establish links with those areas of interest. The first Consortial member to be featured is Dr. Walter Herzog at the University of Calgary.

1 Personnel

The Human Performance Laboratory [HPL] contains the Natural Sciences research branch of the Faculty of Kinesiology. It comprises researchers from the general areas of biomechanics; nutrition, exercise, and health physiology; and motor control. Although not exclusively, the HPL is best known for its biomechanics research and nine of its 16 current faculty members are biomechanists. In a 2002, external, peer-review evaluation, the biomechanics group was ranked as the top scientific lab of its kind in the world by one of the referees.

The current faculty members of the HPL, and their appointments, are shown in Figure 1. Aside from the faculty members, the HPL currently houses 8 postdoctoral trainees, and visiting professors, 29 support staff members including research assistants and technicians, 48 MSc and PhD students, and 16 visiting undergraduate exchange and summer students.

2 Facilities and resources

The Human Performance Laboratory is situated in the Kinesiology B block at the University of Calgary. It occupies two floors for a total research area of 3200 m^2. Through two infrastructure grants from the Federal [CFI] and Provincial [ASRIP] governments, totaling $6.5 million, the Human Performance Lab will be expanded over the next two years to double its research space (Figure 2). This expansion will be accomplished by adding a third and fourth floor to the existing HPL lab.

The HPL is fully equipped for human biomechanics and exercise physiology analysis. Furthermore, it contains a fully equipped biochemistry lab, a cell and molecular biomechanics lab, a neurophysiology lab associated with the Sports Medicine Clinic, and many further small labs for specific research projects.

The total research operating budget for the HPL is currently about $4.2 million per year. Forty percent of this money [$1.68 million] is obtained from competitive research grants, about one-quarter each come from the University of Calgary [mostly as salary support] and from non-competitive grants [primary industry contracts], and about 10 percent of the money in scholarship support for students from federal and provincial granting agencies, as well as from the University of Calgary and the private and not-for-profit sector (Figure 3).

3 Research themes and current projects

Below, I will introduce the research themes and topics of the past year from each research group in their own words.

Benno M. Nigg, Gerald K. Cole, Darren J. Stefanyshyn, Vincent von Tscharner, and James M. Wakeling

The major research topics of this group focuses on soft tissue vibrations, muscle activity, orthotics, robotics and simulation, sport performance and signal processing.

Soft tissue vibrations (Nigg, Wakeling)

This group has conducted a series of experiments to test the hypothesis that impact forces, soft tissue vibrations, and muscle tuning are closely correlated. There is good evidence for this hypothesis in quasi-static situations. However, at present, this team is struggling to confirm similar results in dynamic situations, such as walking and running.

