MyoChallenge 2024: Physiological Dexterity and Agility in Bionic Humans

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Abstract

Limb loss represents a traumatic and destabilizing event in human life, significantly impacting an individual's quality of life and independence. Advancements in bionic prosthetic limbs offer a remarkable opportunity to regain mobility and functionality. Bionic limb human users (*Bionic Humans*) are able to learn to use those prosthetic extensions to compensate for their lost limb, and reclaim aspects of their former motor abilities. The movement generalization and environment adaptability skills displayed by humans using bionic extensions are a testament to motor intelligence, a capability yet unmatched by current artificial intelligence agents.

To this end, we propose to organize MyoChallenge 2024: Physiological Dexterity and Agility in Bionic Humans, where we will provide a highly detailed neuromechanical and robotic simulation environment and invite experts worldwide to develop any type of controller for both the biological (muscle) and mechanical (bionic), including state-of-the-art reinforcement learning to solve a series of dexterous motor tasks involving human-to-bionic-limb interaction.

Building on the success of the MyoChallenge on the NeurIPS 2022 and 2023 editions, this year's challenge will push the boundaries on how symbiotic human-robotic interaction needs to be coordinated to produce agile and dexterous behaviours. This year MyoChallenge will have two tracks: manipulation and locomotion. The manipulation track will require bi-manual coordination of the *BionicMyoArms* model – a combination of a virtual biological arm and a Modular Prosthetic Limb (MPL). The goal will be to coordinate the use of those two limbs to manipulate a series of objects. In the locomotion track, we will exploit a new *BionicMyoLegs* model made from the combination of a virtual bilateral biological leg with a trans-femoral amputation together with an Open Source prosthetic Leg. The goal will be to coordinate the musculo-skeleto-bionic model to navigate challenging terrains and obstacles in an oval running loop. This running circuit is inspired by the Paralympic steeplechase and Cybathlon.

Keywords

Reinforcement learning, Embodied intelligence, Neuromechanical simulation, Biomechanics, Motor control, Prosthetics, Wearable robotics.

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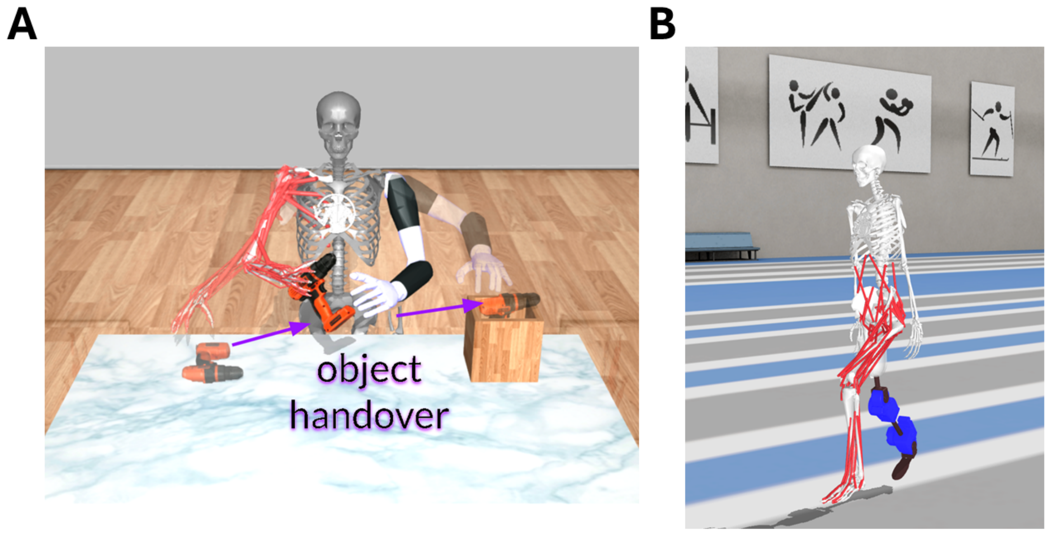

Figure 1: Two tracks of MyoChallenge 2024: **A.** the manipulation track where a *BionicMyoArms* – a combination of a MyoArm with the Modular Prosthetic Limb (MPL) – will be reaching, grasping, controlling and moving a real object to achieve a goal and **B.** The locomotion track, where a *BionicMyoLegs* – extension of the MyoLeg model with Open Source Leg (OSL), will navigate across challenging terrains and obstacles in a oval circuit.

