DESCRIPTION DU PROJET DE RECHERCHE

**Problématique:**

Although pianists develop various techniques based on their rich experiential knowledge, a widely agreed-upon description of the specific movements favored to reduce the risk of exposure to factors that may cause injury has yet to be established. The investigation of this problem is made possible by the use of numerical simulation for optimization, which eliminates the necessity of conducting extensive experiments involving a large number of participants. The main objective of the research axis on pianists' gestures (i.e., movement strategies), developed at the Laboratoire de simulation et modélisation du movement (S2M), is transferring knowledge between musical and scientific communities1-3. Based on an interdisciplinary approach, this research axis combines empirical data from musicians' movements with theoretical models to develop evidence-based recommendations/platform for optimizing music practice and performance. These research initiatives significantly enhance the practical application of research outcomes in the realm of music practice and performance by establishing a closer relationship between musicians and scientific knowledge. Moreover, by analyzing and interpreting Biomechanical datasets into digestible reports for musicians, researchers can formulate research inquiries that are better aligned with the requirements of musicians and develop innovative solutions to the challenges faced by musicians.

**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 project will impact the clinical field, as it will contribute to the development of research-based valuable knowledge for healthcare practitioners who work in the domain of musicians’ injury treatment and prevention. Finally, selecting a research question extracted from the musical community will ensure the production of knowledge that could be of high value for musicians’ professional activities.

**Keywords:**

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

**References:**

1. Verdugo et al. (2020). Frontiers in Psychology 11, 1159.
2. Verdugo et al. (2021). Journal of Motor Behavior. 1-11.
3. Goubault et al. (2021). Scientific Reports. 11, 8117.
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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 us an ideal research group in bridging the gap between the musical and scientific communities on a global scale. The high injury rates among pianists and other music performers may be attributed to the lack of scientific evidence-based performance approaches. S2M laboratory has achieved notable advancement in portraying whole-body movements and distal muscle fatigue in pianists. The S2M laboratory, which includes students and supervisors from diverse academic backgrounds (), has demonstrated an impressive research output of more than 40 papers in the past three years. The laboratory offers advanced biomechanical data-collecting equipment, such as surface electromyography (EMG), a Vicon 3D motion capture system, as well as force plates and pressure sensors. Moreover, a grand piano is installed with capturing key and hammer kinematics. My research at the S2M laboratory 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. It would also bring insights into the most effective ways for pianists to use their whole bodies to improve their performance, potentially leading to innovations in piano technique and training methods. Additionally, I am fortunate to have a supervisor, Felipe Verdugo, who is both a researcher and a professional pianist. His unique expertise and academic degree in music and science facilitate the transfer of knowledge between research and music and grant the project the opportunity to interact with a considerable population of skilled piano performers. Additionally,

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

The proposed research framework for my Ph.D. thesis originates from my interdisciplinary attitude toward engineering, personal experiences in multidisciplinary projects, and previous research on neuro-musculoskeletal modeling (NMM) in grad. /Undergrad. education. 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 B.Sc. project involved developing a new mathematical model for passive dynamic walkers. This project included the insight of mathematical modeling of the passive biped robot and motor control that interested me in NMM. I did my M.Sc. degree at the Amirkabir U. of Tech., ranked 1st in Biomedical in Iran (GPA: 18.11/20). My M.Sc. thesis individualized the Hippotherapy sessions (HTS) as a treatment modality to choose the most suitable combination of horse and exercises for each patient. This NMM approach addressed how alternative physical activities, such as reaching or throwing exercises, affect the patient's dynamic stability or core muscle activity during HTS. This research provided therapists with a tool to assess the effects of exercises before the HTS, resulting in one journal paper (International Journal of Engineering, Transactions B.) and two conference papers (CSB, Canadian Society for Biomechanics, Halifax 2018). 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 have co-written a book published in Oct. 2021 ("Biomechatronics Systems, Bond Graph Methodology, Authors: A. R. Arshi and M. A. Shahiri, Language: Persian), which enhanced my knowledge of the modeling principles and approaches. During 2021-22, I worked as a researcher in a study on the Opto-biomechanical self-adjustment model of the human eye 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). This study found the optimal combination of biomechanical circumstances (an optimization problem) to satisfy the self-adjustment hypothesis, which compensates for the variation to reflect the image on the retina. 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 proposed Ph.D. thesis in rehabilitation solutions/kinesiology will contribute to my personal development and enhance the life quality of individuals with playing-related musculoskeletal disorders (PRMDs). The great opportunity of researching as a Ph.D. student in biomedical engineering helps me extend my knowledge in my field of interest, strive to know the unknown, and extend the borders of science only a little bit. These are my greatest desires and expectations, which could be satisfied through this program in developing recommendations for clinical applications of research on musicians' health by integrating the interdisciplinary research team on musicians' injuries.

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 an integrated funding package less than the required annual fund based on the latest updated information in CIC (Citizenship and Immigration Canada), bringing him financial concerns about not coping with expenses. However, if he receives a Merit Scholarship from the Faculty of Medicine, he will be able 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.

In conclusion, the research directors strongly recommend Shahiri's application for a Merit Scholarship from the Faculty of Medicine. Mohammad has demonstrated excellent organizational skills, responsibility, and interest in the academic and research environment at the University of Montreal. The directors are confident that Mohammad's outstanding background in biomedical engineering will be an excellent addition to our interdisciplinary team (kinesiology, musicology, music performance) working on optimizing pianists' playing strategies.

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

Best regards,

Felipe Verdugo, Associate Professor

Mickaël Begon, Full Professor

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

Professor Verdogu's research journey commenced by concentrating on two research undertakings: the MappEMG system, which exhibits haptic stimuli depending on musicians' muscular exertion while performing, and extensive analysis of pianists' proximal motor tactics and distal muscle exhaustion. The interdisciplinary research aimed to achieve two primary objectives. First, to devise innovative music interaction opportunities and biofeedback tools influenced by musicians' gestures. Second, to investigate expert playing techniques aimed at minimizing the risk of injuries while promoting high levels of music performance. This research has practical applications in various music performance subjects, including expression, embodied interaction, physical health, sound control, and music teaching and learning. Various factors, such as incorrect posture, poor practice habits, and muscle fatigue, can lead to injuries. Piano teachers can assist students in developing appropriate techniques, posture, and practice habits, while medical practitioners can provide diagnoses and treatment plans for any injuries that may occur. Ergonomics experts can assist in designing and evaluating piano equipment and accessories to ensure their safety, comfort, and practicality. In order to promote safe and effective piano playing, a collaboration between musicians, educators, medical professionals, and ergonomics experts is required for injury prevention and understanding of piano-playing biomechanics. The proposed research project will offer a platform for new research directions in the knowledge translation process. The integration of Experimental and Simulation Research Approaches, facilitated by Bioptim technology, can materialize knowledge flow and exchange in this intra/interdisciplinary initiative. Bioptim uses algorithmic differentiation and multiple shooting formulation to enable the definition of several biomechanical problems, including muscle-driven simulations, motion tracking/prediction, parameters optimization, multiphase problems, and more.