The Human Performance Laboratory

Faculty

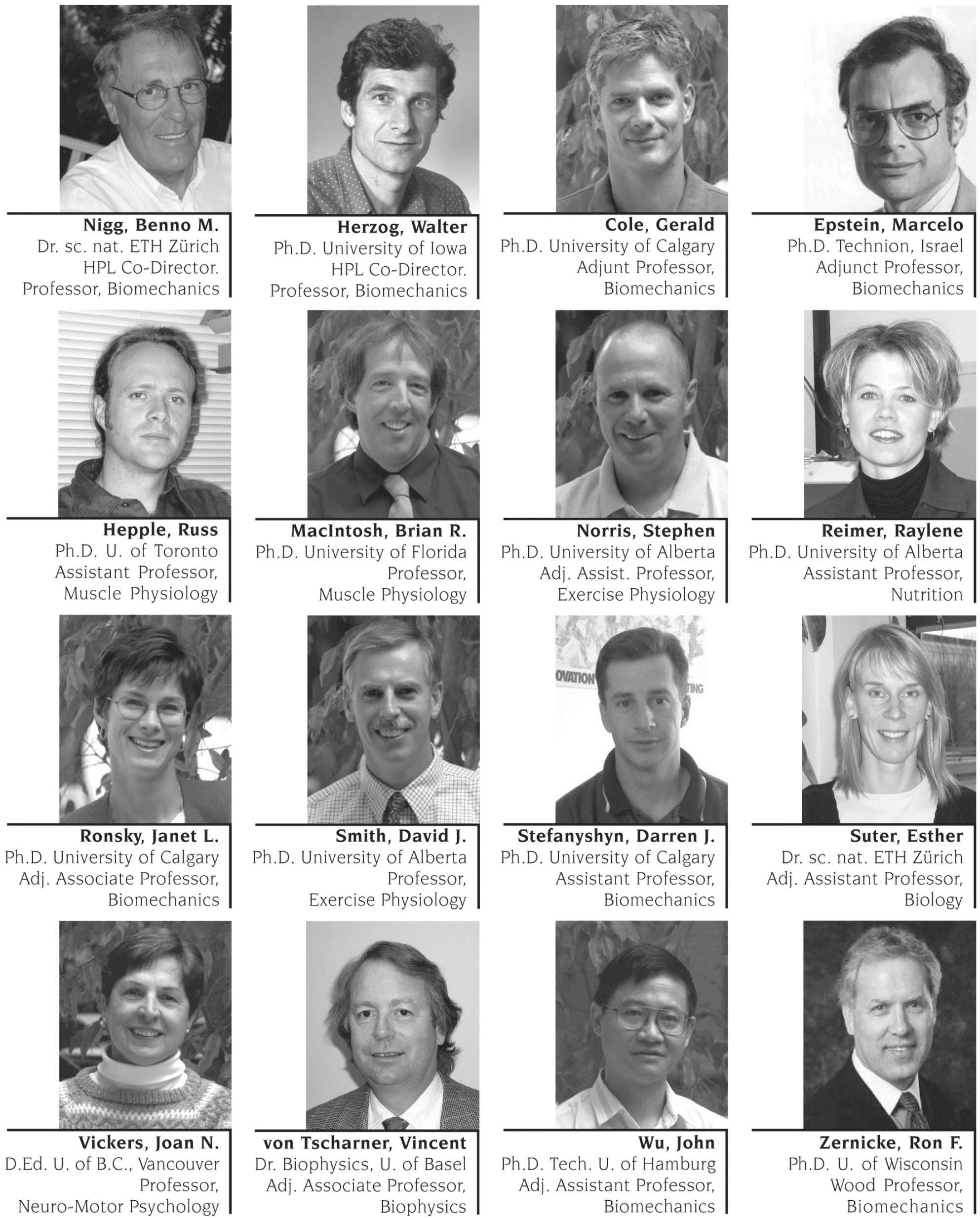

Figure 1 HPL faculty members.

