**Page 3\_ DESCRIPTION DU PROJET DE RECHERCHE (Limiter la description à l’espace alloué.)**

**Titre.** Optimization of pianists' whole-body gestures through the integration of experimental and simulation research approaches

**Problématique**

A significant proportion of professional pianists (from 40% to 90%) suffer from PRMDs during their careers1. PRMDs usually affect the pianist’s upper body, especially the back, neck, and upper limbs. Not only do PRMDs adversely influence musicians’ physical health, but they also affect their economic situation. Indeed, PRMDs might lead to the cessation or reduction of musicians’ professional activities, while an average Canadian musician earns 18,000$ annually2. Prominent risk factors include long hours of practice and the production of repetitive movements, which result in muscular fatigue3. The different pianistic approaches developed by performing musicians constitute a rich experiential knowledge that does not offer a consensual description of the movements favored to reduce the risk of PRMDs. 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 to produce objective knowledge helping pianists optimize technique by using the whole body and reduce the risks of developing PRMDs3-5. Based on an interdisciplinary approach, this research axis combines tools, methods, and experts from biomechanics, music performance, musicology, acoustics, and music technology.

A considerable portion of professional pianists (ranging from 40% to 90%) experience PRMDs at some point in their careers. Typically, these injuries affect the upper body, especially the neck, back, and upper limbs, and not only have negative consequences on the musician's physical health, but also on their economic status. PRMDs can lead to reduced or halted professional activities, which is particularly impactful considering that the average Canadian musician earns $18,000 annually. The production of repetitive movements during long hours of practice can result in muscular fatigue and is a significant risk factor for developing PRMDs. Although performing musicians have developed various pianistic approaches, there is no consensus on the movements that reduce the risk of PRMDs. The research axis on pianists' gestures at the Laboratoire de simulation et modélisation du mouvement (S2M) aims to provide objective knowledge to help pianists optimize their technique by using their whole body and reduce the risks of developing PRMDs. This interdisciplinary research combines the expertise of biomechanics, music performance, musicology, acoustics, and music technology.

**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.** To apply a mixed research approach integrating digital simulation and experimental methods to a research question that 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 recruited 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 develop innovative movement strategies that might help pianists optimize performance and reduce the risks of developing PRMDs. Particularly, developing a simulation approach based on optimal control theory will facilitate the investigation of new strategies that might remain unexplored by pianists. 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.

**Références bibliographiques (maximum 5)**

1. Kaur, J. & Singh, S. (2016). Int. J. of Therapies and Rehabilitation Research 5, 14.

2. Hill Strategies Research Inc. (2019). A statistical profile of artists in Canada in 2016.

3. Goubault, E., et al. (2021). Scientific Reports, 11, 8117.

4. Verdugo et al. (2020). Frontiers in Psychology 11, 1159.

5. Verdugo et al. (2021). Journal of Motor Behavior. 1-11.

**Page 4\_ ANNEXE 1 – LETTRE DE MOTIVATION  
Les raisons justifiant le choix du laboratoire au sein de la Faculté de médecine de l’Université de Montréal**

Few researchers at the international level address pianist injury prevention and treatment strategies. The lack of performance approaches grounded on scientific evidence might contribute to the high rates of PRMDs among pianists and music performers in general. An interdisciplinary research effort between pianists, biomechanists, and healthcare practitioners is required to ensure that research meaningfully addresses these problems. This interdisciplinary approach is at the center of the research collaboration between my two co-supervisors, Felipe Verdugo and Mickael Begon, as their joint expertise covers the fields of biomechanics, piano performance, injury prevention, performance optimization, and empirical musicology, among others. This interdisciplinary collaboration hosted by the S2M laboratory has advanced knowledge concerning pianists' whole-body movements and distal muscle fatigue, two central areas of my research project. My supervisors' combined expertise, unique in Canada, will be a crucial asset in attaining my research objectives. As several research projects related to musicians' health are currently in progress at the S2M laboratory, I will benefit from a dynamic and rich research environment in my field of interest. The S2M laboratory has an impressive research output (More than 40 papers in the last three years). The laboratory is composed of national and international students from different cultural and academic backgrounds (such as kinesiology, biomedical engineering, and music), which promotes a diversity of research projects funded by Canadian and Quebecois research councils.