1 Competition description

The *MyoChallenge 2024* aims to advance human movement modeling and push the boundaries of musculo-skeleto-bionic control in manipulation and locomotion tasks, while establishing a new benchmark for reinforcement learning (RL) techniques in highly dimensional physical systems. The competition will utilize the MyoSuite framework [1], an RL-friendly platform for large-scale musculoskeletal models with rich-contact dynamics. The challenge features two independent tracks (Fig. 1). The first track involves full bi-manual musculo-skeleto-bionic coordination to manipulate and handle complex real objects. This requires continuous control of all arm muscles and motors to reach, grasp, stabilize, pass and place an object. The second track focuses on locomotion with a prosthesis over complex terrain. This represents an additional level of complexity where coordination of the musculo-skeleto-bionic is required to balance and coordinate the body under highly dynamic and unstable conditions while reacting to external influences.

1.1 Background and impact

One hallmark of humans' motor intelligence is the ability to act and adapt in the interactions with the environment. This capability becomes even more incredible when in the presence of traumas or diseases, our actuation system is compromised and we are able to recover motor functions via the use of artificial bionic system. The resilience and adaptability of the human motor system under such circumstances underscore the necessity for nuanced modeling approaches that not only capture normal function but also account for the complexities of adaptation and recovery [2]. Integrating these aspects into modeling frameworks holds promise for advancing rehabilitation strategies, prosthetics, and assistive technologies, ultimately enhancing the quality of life for individuals affected by motor impairments [3, 4]. Although many simulation platforms and models have been suggested, they lack scale and realism leaving the musculo-skeleto-bionic control still an open challenge [5, 6, 7]. An integrated musculo-skeleto-bionic environment will provide a comprehensive test-bed for the fields of robotics, motor control, physiology, and machine learning to come to together for developing and evaluating control models with real world implications[8, 9, 10].

To address this gap collectively, MyoChallenge 2024 provides a physically realistic simulation environment, large-scale musculoskeletal models with robotics prostheses and well-designed tasks, inviting experts from various fields to test their learning and control approaches in achieving dexterous manipulation and agile locomotion in bionic humans. We are organizing two independent tracks. One track focuses on bi-manual manipulation as performed by a musculoskeletal twin incorporating a biological arm and a bionic arm, thereby representing the real-world use case of bionic limbs for upper limb amputations. The second tracks focuses on digital human twins incorporated with bionic leg replacement. This year Paralympics, the olympics games for par-athletes, inspired us to put together a task that expresses the real-world challenges of athletic competitions for lower limb amputations with bionics. Learning athletic motor behaviors in simulated musculoskeletal systems with serial robotic limbs represents an open challenge that needs collective attention from the community [11].

MyoChallenge 2024 will require the development of new musculo-skeleto-bionic models and associated controllers within MyoSuite [1], an open-source framework that implements realistic musculoskeletal models in the MuJoCo simulation environment [12] wrapped by an RL-friendly OpenAI Gym interface [13]. Participants can employ any approach, including robotic controllers [14], physiology-based models [15], and various machine learning methods [16, 17, 18], such as brute-force RL [19], imitation learning [20], and data-driven techniques [21].

The significance of this competition for the NeurIPS community lies in its interdisciplinary nature, bridging human motor control, biomechanics, wearable robotics, and machine learning. We anticipate that numerous teams, including machine learning and computational biomechanics researchers as well as experts in manipulation and locomotion, will engage. Building on the NeurIPS 2022 [22] and NeurIPS 2023 [23] MyoChallenge's success, which attracted 60+ teams from 15+ countries resulting in over 600 submissions. We expect even more participants this year. One of the most requested tasks from the last edition's participants was the bimanual manipulation, which we included in this year's manipulation track. Furthermore, in preview challenges – NeurIPS 2018: AI for Prosthetic challenge [24] – the excitement to solve challenges with real-world implications for amputees attracted 200+ teams. To broaden the competition's reach, we will present and advertise this challenge in already planned events and workshops at IEEE International Conference on Robotics and Automation (ICRA) 2024, Conference on Biomedical Robotics and Biomechatronics(BIOROB) 2024. In addition, we will schedule talks across robotics (ICRA, Robotics: Science and Systems Conference (RSS)), biomechanics (American Society of Biomechanics Conference, Canadian Society of Biomechanics conference), and machine learning (ICML) conferences, and promote them through social media platforms. This year is also an Olympic year and the proposed Bionic task will connect with the paralympic [8] and cybathlon[9] events.