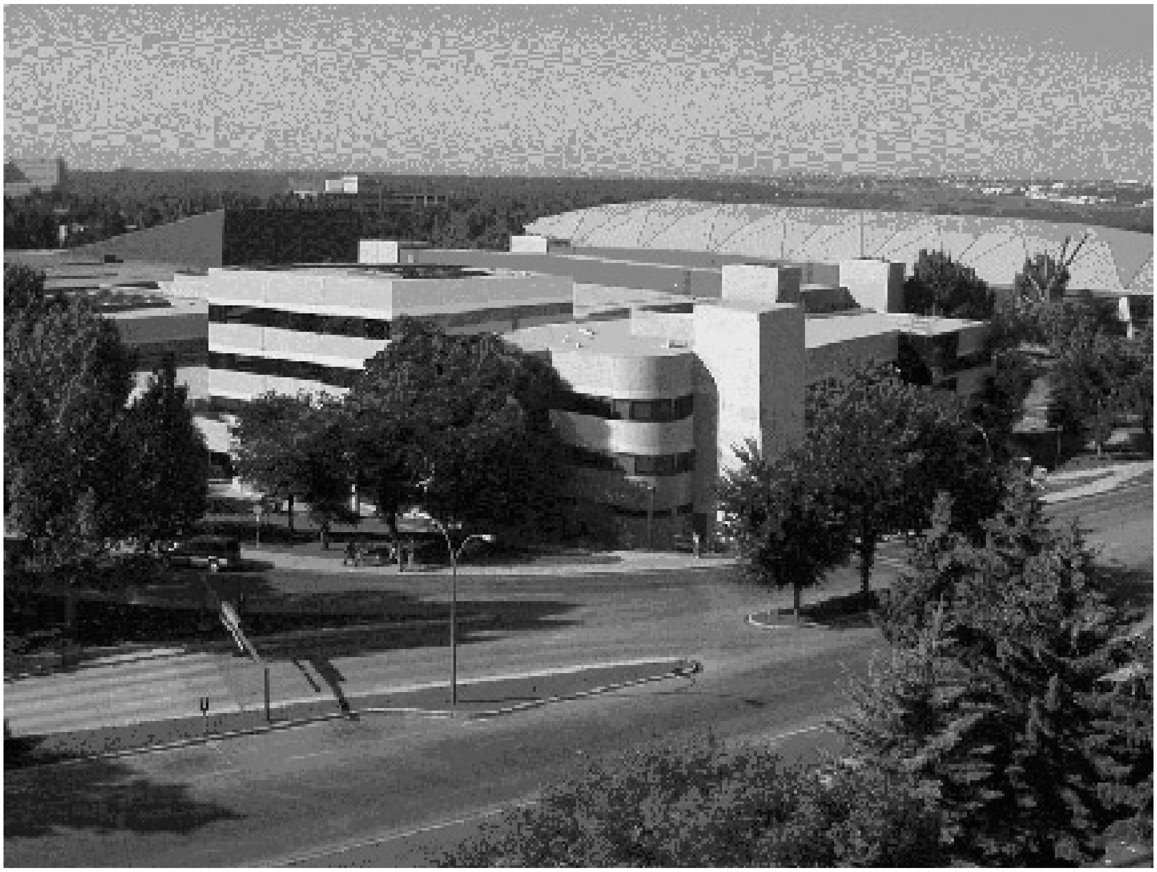

Figure 2 Expansion of the Human Performance Laboratory in the Faculty of Kinesiology, University of Calgary.

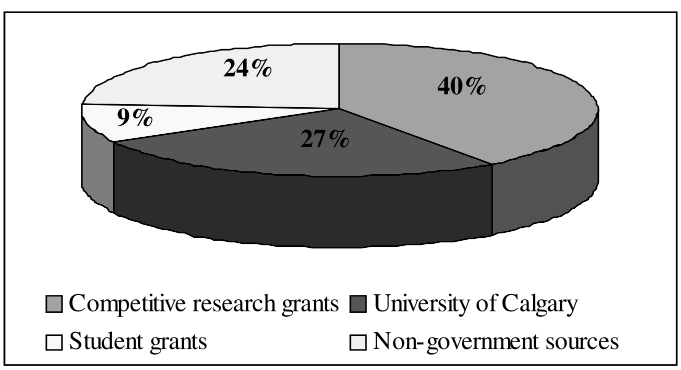

Figure 3

Muscle Activity (Wakeling, von Tscharner)
During human motion, there are bursts of muscle activity that are distinct in both their timing and myoelectric frequency content. This led to the proposal that the myoelectric frequency spectra could be used to distinguish activity between different types of motor units in mixed muscle. A series of hypotheses were tested from the muscle of fish, cats, rats and man in a range of in vivo and in situ experiments. These studies all pointed to the same conclusion that the myoelectric frequency is related to the muscle fiber type. This finding opens up many possibilities for measuring motor unit recruitment patterns used for muscle contractions.

Orthotics (Nigg, Stefanyshyn, Wakeling)
Orthotics and shoe inserts are often used. However, the precise functioning of these interventions is not well understood. Two theses were finished around the end of the year 2002, both of them contributing to the basic under-

standing of the functioning of specific aspects of orthotics/inserts. It was shown that molding and posting of orthotics have very different effects on kinematics and kinetics. Molding seems to override posting when both are applied simultaneously. Furthermore, it has been shown that the individual reaction to insert intervention is strongly influenced by the vibration sensitivity of the plantar surface of the foot, especially in the area of the first metatarsal and the hallux.

Robotics and simulation (Cole, Stefanyshyn, Nigg)
For a few years, our group has worked on the development of a computer simulation controlled footwear testing device. The goal of this project is to develop a system that can reliably test the functional differences between footwear. The system includes a Stewart Platform that moves relative to a fixed prosthetic foot/shoe. Motion of the platform is controlled by a lower extremity, musculo-skeletal simulation model. The 3D loading conditions of the foot are measured and provide the force feedback of the shoe/ground interaction required by the simulation model. There was extensive progress on this project in 2002. The Stewart Platform and all associated hardware were installed. All control software was developed and tested. With a running shoe installed on the robot, we are currently determining the muscle stimulation patterns for the simulation model that produce a typical running motion. Results are extremely encouraging, and we expect to soon be running the simulation with different test shoes to see if we correctly predict the differences between them.