Furthermore, lab activities involve weekly group meetings, a journal club, and monthly meetings with statisticians. Clearly, not only does the research focus of the S2M laboratory fit my research interests, but it also has many resources to support my academic development throughout my doctoral studies. The S2M laboratory also offers access to the necessary high-level data collection infrastructure. The technology includes surface electromyography (EMG) (Delsys Trigno TM Wireless system; high-density TMSi system, Oldenzaal, Holland), a Vicon optoelectronic 3D motion capture system composed of 18 cameras, an XSens full-body system of 17 inertial measurement units, and various force plates and pressure sensors. The S2M laboratory also possesses a grand piano (Bösendorfer CEUS, lent by the International Laboratory for Brain, Music, and Sound Research) equipped with sensors to capture key and hammer kinematics. Capturing data on a grand piano ensures ecological validity, as digital pianos (generally used by researchers in the field) require significantly less force to depress a key and produce electronic sound, which might be confounding variables that alter pianists' motor behaviors. Through research at the S2M laboratory, I will be able to enhance my knowledge and experience in signal acquisition and processing methods of kinematic, kinetic, and muscle activity data, as well as in programming/scripting languages such as MATLAB and Python. As the laboratory is located in the Greater Montreal area, I would have access to a large population of expert pianists, as shown by a recent study conducted by my supervisors where 50 pianists took part in the experiment (an unprecedented population size in this field). Finally, the supervision of F. Verdugo, who is not only a researcher but also a professional pianist holding a doctoral degree in piano performance, will help ensure a knowledge transfer between the research and musical domains.

**Page 4\_ La pertinence des expériences pratiques antérieures (laboratoire, clinique, stage, etc.) dans le cadre du projet deformation 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/insight on neuro-musculoskeletal modeling in graduate /undergraduate education. Committing myself to the world of scientific research and 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. During the undergraduate program, I have tried to explore different realms of mechanical engineering. In the B.Sc. project, I focused on passive dynamic walker concepts to develop a new mathematical model of passive dynamic walking. This project included the insight of mathematical modeling of the passive biped robot and motor control that interested me in neuro-musculoskeletal modeling. To achieve more in-depth knowledge in BME, I decided to pursue higher education. I did my M.Sc. degree at the Amirkabir University of Technology, ranked 1st in Biomedical in Iran (GPA: 18.11/20). In the M.Sc. course, I preserved the interdisciplinary attitude of the BME toward my projects. I designed the thesis with an appreciation for medical disorders and the perspective of a biomechanical engineer. 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 Neuro-musculoskeletal modeling approach addressed how alternative physical activities, such as sitting position, 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 neuro-musculoskeletal modeling. I also was a teaching assistant for Continuum Mechanics, Engineering Statics, and Biomechatronics, both on undergraduate and graduate levels, for three consecutive years. This task required vast knowledge of Biomedical Engineering, deep enough to teach the students and convey this information to the learning minds. Moreover, I have co-written a book published in Oct. 2021 ("Biomechatronics Systems, Volume one: 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 the second manuscript is under preparation). This study found the most proper and demanded combination of biomechanical circumstances 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. I am a hard-working student aiming to constantly generate innovative research and achieve my academic goals in the best possible. Therefore, based on my background knowledge, implementing the proposed Ph.D. thesis in rehabilitation solutions/kinesiology will lead to my personal development and, more importantly, improve 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. This is my greatest desire and expectation, 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.

**Page 6\_ANNEXE 3 – ARTICLES PUBLIÉS/SOUMIS, ABRÉGÉS, CONFÉRENCES, RÉSUMÉS DE PRÉSENTATIONS ORALES ET PAR AFFICHE \*Ne pas inclure les articles, conférences et résumés en préparation.**

**PUBLICATIONS  
Articles à titre de 1 er auteur dans une revue avec comités de pairs (publiés, acceptés ou sous presse) Autres articles revus par des pairs et publiés, acceptés pour publication/sous presse/soumis, chapitres de livres et ouvrages collectifs, autres documents (précisez au besoin)**

• SHAHIRI, M. A., et al. "Opto-mechanical self-adjustment model of the human eye." Biomedical Optics Express 14, no. 5 (2023): 1923-1944.