1.2 Novelty

The proposed competition is the third iteration of the MyoChallenge, following the success of *MyoChallenge 2022* [22] and *MyoChallenge 2023* [23]. Similarly to last year's edition, we will host two tracks: the manipulation track and a locomotion track. Both tracks will significantly depart from last year's edition by featuring a musculo-skeleto-bionic control challenge. For this year challenge we have developed two new models used for two new tasks.

I) A *BionicMyoArms* model, a upper torso model that combines a right MyoArm model and a left Modular Prosthetic Limb (MPL) from the Applied Physics Laboratory at Johns Hopkins University 1-A. II) A *BionicMyoLegs* model, which is based on a MyoLeg with a trans-femoral amputation and extended with an Open Source Leg (OSL) [25] 1.-B

Manipulation: Compared to *MyoChallenge 2023*, the musculoskeletal model to be controlled – *BionicMyoArms* – increases the number of overall degrees of freedom (DOFs) from 27 to 44 and the number of actuators to 84: 63 muscles and 21 motors. The *BionicMyoArms* will allow to perform this year's task: bi-manual manipulations on everyday objects.

Locomotion: In contrast to the *MyoChallenge 2023* competition, which utilized a musculoskeletal model with 16 internal DOFs and 80 muscles, this year, our locomotion track features the *BionicMyoLegs* that has 60 muscles, 12 internal biological DOFs, and 3 motorized DOFs. Furthermore, in contrast to the *NeurIPS 2018: AI for prosthetics Challenge*, which used a simplified musculoskeletal model with 19 muscles with an ankle prosthetic and only required to walk on a straight line, both our model and the challenge are more complex. Inspired by both the Olympics Steeplechase specialty,

[8] `https://www.paralympic.org/`
[9] `https://cybathlon.ethz.ch/en`

and the Cybathlon [26], we designed a task that challenges participants to develop controllers that are able to perform multiple tasks at the same time and over different terrain and obstacles.

To promote and incentivize physiological behaviors, emphasis will be provided on physiological metrics with a special award to teams that achieve higher naturalistic and realistic solutions.

1.3 Data

Participation in our competition does not require specific data for training and validation, as the challenge is to develop controllers or policies within the provided MyoSuite environment. Thereby, the policy will collect its own data during the learning process. However, we encourage participants to utilize any available approach, including those relying on reference data, such as imitation learning. To facilitate this, we will provide links to several publicly available datasets on our website `https://sites.google.com/view/myosuite/myochallenge/myochallenge-2024`.

1.4 Tasks and application scenarios

The competition consists of two tasks designed to push the boundaries of human-like motor control and human-machine interface.

Manipulation track(Fig.1-A). Participants' feedback from previous years (collected at the end of the challenge via an online form) showed a strong desire to have bi-manual manipulations. This task follows that request with a complex generalization requiring to coordinate a *BionicMyoArms* for reaching to grasp, handover to the other hand and properly maneuvering everyday objects (pen, power tool, etc.) to move them to a specific target location of the workspace.

Locomotion track (Fig.1-B). Participants are challenged to produce a controller that is able to control at the same time the biological body and the prosthesis, for a *BionicMyoLegs* model that can handle multiple tasks over rough terrain, for example jumping over obstacles while running with the prosthesis. The reduced degree of freedom in the prosthesis, lack of knowledge of the prosthetic state, and rough terrain, makes this a highly challenging task.

Completing those task would require understanding in all three aspect: biological control, prosthesis control and human-machine interaction, promoting interdisciplinary collaborations, which are crucial in the field of prostheses. As part of a special award, teams will also be evaluated on how well their controllers match physiologically-plausible metrics for an initial flat stretch of the environment.

1.4.1 Manipulation Track:

Model: The *BionicMyoArms* (Fig. 1-A) consisting of a MyoArm and a MPL arm with 63 muscles, 27 internal biological DOFs, and 21 motorized DOFs. It features a skin layer that implements rich contact interactions with the environment.

Task: Develop a general bi-manual manipulation policy capable of interacting with common household objects and another agent (the hand prosthesis controller). The objective is to move an object presented in random locations on the right part of the space (only reachable from the MyoArm) and to move into a space on the left which is not reachable directly from the MyoArm. The object needs to be passed to the bionic arm in order to be properly placed in the target location.

