GRAND CHALLENGES IN UPPER-LIMB BIOMECHANICS

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INTRODUCTION

Identifying priority research areas has a variety of positive effects. In addition to focusing individual researchers’ attention on issues that are important and urgent, it requires an honest assessment of the state and direction of one’s field of research, creates community-wide communication around a common theme, and invites collaboration and cross-fertilization.

The Grand Challenge to Predict In Vivo Knee Loads was announced in 2009 and has had a positive impact on the biomechanics community. The associated competitions have benchmarked current methods, encouraged innovation, raised awareness, and increased conversation in the lower-limb biomechanics community [1, 2].

However, upper limb biomechanists face a different set of important and urgent issues. There are fundamental differences between lower- and upper-biomechanics on a variety of levels, including function, loading, control, and pathology. In addition, methods employed in upper-limb biomechanics research are generally less standardized than lower-limb methods, making comparisons and community-wide communication more difficult. The upper-limb biomechanics community would greatly benefit from efforts to identify its own set of priority areas and grand challenges. Although identifying such priority areas and grand challenges is beyond the scope of a single symposium (let alone coming to agreement), this symposium can serve to start a community-wide discussion of priority areas and potential grand challenges (for the purposes of this symposium, a priority area is defined as a research area of exceptional importance, whereas a grand challenge is defined as a specific, tightly defined problem that addresses an aspect of a priority area and draws attention to it, often through an organized competition).

SYMPOSIUM FORMAT

The symposium will begin with a short presentation by each author in which he/she presents his/her opinion of priority areas in upper-limb biomechanics, and suggestions for potential grand challenges. After these presentations, the audience will be divided into groups and encouraged to discuss the presentations and develop their own priority areas and grand challenges, which each group will briefly present to the entire audience. The symposium will end with a moderated debate involving the authors and the audience.

PRESENTATIONS

Charles: The gap between researchers and clinicians is a significant obstacle to the progress of upper-limb biomechanics research. This gap is arguably larger for upper limb movements than for lower-limb movements, perhaps in part because standardization is more pervasive for the lower limb (gait is more easily standardized than upper limb function) and because the lower-limb research community has more researchers who bridge that gap (e.g. researchers in exercise science, who often pursue applied research, make up a large part of the lower-limb biomechanics research community but rarely
research upper limb biomechanics). There appears to be relatively little discussion (or even common ground) between researchers in upper-limb biomechanics and motor control and clinicians such as occupational therapists and surgeons. Greater communication between researchers and clinicians would greatly benefit patients with movement disorders by informing researchers of clinically relevant problems and by assisting clinicians in adopting more quantitative tools for evaluation and diagnosis. One potential first step may be to take advantage of recently developed motion capture systems that are low-cost, quick-and-easy (markerless), and high-resolution (e.g. Leap Motion sensor). Gathering and sharing upper-limb movement data from large numbers of subjects would allow us to establish quantitative norms of upper limb movements (intra- and inter-subject variability as well as means). Although such an endeavor is difficult because upper limb function is highly variable, it could enable identification of subtle movement abnormalities believed to cause the movement impairment syndromes so common in clinical practice (60% of patients seen by physical therapists, for example [3]).

**Li:** Biomechanics is an applied science that bridges basic research and clinical applications, effectively translating research findings to benefit patients. Research in musculoskeletal biomechanics has led to significant advances in clinical practice in orthopedic surgery and rehabilitation, including implant design, joint replacements, medical devices, surgical techniques, orthotics and prosthetics, and performance evaluation. However, biomechanics for the hand is somewhat underdeveloped in comparison to other musculoskeletal areas. Yet, the hand offers a unique research opportunity for biomechanics research because of its anatomical complexity, functional versatility, and pathological vulnerability. My research for over 15 years has focused on hand biomechanics and motor control with a clinical application to carpal tunnel syndrome. I will share my experiences of disease-centered research development and discuss the challenges and opportunities of biomechanics research related to several main hand disorders.