Sport performance (Stefanyshyn, von Tscharner, Nigg)
Our sport biomechanics research continues to focus on identifying athlete characteristics that determine the necessary footwear and equipment properties required for maximal performance of individual athletes. We continue to investigate the influence of shoe stiffness on sprinting performance and have found that the more an athlete's shoe bends, the more his or her performance can benefit from increasing the shoe stiffness. We are currently expanding this line of study into running with some positive initial results. In speed skating, we are working on optimizing the placement of the klap-skate hinge mechanism based on each skater's lower limb force and power output. In golf, our studies focus on matching the important features of a golfer's individual swing to quantifiable club parameters. In the future we will continue to expand our focus to include additional sports and already have plans to investigate aspects in short-track speed skating and ice hockey.

Signal processing (von Tscharner, Wakeling)
In this area of research, we have focused on the analysis of electrophysiological data from muscles. Muscles are known to have fiber types that have individual motor unit action potentials and conduction velocities and thus generate electromyographic signals with characteristic frequency components. The wavelets used previously have been tuned to have an optimal time/frequency resolution to discriminate between the signals resulting from fast and slow muscle fibers in animals and humans. More complex electromyograms are a result of an overlap of a large number of motor unit action potentials recorded during dynamic exercises. For the analysis of these, most frequently measured electromyograms, a wavelet analysis based on multiple wavelets was developed, presented at conferences and is commercially available as a "Wavelet-Engine" software package.

Another signal analysis project concentrated around the identification of functional groups. Pattern recognition methods were used to create a pattern space where each intensity pattern of a data set (e.g. an electromyogram) can be represented as a single point. Points that cluster together in pattern space represent similar group characteristics. This method was successfully applied to electromyographic signals quantified during cycling on a cycle ergometer and during running for male and female runners.

Walter Herzog and Marcelo Epstein
Our research continues to drift towards the understanding of cellular and molecular events involved in tissue adaptation and degeneration, the mechanisms underlying muscle contraction and muscle coordination during normal and pathologic movements, and the application of these basic principles to musculoskeletal injury and disease.

In the area of tissue mechanics and adaptation, we have started three novel experimental studies this year. The first focuses on identifying the biosynthetic response of articular cartilage to controlled knee loading using muscular forces, the second investigates the mechanisms of sarcomere number adaptation as a function of muscle fiber strain, and the third is aimed at determining the possible degenerative effects of knee extensor weakness on the knee.

In the area of muscle mechanics, we have begun to study questions of sarcomere stability and sarcomere length non-uniformity on the descending limb of the force-length relationship. We showed in single myofibrils that upon stretch all sarcomeres are stretched, and that, at the end of stretch, all sarcomere length remain perfectly constant, providing first direct evidence that sarcomeres are stable on the descending limb of the force-length relationship. Also, we have now strong support that the force enhancement following active muscle stretch is caused by an active (cross-bridge type) and a passive component. Finally, we found that force enhancement can exceed the isometric force at optimal length in single fibers, in situ muscles, and in vivo muscles during voluntary contraction.

Regarding our applied research, we confirmed that the vertebral artery elongates by about 6% during chiropractic neck manipulation, and by about 12% during active movements, such as head rotation to the end range of motion. Furthermore, we have now firmly established that the contractile history influences the steady-state force in muscle during maximal voluntary contractions and have preliminary evidence that this is also true for submaximal contractions (Figure 4).

Janet Ronsky

Our research group is focused on understanding relations amongst static and dynamic function and neuromotor control of the musculoskeletal system, as well as the role which alterations to bone and joint structures, mechanics and integrity associated with injury and aging play in joint