Evaluation: The reward design will prioritize solutions that achieve a higher success rate in accomplishing the displacement of randomized objects between two locations via handover.

Action: A 84-dimensional vector representing both the muscle activation signals and the motor actuators of the *BionicMyoArm*.

Observation: Kinematic, muscle and motor states of the *BionicMyoArm*, object state, and target location.

1.4.2 Locomotion Track:

Model: A *BionicMyoLegs* (Fig. 1-B) consists of a torso with one articulated leg and one leg with a prosthesis. This model has 60 muscles, 12 internal biological DOFs and 2 motorized DOFs. It features a skin layer that enables full contact with the environment.

Task: Develop a general agent that control the *BionicMyoLegs* to efficiently navigate over rough terrain (*terrain variations*) and obstacles with a prosthesis. An initial stretch of flat ground of 10 meters will be used for evaluation of physiological metrics.

Evaluation: The reward design will prioritize solutions that achieve the furthest distance travelled. For the special award on physiological metric matching, the reward will prioritize muscle activation minimization, and joint loading (joint over-extension minimization),

Action: A 62-dimensional vector representing the muscle stimulation signals of the MyoLeg (60), and 2 motor actuators.

Observation: Kinematic, ground reaction force, and muscle states of the MyoLeg, joint torques, height-field observations (for rough terrain and obstacles)

1.5 Metrics

The manipulation track will consider a task successful if the object is moved to a position X_t which is smaller than a threshold T from the goal X_{goal}. The initial position of the object, target location, as well as object shape and physical parameters (weight, inertia, etc..) will be randomized. The success rate will be evaluated over 100 repetitions with different objects and physical parameters. Solutions will be ranked according to the maximum success percentage. In case of a tie, the time to achieve the task will be used as a supplementary metric.

For the Locomotion track, the task is considered a success when the model completes a full lap of the oval circuit. The distance of the oval circuit is 100 meters, with two 20m of straight tracks, and two 30 meters semicircle track on each side. Other than the first 20m of the track, the terrain and position of obstacles will be randomized. Success rates will be evaluated over 100 repetitions with different randomized environments. Solutions will be ranked according to the maximum success percentage, and in the case of a tie, the time taken to achieve the task will be used as a supplementary metric.

For the physiological metric award, we will consider only the first 20m of the running circuit, which will be free of obstacles and features even ground. For this interval, a weighted sum of several measures will be considered including, muscles activations, $C_E = \frac{E_M}{|D|}$, where C_E represents the cost of transport, given by the squared sum of all muscle activations, E_M, divided by the distance covered, $|D|$ [27]. This will be used as a metric to represent total metabolic power (MP)[28]. $\frac{1}{D}\sum JointLimit_n$, a metric to represent the sum of all over-extension or over-flexion torque for each joint n over distance travelled D will be introduced. Over-flexion and over-extension of joints are implicated in injuries [29]. Finally, we introduce a metric $N_{synergy}$ for the minimum number of spatial synergies that can explain 90% of the muscle activations of all the muscles.

For quantitative evaluations of the submissions, participants will be asked to upload their behavior policies to our online platform which will be automatically scored. The final score for the competition will be determined by executing the simulations over 100 repetitions across various seeds and task variations. This approach ensures statistical power, lending significance and reliability to the competition's leaderboard.

1.6 Baselines, code, and material provided

The following materials will be publicly available by the announcement of the competition in July:

- The main MyoSuite repository, which will include the models and competition environments for each task and track, will be accessible at: `https://github.com/MyoHub/myosuite`
- The baseline codes will be accessible on the readthedocs.io website: `https://myosuite.readthedocs.io/en/latest/baselines.html`
  - Manipulation task: a baseline code demonstrating simple random objects manipulation.
  - Locomotion task: a baseline code demonstrating walking on flat terrain.

1.7 Website, tutorial and documentation

Following the previous years approaches (which was well received by participants), we will have a landing page on the MyoSuite website that will function as the main resource for the challenges, containing the latest information, links to the Github and readthedocs documentation with installation examples and tutorials. It will also contain a link to the evalAI page of the competition, where the scoreboard is automatically generated. The latest information on the competition will also be posted on the MyoSuite Twitter account.

