Preface

This book is born from the need for a succinct means to convey basic concepts of engineering, mechanics, and mathematics to those who care deeply about combining neuroscience and biomechanics to forge an understanding of the function, control, and rehabilitation of vertebrate limbs. And conversely, to convey my fascination with organisms and neuroscience to engineers who are inspired by Nature to create versatile robots. The principles of mechanics are at the root of both evolutionary biology and robotics. Darwinian evolution and Newtonian mechanics are unforgiving arbiters that continually shape what is possible and successful in the physical world. Thus animals have had to evolve to successfully withstand and exploit the laws of mechanics.

The scope of this book on neuromechanics is heavily biased toward mechanics because it is least emphasized in today's efforts in neuroscience. We have historically emphasized reductionist neurophysiological preparations and recordings that have given us such triumphs as the Hodgkin–Huxley model that describes how action potentials in neurons are initiated and propagated, as well as the understanding of neuron structure, function, and connectivity—and their role in memory and learning—in the tradition of Ramón y Cajal, Brodmann, and Kandel, to name a few. At the larger scale of populations of neurons, we have the discovery and description of central pattern generators, the connectome, and cortical networks. And medical imaging now even allows us to obtain whole-brain views in real time with MRI, fMRI, PET, etc.

In parallel, we have the emergent understanding of whole-body function from the biomechanical perspective, as first introduced by Borelli and Da Vinci, which is now a mature field able to study complex systems using computer aided design platforms such as openSIMM, AnyBody, and MSMS. Similarly, muscle physiology, structure, and function is an active field of study that has enabled our ability to understand the nanomechanical interactions and molecular motors at the center of sarcomere and muscle function. Add to this the crucial contributions from electrical engineering and signal processing that have allowed us to analyze physiological signals, such as the electromyogram and electroencephalogram, to extract estimates of motor commands and brain function, respectively.

But, in the domain of understanding the principles, strategies, and mechanisms that the nervous system uses to control vertebrate limbs, we have theories that remain biased toward the notion that muscle redundancy is the central problem of motor control. Thus, the problem that the brain solves is cast as one of mathematical optimization. However, this classical notion of muscle redundancy is paradoxical with respect to the evolutionary process and clinical reality.

This book at its core seeks to reconcile these conflicting views: engineers and neuroscientists who think that we have too many muscles, versus evolutionary biologists and clinicians who cherish every one of them as functionally relevant. This motivates questions of why vertebrates have evolved the way they have, and what neural computational problems confront the brain when it controls its mechanical body. My hope is that the presentation of this mechanically-centered material will complement current thinking and advance the state of the art in robotics, neuroscience, and rehabilitation.

I write this book with trepidation as I inevitably run the risk of potentially—yet without intent—antagonizing esteemed colleagues by acts of omission or over-simplification of the many nuanced issues and concepts that have critical bearing on this topic. But this is an unavoidable risk, as it is intended as a succinct introductory textbook for upper class or early graduate students and working scientists. I also provide extensive online supplemental material, references, and suggested reading to help fill in the inevitable technical gaps and scientific nuances.

Nevertheless, I believe that engineering is critical to progress in life sciences—and that this particular neuromechanical approach is underdeveloped and has lacked sufficient attention. My experience over the years of teaching related courses at Cornell University and the University of Southern California confirms my belief that it enables engineers, neuroscientists, and clinicians to evolve their intuition and understanding of neuromusculoskeletal systems. It is my sincere hope that it will do the same for you.

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