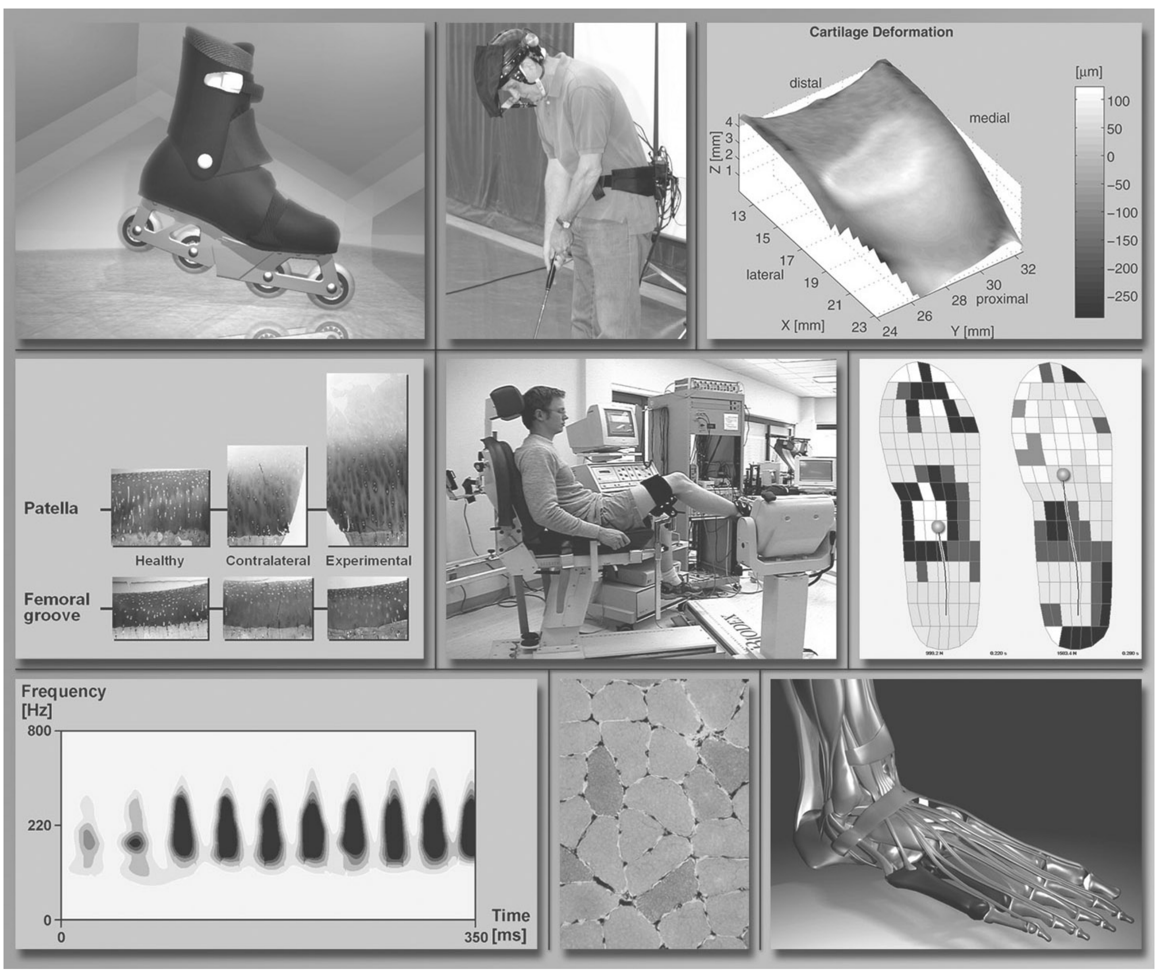

Figure 4 Selected research projects: Top Row; left to right: sports biomechanics, vision control in golf, patellofemoral contact analysis. Middle row; left to right: osteoarthritis research on articular cartilage, human strength, and rehabilitation lab; insole pressure measurements. Bottom Row; left to right: wavelet analysis of electromyographical signals, sarcopenia in aging muscle, animated foot model.

health status. Research in joint contact mechanics focused on relations between altered joint structure and altered dynamic joint function associated with ACL deficiency and patellofemoral pain syndrome. We have initiated studies integrating 3D motion and force analysis of functional tasks, and determination of the IHA of the knee, combined with MR imaging of joint structures. Advances with our computational models now enable feature extraction and solid modeling of tissue structures from MR images. Techniques were developed for determining subject specific segmental inertial properties of limbs based on MR images. These inertial properties have enabled more accurate predictions of joint moments and forces during functional activities, for the various adult, child and animal populations of interest in our studies.