The following pages will be made available at the start of the competition:

- MyoChallenge landing website: `https://sites.google.com/view/myosuite/myochallenge/myochallenge-2024`
- Competition repository containing utilities for submission: `https://github.com/MyoHub/myochallenge_2023eval`
- MyoSuite documentation, tutorial, and examples: `https://myosuite.readthedocs.io/en/latest/index.html`

2 Organizational aspects

To ensure a smooth and successful competition this year, we have carefully determined the details of protocol, rules and engagement, schedule and readiness, as well as competition promotion and incentives, drawing from our experience of organizing MyoChallenge 22 and 23, and detailed feedback from participants.

2.1 Protocol

To relieve pressure from participants, scores on EvalAI will not be made public until September to not discourage late entry in the competition. Participants will be able to publish their scores only in the last two months of the competition. This is a new implementation for this year, as in previous years, we received feedback that it was very difficult to participate competitively for an extended duration. Additionally, instead of having two hierarchical competition phases like in previous years, we will host a single-phase competition that introduces two distinct tasks with a special award given to the teams creating the most physiologically correct results. This adjustment encourages people from other communities which might have more physiological approaches to solve the task instead of using brute force machine learning approaches.

Even though cheating has never been an issue in previous competitions, to prevent it, data and the final testing environment will not be available to the participants, and a daily submission limit (10) will be established.

The participation protocol for the competition will follow the same adopted in the previews editions:

- Register a team on `https://eval.ai/web/challenges/challenge-page/1844`
- Download the 'Getting Started' tutorial and set up local installation
- Run our baselines or tutorial to build the first policy or agent
- Test interaction with the grading environment
- Upload a test model
- The grading EvalAI platform will update a leaderboard with the results from the submitted model (private before September then public in September).

Helper scripts will be provided along the lines of the MyoChallenge 2022 and 2023 (`https://github.com/MyoHub/myochallenge_2023eval`)

2.2 Rules and Engagement

The contest rules for this competition are designed to promote fairness and inclusivity while encouraging the development of innovative solutions. The following rules will govern participation in the competition:

- Participants are expected to adhere to ethical practices and the protocol set by the organizers.

- The organizers reserve the right to modify challenge rules in case of unexpected events or technical challenges that may require interventions, such as limiting the number of registered participants or the number of submissions per day.

As per the previous MyoChallenge, participant-organizer communication will occur via email, Slack, and GitHub issues for transparency and responsiveness. We will monitor the competition for rule adherence and address unfair behaviour or unforeseen issues. Incomplete submissions won't be penalized or called out.

2.3 Schedule and readiness

The proposed MyoChallenge 2024 will unfold in two phases. The first phase will start in July, during which we will reveal the tasks and environment so that participating teams can start testing their algorithms. The second phase opens in September with a scoreboard made public. Winners will be selected from this second phase. The schedule for the competition is outlined in Table 1, with a description of the timeline.

Table 1: Competition timeline

Month	Task
May - June	Preparation of the competition Beta version, tests, documentations
July - August	Open source challenge and baselines Promotion
September - October	Competition: scored submission open
November	Verification of results, preparation of awards Preparation of NeurIPS workshop
December	NeurIPS workshop Workshop reports and competition analysis paper

2.4 Competition promotion, inclusion and incentives

The competition will be promoted through multiple channels for wide reach and participation. We'll advertise via mailing lists (e.g., roboticsworldwide, connectionist, euron-dist), forums (e.g., Biomch-L), social media (e.g., Twitter (@myosuite), LinkedIn, Instagram, Weibo), University networks (e.g., local representatives from different continents) and student association. Additionally, we'll directly contact previous participants from MyoChallenge 2022, MyoChallenge 2023, and Learn to Move 2019. We have been establishing an advocacy group to better outreach in communities and geographies where we observed little or no participation. For example, we are engaging representatives in Central America, South America, Oceania and Africa. This will extend our outreach and promote even a more diverse participation.

We are discussing potential sponsorships with the University of Twente, Northeastern Institute for Experiential Robotics, Google Cloud Platform, Deepmind, OttoBock and Delsys for prizes and awards.

For MyoChallenge, six awards will be distributed: one for each task, one for the best physiologically correct solution, one for the best student team, and one DEI award. Each award will consist of cash award, plates for the team, and goodies for each team member some goodies (t-shirts, hoodies, stickers,...). Additionally, winners will be invited as co-authors on the competition analysis paper and present results at the workshop hosted at NeurIPS 24.