• SHAHIRI, M. A., et al. "Kinesiological Description of Hippotherapy as a Treatment Modality." International Journal of Engineering33.11 (2020): 2347-2355.

**BOOKS:**

•Arshi A.R., SHAHIRI M. A. “Design and Modeling of Biomechatronic Systems " (2021): Volume one, in Persian.

**CONFÉRENCES  
Au sein de l’établissement d’accueil, envergure régionale, provinciale, nationale ou internationale**

•SHAHIRI, M. A., et al. "A Finite element modeling Approach for Investigating Opto-Mechanical correlations in the Human Eye." The 10th VPO Conference (2022), UK, Cambridge (Podium).

•SHAHIRI, M. A., et al. "Principles of Event Detection in Biomechanical Interactions during Hippotherapy" The 20th CSB Conference (2018), Canada, Halifax (Poster).

•SHAHIRI, M. A., et al. "Mathematical Modeling of Horse-Rider kinesiological Interaction in Hippotherapy" The 20th CSB Conference (2018), Canada, Halifax (Poster).

**RÉSUMÉS DE PRÉSENTATIONS SCIENTIFIQUES ORALES ET PAR AFFICHE  
Au sein de l’établissement d’accueil, envergure régionale, provinciale, nationale ou internationale**

**VPO Abstract:** The eye has specific optical and biomechanical properties that jointly regulate the eye's quality of vision, shape, and elasticity. These two characteristics are interdependent and correlated. Contrary to most currently available computational models of the human eye that only focus on biomechanical or optical aspects, the study explored the inter-relationships between biomechanics, structure, and optical properties. Possible combinations of mechanical properties, boundary conditions, and biometrics were specified to ensure the opto-mechanical (OM) integrity to compensate for physiological changes in intraocular pressure (IOP) without compromising image acuity. The study evaluated the quality of the vision by analyzing the minimum spot diameters formed on the retina and drew how the self-adjustment mechanism affects the eye globe shape by adopting a finite element (FE) model of the eyeball.

**CSB Conference:** Hippotherapy as a treatment modality relies on patient-equine dynamic interaction to enhance physical abilities in a range of neuromuscular diseases. The modality takes advantage of external stimulations in the form of kinetic and kinematic inputs to the patient’s upper body. An objective approach to session planning based on a predictive neuromuscular model could greatly enhance current practices and procedures. Individualization of the treatment program is both subject-specific and equine-specific. To this effect, the kinesiological aspects of the three main upper body flexor-extensor muscles are directly affected by this treatment modality presented in a biomechanical model. The study adopted a combination of inverse and forward dynamic approaches toward musculoskeletal modeling to determine kinematic parameters as well as muscular forces to provide the therapist with a tool to evaluate the effects prior to therapy sessions and choose the most suitable combination of horse and exercises. The validation process was performed by using a combination of inertial measurement units (IMU) and EMG sensors.

**Research Experience:**

•Researcher, Wroclaw University of Science and Technology, (Poland, 2021-2022)   
•Scientific Advisor, TAPESH Journal of Biomedical Engineering, Amirkabir University of Technology (Iran, 2018).

**Teaching experience:**

• Lecturer, Buein Zahra Technical University, Rehabilitation Engineering, Undergraduate 2022.

Teaching Assistant at the Amirkabir University of Technology, Department of Biomedical Engineering:

•Continuum Mechanics (Graduate) – 2017 & 2018

•Biomechatronics (Undergraduate)– 2016

•Engineering Statics (Undergraduate) – 2016 & 2017

•Fundamental of Biomechanics (Undergraduate) – 2018

**Page 7\_ANNEXE 4 – BOURSES OBTENUES**

•Aug. 2019- Iran’s National Elites Foundation- National Funds for R & D, Design  
and Manufacturing of an Underwater Scooter- 3000 $

•Sep. 2018- The Amirkabir University of Technology, Department of Biomedical Engineering- Tuition Fee Waiver Scholarship (M.Sc. Program)- 8000 $

•Dec. 2015- The presidential deputy for science and Technology, IRAN- National Funds for R & D, Design and Manufacturing of a Hybrid Bicycle- 1500 $

•Sep. 2011- The Babol Noshirvani University of Technology, Department of Mechanical Engineering Tuition Fee Waiver Scholarship (B.Sc. Program)- 4000 $

**Page 8\_ANNEXE 5 – PRIX ET DISTINCTIONS**

•Aug. 2018- The Amirkabir University of Technology, Department of Biomedical Engineering-Talented Student, Ranked 3rd out of 21 students of biomechanical science.

