DESCRIPTION DU PROJET DE RECHERCHE

**Problématique:**

There is still no generally agreed-upon description of the specific movements that are considered ideal for minimizing the risk of injuries, despite pianists adopting various strategies based on their significant knowledge. Numerical simulation for optimization, which removes the need for performing extensive experiments involving a large number of participants, allows for the analysis of this topic. A research axis focused on pianists' motions is being developed by researchers at the Laboratoire de simulation et modélisation du mouvement (S2M) 1-3 to investigate this. This research axis utilizes an interdisciplinary approach to combine theoretical models with empirical data from musicians' movements to provide an evidence-based platform to optimize pianist performances. These research efforts aim to create a stronger bond between musicians and scientific knowledge, leading to more practical applications of research in music practice and performance. Additionally, researchers can also create study topics that are more pertinent to the needs of musicians and develop creative solutions to the problems they face. To do this, they examine and analyze biomechanical data, then provide their conclusions in reports that are simple to read and comprehend for musicians. This enhances their overall experience by enabling musicians to immediately apply the learnings from the research to their own 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 study allows the comparison of digitally simulated gestural strategy to the results obtained through the experimental research approaches previously used at the S2M laboratory. The specific objectives (SO) are the following:

**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.** By incorporating the proposed doctoral research into a broader collaborative initiative aimed at establishing a data-driven Biofeedback platform for addressing the needs and inquiries of the musical community in a comprehensive manner. It will emerge from the musical community in the context of an ongoing knowledge transfer project lead by Dr. Verdugo (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 a Vicon motion capture system composed of 18 cameras. A force plate will be placed under the piano bench to quantify contact forces between the bench and the floor. 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. Data will be processed and analyzed in MATLAB and Python. The data collected will be used as (sub) optimal solutions that will feed digital simulations and the optimization process. The dynamic model of the pianist (from the pelvis to the fingertip) will be implemented in the form of an Euler- Lagrange equation under the Bioptim Python framework for musculoskeletal optimal control developed at the S2M lab. We will focus on minimizing several parameters of distal joints, such as eccentric joint torques and mechanical work. The results obtained from this optimization process will be compared to the initial ones collected from actual pianists' gestures.

**Résultats prévus / impacts cliniques potentiels:**

This research will help pianists in developing innovative movement strategies that can enhance/optimize their performance and reduce the risks of developing injuries, such as PRMDs and muscle fatigue3-4. Particularly, developing a biomechanical description based on optimal control theory will facilitate pianists' investigation of new untouched and unexplored strategies. Comparing digital simulation and experimental results will allow a deeper understanding of available research on pianists’ biomechanics and injury prevention strategies. Integrating the proposed Ph.D. thesis in a more extensive partnership project on knowledge transfer activities between musical and scientific communities will generate extensive dissemination of the results. The impact of this project extends to the clinical field, providing valuable research-based knowledge for healthcare professionals involved in musicians' injury treatment and prevention. Last but not least, addressing research questions raised by the musical community will guarantee the production of knowledge that could be highly beneficial for musicians' professional activities.

**Keywords:**

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

**References:**

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2. Verdugo et al. (2021). Journal of Motor Behavior. 1-11.
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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 worldwide. 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. Powerful tools like the Bioptim library and Biorbd benefit those working in biomechanics and optimization fields. Using IT infrastructure and Bioptim Tech, 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 together. 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 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 not only promotes knowledge sharing across the two disciplines but 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.

My passion for interdisciplinary engineering, prior research in neuro-musculoskeletal modeling (NMM), and participation in multidisciplinary projects all contributed to the structure of my proposed 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 that was 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 rank in the program with a GPA of 18.11/20. In my Master's thesis, I examined how to tailor hippotherapy sessions (HTS) to each patient in order to get the most 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 a journal (International Journal of Engineering, Transactions B.), and two papers were presented at conferences (CSB, Canadian Society for Biomechanics, Halifax 2018), allowing therapists to evaluate 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 individual subjects 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 researcher in a study that includes 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 published journal paper [Biomedical Optic Express], one conference paper [VPO, Visual & 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. It will benefit my own personal development to pursue a Ph.D. thesis in rehabilitation solutions/kinesiology because it will enhance the quality of life of individuals with playing-related musculoskeletal disorders (PRMDs). The great opportunity to do 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 is conducting a research project at the S2M lab that aims to optimize pianist movements by combining experimental and numerical simulation approaches. 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 18,000$/year (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. The directors are confident in Mohammad's exceptional biomedical engineering background, as he graduated from the Amirkabir U. of Tech., one of Iran's most prestigious institutions, with an impressive GPA of 3.91/4. Shahiri ranked third among biomedical students. Among Mohammad's academic accomplishments is his top-notch performance in pertinent graduate courses, including Occupational Biomechanics and Modeling of Biological Systems, where he received perfect scores. Additionally, he has acquired strong programming skills essential for completing his study goals. Mohammad is a Ph.D. candidate with notable research achievements. As he has already published two articles, co-authored a book, and submitted another essay. Additionally, he has engaged in three international conferences. These successes highlight his commitment to the subject and his ability to further his knowledge. The multidisciplinary team, which includes expert researchers in musicology, kinesiology, and performance, believes Mohammad would be a crucial addition to their research projects and strongly recommend Shahiri's application for a Merit Scholarship from the Faculty of Medicine.

We are at your complete disposal if you need additional information and would be happy to assist you.

Best regards, Felipe Verdugo, Associate Professor and Mickaël Begon, Full Professor

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

The research journey began with a focus on two research projects: examining pianists' motor strategies and muscle fatigue, as well as the development of 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 make use of Bioptim technology, 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 a range 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 optimum 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 guidance, Mohammad will have access to valuable knowledge that will enhance his research into pianists' optimal control.