In summary, the award will be:

- **Manipulation task Award**: the best scoring team able to solve the handout task.
- **Locomotion Award**: the best scoring team able to solve the rough terrain running task.
- **Best Student Teams Award**: Exclusively for teams comprised of university or high school students.
- **DEI Award**: Awarded to the team with diverse and inclusive backgrounds.
- **Physiology Award**: the best scoring team able to solve the running task with the highest physiologically metric.

To attract the best teams and obtain high-quality results while increasing team diversity, we will reach using the following means:

- Dedicated MyoChallenge Medium blog for updates, discussions, and write-ups.
- Continuation of the MyoChallenge podcast (`https://open.spotify.com/show/3dQjP4kQ9nM3IaD5pHYvxB`)
- Organizing a press release across the University of Twente, McGill University, Northeastern University, and Max Planck Institute to engage scientific and general media.
- Establishing invited talks in research subgroups for motivation and excitement.
- Reaching out to underrepresented committees to advertise our challenge. We will offer computer credits and Colab tutorials to support participation. We will contact the following groups: Black in Biomechanics, Black in AI, Latinx in AI, Latinx in Biomechanics, African Artificial Intelligence Society, Women in AI.
- Providing workshops and Q&A sessions about the competition to lower barriers of entry for marginalized participants.

3 Resources

3.1 Organizing team

The organizing committee 2 is diverse in terms of gender, location (USA, NL, CAN, GER, UK), origin (Italy, India, France, Korea, Singapore, China, and Luxembourg), and career stage (graduate student, postdoc, assistant professor, professor and chair). With expertise spanning across deep reinforcement learning, physics-based simulation, wearable robotics and composite neuromusculoskeletal modeling, the committee is well-equipped to address the challenge's needs. They have experience in organizing musculoskeletal model-based challenges (NeurIPS 2019: Learn to Move, MyoChallenge 22 and 23), general challenges, scientific hands-on workshops, tutorials, and serving as track chairs at conferences such as NeurIPS, ICRA, RSS, ICORR, WeRob, BioRob, and IROS.

3.2 Resources provided by organizers

The organizers possess all the necessary resources to develop the framework and organize the competition effectively. Additionally, we are in discussions with potential sponsors to support participants' computational needs. For more information about sponsorships, please refer to Section 2.4.

3.3 Support requested

The organizers request support from the conference to officially promote the challenge and secure registration tickets for some organizers and participants. Promotional support could be provided through a dedicated time-slot during the conference to recognize the winners and discuss the lessons from the competition.

Table 2: Challenge organization members

Name, Title, Affiliation	Role, Expertise, and Other Note
Vittorio Caggiano Research Scientist MyoLab	Framework creator Motor control, neuromusculoskeletal modeling Lead organizer of MyoChallenge 22 and 23 Lead for EvalAI.
Guillaume Durandau Assistant professor McGill University and Jewish Rehabilitation Hospital	Framework creator, Neuromusculoskeletal modeling, wearable devices Organizer of MyoChallenge 22 and 23. Lead manipulation task.
Huiyi Wang PhD Student McGill University and Jewish Rehabilitation Hospital	Neuromusculoskeletal modeling, Machine learning Communication for MyoChallenge 23 and 24. Lead for communication.
Seungmoon Song Assistant professor Northeastern University	Technical advisor Neuromechanical simluations, motor control Organizer of MyoChallenge 22 and 23, lead organizer of NeurIPS 2019: Learn to Move Lead of the locomotion task
Chun Kwang Tan Postdoctoral researcher Northeastern University	Lead of locomotion track, baseline method provider Clinical gait analysis, deep reinforcement learning Organizer of MyoChallenge 23. Lead for the physiological Award.
Balint Hodossy PhD Student Imperial College London	Prosthesis, deep reinforcement learning Environment creator.
Pierre Schumacher PhD Student Max Planck Institute	Robotics and deep reinforcement learning 2nd place in MyoChallenge 22, Baseline & environment creation as organizer in 23 for the locomotion track.
Letizia Gionfrida Assistant professor King's College London	Robotics and deep reinforcement learning. Lead for EDI Award.
Massimo Sartori Professor & Chair University of Twente	Framework creator Organizer of NeurIPS 22 and 23 Lead for Sponsorship.
Vikash Kumar Senior research scientist Adjunct Professor, CMU	Core developer of MuJoCo, Framework creator Deep Reinforcement Learning, optimal Control Organizer of MyoChallenge 22 and 23 Lead baseline creator.

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