**Murray:** In biomechanics, the upper limb is often considered somewhat of a niche area. In addition to the complexity of the system and the difficulty in stereotyping the most common way humans use their arms and hand (compared to gait, for example), this viewpoint is a challenge to progress and momentum in the field of upper-limb biomechanics. Researchers interested in the upper limb need to continue to demonstrate how advances in this area add and advance a common knowledge base that should be of interest to a wide community, not to just those who focus their efforts in this area. Similarly, upper limb researchers often face difficulties in translating their research to the clinic. Without a specialized journal or society that brings researchers and clinicians together (such as the Gait and Clinical Movement Analysis Society), researchers interested in the upper limb often have difficulty finding clinicians who are familiar with upper-limb biomechanics research. This can limit the clinical collaborations and can make distribution of research findings challenging; sometimes findings are considered too clinical for a scientific journal and too research-oriented for a journal with clinical interests. Finally, in the lower limb, joint replacements are considered to be one of the most successful medical devices of our time. In contrast, joint replacements in the upper limb have had relatively limited success; degenerative pain in the wrist and thumb is most commonly treated by simply removing the bones associated with the degeneration, without any replacement.

**Perreault:** Understanding the proximal-distal differences in the neural control of upper limb biomechanics is a priority area. Different levels of the nervous system are engaged in different proportions as we consider proximal and distal joints in the human arm. We do not presently have a good understanding of how these differences contribute to our ability to complete various motor tasks, or how these abilities are altered by injury. This is arguably a much greater issue for the upper limb than it is for the lower limb. Also, efforts to identify neural control strategies need to incorporate task and biomechanical constraints. Many studies attempt to infer neural control strategies from recorded muscle activations but fail
to consider how those activations are constrained by the biomechanics of the limb and the task being performed. This issue is relevant to both upper and lower limbs, though solutions may be more feasible for the upper limb.

Valero-Cuevas: We should re-evaluate the current cortico-centric view of the neural control of the upper extremity and hand. For over a century, researchers have agreed that our anatomy and brains exhibit dramatic, specific, and useful adaptations for control of the upper extremity and hand. But if we roll back evolutionary time, it is not at all clear what were the evolutionary pressures that drove such drastic neural adaptations. For example, the advantages of monosynaptic corticospinal projections are often taken to be self-evident for biomechanical function—but it is equally evident that the larger proportion of oligosynaptic corticospinal and rubrospinal projections serve humans and other dexterous vertebrates well. Similarly, time delays argue against cortical circuits being the dominant drivers of time-critical biomechanical dexterity. Roger Lemon has argued that these adaptations cannot be the sine qua non of dexterity [4], yet this caveat has largely gone unheeded. Therefore, let us explore a hierarchical and distributed neuromechanical architecture that leverages, yet does not supersede, phylogenetically older structures shared by humans and other dexterous vertebrates.

Vidt: There is a movement toward developing models for individualized medicine, but more work is needed before this can become a plausible solution for the upper-limb. There are several aspects of shoulder biomechanics notably absent or simplified in current models [5]. These exclusions necessitate further model development and should be considered as priority areas for the upper limb research community. For example, muscle scaling and humeral head translation are needed to more accurately represent different individuals, and these parameters become increasingly important in the context of orthopaedic injury (e.g. rotator cuff tears, subacromial impingement). Muscle force and the relative positions of the bony structures are essential determinants of the magnitude and direction of joint contact forces. To bridge the gap between biomechanics and the clinic, it is important to quantify how these measures change following injury and the extent to which they affect joint loading and contribute to subsequent joint damage during typical upper limb movements.

A potential grand challenge would include model prediction of glenohumeral joint contact forces measured using instrumented shoulder implants. Being able to accurately predict in vivo loads would require a model that effectively captures the muscular changes associated with injury, as well as the intrinsic bony kinematics. The challenge would be in the same spirit as that of the lower limb, but due to the anatomical and functional differences of the shoulder, it would require a markedly different approach.

REFERENCES