Relations between joint mechanics and cartilage degeneration continue to be investigated with the in-vivo ovine stifle joint model. We have successfully identified that transection of the ACL and MCL result in cartilage degeneration and consistent changes in joint kinematics and kinetics after 20 weeks. Based on 3D models generated from MR images, we produced subject specific bone models using rapid prototyping technologies. The bone models are used with a new robot to recreate subject specific joint kinematics, enabling direct quantification of altered joint mechanics and distribution of joint forces associated with ligament deficiency.

In clinical applications, we continued to study locomotion and stability in people with spastic diplegia and Parkinson's disease. Development was completed of an experimental apparatus for perturbation of postural stability and assessment of neuromotor response, and a postural control model. Applying wavelet analysis to EMG data, we have been able to identify significant reductions in muscle co-contraction using ankle-foot orthoses in children with spastic diplegia. In our collaborative scoliosis research, we have identified new indices that strongly relate internal spine and rib cage geometry with external torso geometry using neural networks. New image calibration and registration approaches are in progress. The first prototype of a custom scoliosis brace based on torso surface geometry and computer aided manufacturing techniques was successfully developed.

Ronald F. Zernicke

Human motion biomechanics and the functional adaptation of bone to exercise, diet, and injury constitute the major areas of my research. In the area of human locomotion, we are analyzing the kinematics and kinetic patterns of patients with chronic malrotated tibias as a result of compound fracture malunions. In partnership with the McCaig Centre for Joint Injury and Arthritis Research and paediatric orthopaedic surgeons at the Alberta Children's Hospital, we assessed the consequences of a unilateral clubfoot on children's gait and also the interrelations between femoral antetorsion and anterior knee pain in adolescent females. We have extensively developed methods to relate the surface contours of the torsos of adolescent scoliotic children to the underlying deformities of their spine and rib cage. This work is a collaboration among the Alberta Children's Hospital, Clynch Technologies (Calgary), the University of Montreal and Ste-Justine Hospital (Montreal), and the University of Calgary. We are using a unique application of a 3-D laser-optical system, surface shape modeling, and artificial neural networks.

The second major focus of our group is the functional adaptation of bone. The ability of bone to change its morphology in response to local physical stimuli is predicated upon the appropriate recruitment of bone cell populations. In turn, the ability to initiate cellular recruitment is influenced by both local and systemic factors. This year, we continued our research that is probing relations between mechanical stimuli (e.g., strain gradients, strain magnitudes, and strain rate) and the sites of new bone formation induced by exercise. We have examined the microstructural changes in periarticular cancellous bone structure (via micro-CT scanning) and mechanical properties and blood flow in the chronically unstable knee joint. We found that joint injury (loss of anterior cruciate ligament) had a profound and deleterious effect on the structure and mechanical integrity of the periarticular bone. Our current projects will assess whether bisphosphonate therapy blocks remodeling and conserves bone integrity.

In probing the mechanisms that contribute to mechanotransductive remodeling, we are: (1) determining strain gradients, strain rates, and fluid flow in an in-vivo adult mouse model, and (2) establishing a relation between fluid flow and localized bone remodeling activity. The first objective is being assessed by using a controlled mechanical loading regimen in an in-vivo model of tibial bone bending in mice and calculating strain distributions and fluid flow determined by in-vivo microfinite element analysis. For the second objective, in vivo-micro-CT will provide a measure of local bone adaptation (resorption or apposition) and those results will be correlated using histomorphometry to determine bone remodeling activity. The mechanical loading environment assessed by non-invasive finite element analysis will be linked to bone remodeling activity. The use of in-vivo micro-CT will provide a measure of the local tissue remodeling as a function of the loading protocol duration. The experimental design involving the novel combination of in-vivo high-resolution imaging, finite element modeling, and animal-specific controlled loading models will make it possible to determine if strain gradients and rates are potential control mechanisms of bone adaptation.

NUTRITION, GENETICS AND HUMAN PERFORMANCE

Raylene Reimer

There is widespread recognition that diet plays an important role in the incidence of many diseases including cardiovascular disease, diabetes, obesity, some cancers, osteoporosis and inflammatory conditions. The overall objective of my research is to couple the identification of genes involved in the pathogenesis of diabetes and obesity with nutrition-based strategies to prevent and/or treat these conditions. The specific aims of my current research program include:

Role of intestinal adaptation in obesity. Using the genetically obese JCR:La-corpulent rat model we are examining the role of combination diets high in protein and fiber on intestinal adaptation, gut hormones involved in satiety, hepatic lipid synthesis and body weight regulation.

