DESCRIPTION DU PROJET DE RECHERCHE

**Problématique:** Playing-related musculoskeletal disorders (PRMDs) are a recognized problem among professional musicians1. Despite pianists adopting various strategies based on their rich experiential knowledge, there still needs to be a generally agreed-upon description of the specific movements considered optimal for minimizing the risk of injuries. Numerical simulation for optimization offers a means to analyze this topic without extensive experiments involving many participants. Researchers at the Laboratoire de simulation et modélisation du mouvement (S2M) 2-4 are developing a research axis focused on pianists' movement, combining theoretical models with empirical data. Utilizing evidence-based strategies is intended to improve pianist performances and close the knowledge gap between musicians and scientific researchers. This interdisciplinary effort promotes practical applications in music practice and performance, addressing musicians' needs and providing creative solutions. By analyzing biomechanical data and presenting conclusions in accessible reports, musicians can immediately apply research findings, enhancing their overall experience in practice and performances.

**Hypothèse(s) et objectif(s):** The main objective of the proposed Ph.D. thesis will be first to simulate pianists’ whole-body gestures and develop playing strategies that reduce the distal joint load using the optimal control theory. Second, this project will allow the comparison of digitally simulated gestural strategies to the results obtained through the experimental research approaches previously used at the S2M laboratory.

The specific objectives (SO) are:

**SO1.** To develop a dynamic digital model of pianists' whole kinematic chain, from the pelvis to the fingertip.

**SO2.** To feed the developed model with data collected in former studies and compare the results of these studies and the optimization strategies proposed by digital simulation.

**SO3.** To establish a data-driven Biofeedback platform to meet the musical community's needs and inquiries completely. The research question emerges from the musical community and is integrated into this hybrid research technique, which combines digital modeling and experimental methodologies. This methodology is part of an ongoing knowledge transfer project lead by Dr. Verdugo, the supervisor of the proposed Ph.D. thesis.

**Approche(s) expérimentale(s)(préciser notamment si ces approches sont maîtrisées dans le laboratoire d’accueil):** A group of expert pianists (N=12) will be enlisted to perform several tasks on the piano. Pianists' kinematics will be recorded with an 18-camera motion capture system. A force plate will be placed on the piano bench to quantify contact forces between the pelvis and the bench. The upper body's muscle activities will be recorded with surface electromyography (Delsys TrignoTM Wireless system composed of 16 electrodes). Participants’ performances will be audio recorded. A grand piano equipped with sensors to capture key and hammer kinematics (Bösendorfer CEUS, Yamaha Disklavier C7) will allow the acquisition and quantification of different musical parameters.

**SO1:** The Bioptim Python framework will be used to create the dynamic model of the pianist using an Euler-Lagrange equation. The model will include segments from the pelvis to the fingertips, and upper-limb muscles and joint torques may be inserted to explore biomechanical aspects better.

**SO2:** Data collected from former studies performed at the S2M lab will be used to feed digital simulations and optimization. Joint torques during piano keystrokes will be characterized and used as constraints, focusing on minimizing parameters like eccentric joint torques and mechanical work and the integral of joint displacements. The extracted simulated solutions will be compared to the actual pianists’ gestures.

**SO3:** A questionnaire will be distributed to a large pianistic community (U. of Montreal, McGill U., Ottawa U., and 5 conservatories around Quebec), and several important research questions will be extracted. A Ph.D. project will select one question and employ digital simulation and experimental methods. Kinematics will be captured using motion capture systems, contact forces measured with a force plate, and muscle activity recorded using surface electromyography. Data will be processed and analyzed using MATLAB or Python, with digital simulations based on the approach described in SO2. The experimental tasks and the statistical analysis will be defined according to the selected research question.

**Résultats prévus / impacts cliniques potentiels:** This research aims to improve pianists' performance and reduce the risk of injuries, such as PRMDs and muscle fatigue. It will develop innovative movement strategies using optimal control theory and offer pianists a biomechanical description to investigate new methods. The understanding of pianists' biomechanics and injury prevention will be improved by comparing digital simulation and experimental data. Knowledge transfer activities between musical and scientific communities will ensure widespread dissemination of the findings. The research will benefit healthcare professionals treating and preventing musicians' injuries and generate valuable knowledge for musicians in their professional activities by addressing research questions from the musical community.