• 2018- Iran’s National Elites Foundation- Design and Manufacturing of an Underwater Scooter

• 2015- Presidential Deputy for Science and Technology (3rd place)- Design and Manufacturing of a hybrid bicycle

**Page 9\_ANNEXE 6 – LETTRE DE RECOMMANDATION DU DIRECTEUR DE RECHERCHE**

Chers membres du comité d'évaluation,

C'est avec enthousiasme que nous appuyons la candidature de M. Mohammadali Shahiri pour une bourse de Mérite de la Faculté de médecine. Son projet de recherche portera sur l’intégration d’approches de recherche expérimentale et par simulation numérique pour l’optimisation des mouvements des pianistes. Mohammad's work will be framed by a series of ongoing interdisciplinary research projects on piano performance that I lead at the S2M lab. Mohammad has an excellent background in biomedical engineering. He graduated from one of the  
most prestigious universities in Iran (M.Sc, Amirkabir U. of Tech.) with a GPA of 3.91/4 and ranked 3rd among M.Sc. biomedical students. He obtained remarkable results (full mark) in graduate courses related to his Ph.D. project (e.g. Modeling of Biological Systems, Occupational Biomechanics) and developed programming skills that will be essential to reach his research goals. Mohammad has an excellent research record for a recently recruited Ph.D. student (Two published articles, one submitted article, one co-written book, and three international conferences). Mohammad’s outstanding background in biomedical engineering will be an excellent addition to our interdisciplinary team (kinesiology, musicology, music performance) working on the optimization of pianists’ playing strategies.

La réalisation du projet de Shahiri à la Faculté de médecine (ÉKSAP) lui permettra de bénéficier du caractère innovant et diversifié de l’environnement de recherche de la faculté. Axé sur la santé des musiciens, son doctorat réalisé au sein de la Faculté de médecine facilitera également un transfert de connaissances entre les milieux clinique et de recherche, contribuant à la dissémination des résultats qui découleront du projet de Shahiri ainsi qu’au développement de sa carrière sur les plans académique et du réseautage professionnel. Au Laboratoire de Simulation et Modélisation du Mouvement (S2M), nous menons divers projets de recherche sur les TMS en milieu de travail, en y incluant le milieu musical (piano et violon). Le travail réalisé au sein de notre laboratoire est diversifié et innovant de par la pluralité des sujets et approches de recherche qui coexistent, de la diversité des étudiants et de leurs expertises, et de l’interdisciplinarité de nos projets. Nos travaux sur la santé de musiciens sont ainsi basés autant sur des approches expérimentales que de simulation numérique et bénéficient d’une collaboration fructueuse avec la Faculté de musique (facilitée par F. Verdugo, qui est aussi enseignant du secteur piano de la Faculté de musique). Mohammad va rejoindre un groupe dynamique, focalisé sur la formation, la collaboration et la professionnalisation des étudiants, et hautement structuré (journal club, rencontres hebdomadaires par sous-groupe, rencontres mensuelles avec un statisticien, formations sur les plateformes à chaque session, etc.). Nous lui assurons un financement intégré pour qu’il puisse se consacrer à temps plein à ses études et nous l’accompagnerons pour des demandes de bourses aux grands organismes dès cet été.

Depuis le début de nos échanges, Shahiri a fait preuve d’un excellent sens d’organisation et de responsabilité. Il est aussi un étudiant facile d’accès, ouvert et qui démontre un grand intérêt par le milieu académique et de recherche de l’UdeM. Nous sommes convaincus que Shahiri s’adaptera avec aisance à l’environnement de recherche de notre laboratoire et qu’il contribuera au dynamisme de nos projets sur les TMS des musiciens et au caractère interdisciplinaire et intersectoriel de nos recherches. C’est donc sans aucune réserve que nous recommandons la candidature de Shahiri pour une bourse de Mérite de la Faculté de médecine.

Restant à votre entière disposition pour tout renseignement complémentaire, nous vous prions d’agréer nos salutations les plus cordiales,

Felipe Verdugo, Professeur associé

Mickaël Begon, Professeur titulaire