Regulation of GLP-1 (glucagon-like peptide-1) secretion. GLP-1 is a potent insulin secretagogue with high potential for the treatment of diabetes. We have established a molecular screening facility in which we are able to determine the role of specific nutrients and dietary compounds in triggering GLP-1 release. Using cell lines we can further explore the intracellular signaling pathways involved in GLP-1 secretion. Molecular biology techniques used by our lab include DNA microarrays and Real Time PCR.

Role of diet composition in early dietary programming. It is now increasingly clear that dietary influences exerted early in life have long-term consequences, many of which are pathological. The goal of this work is to undertake basic research on how dietary patterns during growth and development affect physiological responses related to lipid and glucose metabolism in later life.

The long-term goal of our work is to identify novel nutritional therapies to prevent and treat chronic disease.

PHYSIOLOGY/BIOLOGY

Russell T. Hepple

Our research interests continue to involve study of the interaction between oxygen and mitochondrial oxidative capacity in the regulation of aerobic metabolism in skeletal muscle. Recently, we showed that these two factors interact to determine maximal aerobic performance (VO_{2max}) in skeletal muscle. We are currently extending this work to investigate the role of alterations in oxygen delivery, from whole muscle blood flow to its distribution in the microcirculation, in the reduction of muscle aerobic performance with aging. The objectives of this work are to identify specific targets that are responsible for the decline in muscle performance with aging, with the long-term objective of developing approaches to restore and/or prevent this loss in function.

Brian R. MacIntosh

The central theme of research in my laboratory is the study of force modulation in cardiac and skeletal muscle. In particular, prior contractile activity is a strong modifier of a muscle's response. Activity can be an acute modifier, as in potentiation and fatigue, or a chronic modifier as in training and disuse atrophy. In cardiac muscle, the frequency of prior activity can modify the contraction of the heart, as can drug or hormone application. Both cardiac and skeletal muscle contractile responses are modified by regulatory light chain phosphorylation, and my research is concerned with understanding the role of this process in modifying the contractile response. Current projects are addressing the following questions: i) can myosin light chain phosphorylation contribute to enhanced force, work and power in cardiac muscle? ii) does calcium sensitivity change during repeated or altered contractile activity? iii) what factors other than myosin light chain phosphorylation contribute to activity-dependent twitch potentiation and iv) How is the force-velocity property of skeletal muscle modified in fatigue? Work in the exercise physiology lab involves investigation of the lactate minimum test for monitoring progress due to training, and further work on determinants of peak power output during cycling. A new area of study that I am developing is the investigation of mechanisms of fatigue in various medical conditions (cancer, pulmonary disease, aging etc.).

David Smith and Stephen Norris
The focus of the Applied Sport Science group is to understand the effects of training load and the development of training methods to enhance both performance in elite athletes as well as the general population. This year we made significant strides in our measurement technique of cardiac output with the development of custom software for our new mass spectrometer. We have demonstrated a strong correlation between stroke volume and 20 km time trial in cyclists and we are currently examining the effect of shock training microcycles on plasma volume and heart rate changes. In addition, we are now branching out into the area of vibration as we believe that this area could have implications for strength and power development in athletes. We also continued our work in the area of hypoxia and are planning another major study in the new year looking at the time course of adaptation to extended exposure to altitude. Finally we continue to provide support to athletes training at the Canadian Sports Centre – Calgary. At the Winter Olympics in Salt Lake City, the athletes and teams did well achieving medals in women's hockey, speed skating, and cross-country skiing. In the health and wellness area we began a long-term study with colleagues at the Tom Baker Cancer Center (Calgary) examining the effects of physical training on post stem cell transplant patients.

NEURO-MOTOR PSYCHOLOGY AND APPLIED SPORTS PSYCHOLOGY

Joan Vickers
The Neuro-Motor Psychology Laboratory specializes in the following research areas: (a) Cognition, motor behaviour and gaze control in complex motor skills; perception-action coupling. (b) Research in attention deficit hyperactivity disorder (ADHD); eye movement desensitization reprocessing (EMDR) therapy. (c) Decision making and decision-training in coaching and high performance sport.