**Keywords:**

Biomechanics; Applied Kinesiology; Whole-body movement, Optimization, Injury prevention

**References:**

1. Verdugo et al. (2020). Frontiers in Psychology 11, 1159.
2. Goubault et al. (2021). Scientific Reports. 11, 8117.

ANNEXE 1 – LETTRE DE MOTIVATION

My background in biomechanics, particularly neuro-musculoskeletal modeling, and my co-supervisors' combined expertise in biomechanics, piano performance, injury prevention, performance optimization, and empirical musicology make our research group ideal for uniting musical and scientific communities on a global scale. The S2M laboratory provides state-of-the-art data-collection equipment, including surface EMG, a Vicon 3D motion capture system, force plates, pressure sensors, and a grand piano with key and hammer kinematics. The lab has made significant progress in studying pianist movements and muscle fatigue, publishing over 40 papers in three years. Powerfulopen-source librairies developed by S2M students like Bioptim and Biorbd benefit those working in biomechanics and optimization fields. Using infrastructure and Bioptim, the S2M lab offers features that enhance research applications: 1) Effective optimization techniques, including parameter identification, motion prediction, and optimal control; 2) User-friendly interface; and 3) Customizability for accurate results. Being part of the diverse academic backgrounds represented in the S2M lab, I will have the opportunity to collaborate with other researchers and developers, sharing ideas and problem-solving. My research at the S2M laboratory, where information and skills are shared, will allow me to develop my knowledge and experience in Biomechanics and motor control of human movement, Experimental research design and methods, Data analysis and statistical modeling, Simulation modeling and software tools, Interdisciplinary collaboration, and communication skills, as well as programming/scripting languages. My research will reveal better ways for pianists to use their whole bodies for improved performance, leading to optimized piano techniques and advanced training methods. Additionally, Prof. Verdugo's dual expertise as a professional pianist and researcher promotes knowledge sharing across the two disciplines. It also enables the project to engage with a considerable population of skilled piano performers.

La pertinence des expériences pratiques antérieures (laboratoire, clinique, stage, etc.) dans le cadre du projet de formation en recherche envisagé.

Based on my strong interest in interdisciplinary engineering, extensive background in neuro-musculoskeletal modeling (NMM) research, and active engagement in multidisciplinary projects, I believe that I am highly suited for this Ph.D. thesis. Exploring different realms of engineering has instilled an investigative mindset, a passion for the scientific process, and an appreciation for the results of multidisciplinary projects, which were useful in medicine. My interest in NMM was inspired during my undergraduate studies when I worked on a project focused on developing a new mathematical model for passive dynamic walkers. I studied Biomedical Engineering for my Master's degree at Amirkabir U.of Tech., ranked 1st in Biomedical in Iran, where I placed third in the program with a GPA of 18.11/20. In my Master's thesis, I examined how to tailor hippotherapy sessions to each patient to get an ideal combination of the horse and exercises. This approach involved studying how different physical activities impacted the patient's dynamic stability and core muscle activity during hippotherapy. The study's findings were published in the International Journal of Engineering (Transactions B.), and two papers were presented at the conference of the (, Canadian Society for Biomechanics (Halifax 2018), allowing therapists to predict the benefits of exercise before hippotherapy sessions. In my M.Sc. thesis, I also did an experimental phase in direct interface with patients, which provided me with excellent experience dealing with participants in laboratories and analyzing human NMM. I also was a teaching assistant for Continuum Mechanics, Engineering Statics, and Biomechatronics, both on undergrad. and grad. levels for three consecutive years. Moreover, I co-wrote a book on Biomechatronics Systems utilizing the Bond Graph Methodology, which was published in October 2021 (Authors: A. R. Arshi and M. A. Shahiri, Language: Persian), in addition to my academic pursuits. My understanding of modeling concepts and approaches has improved as a result of this project. During 2021-22, I worked as a research associate in a study that included adjusting the biomechanical conditions to enable the eye's self-adjustment mechanism for image reflection on the retina at the Wroclaw University of Science and Technology (Poland) (Outcome: one article published in Biomedical Optic Express, one conference paper forVisual & Physiological Optics [2022], and one submitted manuscript). In addition, I have done two product-oriented projects at Iran's National Elites Foundation to design and manufacture an underwater scooter and a hybrid bicycle, which boosted my teamwork and real-life problem-solving skills. Pursuing a Ph.D. thesis in exercise sciences will benefit my personal development because it will enhance the quality of life of individuals with playing-related musculoskeletal disorders (PRMDs). The great opportunity to research while pursuing a Ph.D. in biomedical engineering enables me to deepen my understanding in my area of interest, push the boundaries of science a little bit, and continue to learn more about the unknowable as well. These are my greatest ambitions and expectations, which might be realized through this program by incorporating the interdisciplinary research team on musicians' injuries and producing recommendations for clinical applications of research on musicians' health.