In the cognition and gaze control program, we analyse the gaze, motor and ocular function of the moving performer using the *vision-in-action* method developed in the laboratory. This system simultaneously records the performer's gaze in space and motor behaviour during the performance of complex motor skills. The goal of the research is to define the role of gaze in optimal motor performance. We carry out research in a wide range of motor skills, specializing in locomotion, targeting skills, and more recently tactical problems in sport.

We also use the system to research problems in special areas such as ADHD and EMDR. In the ADHD program, we used three-dimensional kinematic analysis of line-of-gaze, arm and ball to determine the visual and motor behaviour of adolescents. Our results show that ADHD arm movements were normal in a short-duration condition, but impaired in the long-duration condition, establishing a link between a deficit in processing long duration task information and motor control. The research is being carried forward to a computer based and fMRI imaging studies.

We completed our first study in eye movement desensitization reprocessing therapy (EMDR). The study showed that EMDR is an effective method for helping athletes overcome traumatic events. Athletes significantly reduced their anxiety as a result of the therapy. We also found that those receiving therapy have gaze control characteristics that make have an influence on the conduct and outcome of the therapy.

4 Funding agencies and grants

[Only organizations contributing > than $5,000 are listed]

Engineered Air of Calgary is the major sponsor of the Da Vinci Foundation
- Adidas America
- Adidas International
- Alberta Agricultural Research Institute
- Alberta Children's Hospital Foundation
- Alberta Heritage Foundation for Medical Research (AHFMR)
- Alberta Innovation and Science
- Alberta Sport Science

- Arthritis Society of Canada
- Barley Commission
- Calgary Health Region
- Calgary Olympic Development Association
- CAN National Centre of Excellence
- Canada Foundation for Innovation
- Canada Research Chair Programme
- Canadian Chiropractic Association
- Canadian Chiropractic Protective Association
- Canadian Institutes for Health Research (CIHR)
- Canadian Memorial Chiropractic College
- Canadian Space Life Sciences Concept and Ground Studies
- Canadian Chiropractic Research Foundation
- College of Chiropractors of Alberta
- Da Vinci Foundation
- Defense and Civil Institute of Environmental Medicine
- Department of National Defense
- Dynastream Innovations Inc.
- Fraternal Order of Eagles, Alberta and Saskatchewan
- Geomatics for Informed Decisions (GEOIDE) – Network of Centre of Excellence
- Heart and Stroke Foundation of Canada
- Innovation and Science Infrastructure Program (ISRIP)
- Innovation and Science, Province of Alberta
- International Olympic Committee
- Johnston Sport Architecture
- Korean Research Institute
- Markin-Flanagan Summer Studentship Programme
- Markin-Flanagan Undergraduate Student Research Project in Bone & Joint Health
- McCaig Professorship in Bone & Joint Health
- Motion Analysis Corporation – Santa Rosa
- National Centres of Excellence – Canadian Arthritis Network
- National Coaching Institute – Calgary
- National Sport Centre – Calgary
- Natural Sciences and Engineering Research Council (NSERC)
- Noraxon
- Novel GmbH
- Olympic Oval Endowment Fund
- Pfizer
- Procter and Gamble Corporation
- Seaman's Family Nuclear Imaging Centre
- Social Sciences and Humanities Research Council (SSHRC)
- Sport Court Ltd.
- Sport Science Association of Alberta (SSAA)
- TaylorMade adidas Golf
- University of Calgary
- VX Technologies
- Whitaker Foundation
- Worker's Compensation Board
- Zimmer Corporation

5 Future directions

Much of the future research direction is given by the recently awarded infrastructure grants and the corresponding expansion mentioned above. The Human Performance Lab was primarily built to accommodate human research, be it in biomechanics, exercise and health physiology, nutrition, or neuro motor control. The proposed building expansion will enhance our research capabilities in the areas of molecular and cellular biomechanics and physiology, genetics, experimental animal models of disease such as osteoarthritis, osteoporosis, diabetes, and cardiovascular diseases. Thus, for the future, we plan to integrate our applied and clinical research with fundamental research aimed at elucidating the mechanisms underlying age-related disease processes, and the factors contributing to health, wellness, longevity, and quality of life.