Expliquer comment cette bourse s’inscrit dans le montage financier que vous proposez à l’étudiant pour l’année 2023-2024

Mohammad's research project at the S2M lab aims to optimize pianist movements. By combining experimental and numerical simulation approaches, the project seeks to provide valuable recommendations for the clinical application of research findings, specifically related to musicians' health and injury prevention. Mohammad's work is framed by a series of ongoing interdisciplinary research projects on piano performance that I lead at the S2M lab. He will receive a scholarship of at least 18,000$/year (for three years) from the research funds (2022-2025 SSHRC Partnership Development Grant). However, according to the most recent data from Citizenship and Immigration Canada, this amount is lower than the required annual fund, bringing financial concerns for Mohammad. He fulfilled the qualifications for the EKSAP scholarship program but was unable to join the Ph.D. program and take advantage of the opportunity due to delays in obtaining his visa. Receiving a Merit Scholarship from the Faculty of Medicine will able him to devote his full attention to his studies (leading to better grades and knowledge) and research activities (project development, written/oral communication of results, and involvement in S2M lab activities, among others) without any financial concerns. The scholarship would also enable him to improve his French language skills and enhance his communication and integration skills both personally and academically. Mohammad graduated from the Amirkabir University of Technology, one of Iran's most prestigious institutions, with a GPA of 3.91/4, giving the supervisors’ confidence in his remarkable expertise in biomedical engineering. Among students studying biomedical science, Shahiri placed third rank. Mohammad's outstanding success in relevant graduate courses, such as Occupational Biomechanics and Modeling of Biological Systems, where he obtained full marks, is one of his academic accomplishments. He has also developed strong programming skills necessary for achieving his academic objectives. Mohammad is a Ph.D. candidate with a strong record of research success. He has already written two articles, a book with another author, and another submitted essay. He has also attended three international conferences. These accomplishments demonstrate his dedication to the topic and willingness to learn more. Mohammad would be a valuable addition to the multidisciplinary team's projects, according to the team's researchers in musicology, kinesiology, and performance, who also strongly support Shahiri's application for a Merit Scholarship from the Faculty of Medicine.

Best regards, Felipe Verdugo (Associate Professor) and Mickaël Begon (Full Professor).

Lien du projet du candidat avec la programmation de recherche du directeur.

Dr Verdugo has recently focused on two research projects: 1) examining pianists' motor strategies and muscle fatigue and 2) developing the MappEMG system that provides haptic feedback based on musicians' muscular effort during the performance. In addition to examining playing techniques to reduce the risk of injuries and improve musical performance, these interdisciplinary research projects intended to develop new opportunities for musical interaction and biofeedback technologies inspired by players' gestures. The proposed multidisciplinary research project will establish a biomechanical foundation for new research directions in the knowledge translation procedure. Studying pianists' movements is a common theme among the efforts in these categories. Some aim to improve overall performance, while some focus on preventing injuries. The project will rely on the Bioptim library (the most advanced open-source library for optimal control in biomechanics which is developed by Begon’s group), which facilitates the exchange and flow of knowledge by combining experimental and simulation methodologies in this intra/interdisciplinary project. Advanced capabilities of Bioptim, such as algorithmic differentiation and multiple shooting formulation, as well as a variety of muscle models, make it possible to explore various ranges of biomechanical problems such as muscle-driven simulations, motion prediction, parameter optimization, multiphase problems, and more. Mohammad will be under collaborative supervision with Professor M. Begon, who oversees the optimal control group at the S2M lab. The digital simulations for pianists that Mohammad had in mind for his idea can only be possible with the assistance of this collaboration. Under Begon's supervision, Mohammad will have access to valuable knowledge that will enhance his research into pianists' optimal control.