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Preface

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Human factors engineering and ergonomics are multidisciplinary fields dedicated to improving efficiency and productivity and reducing injuries and disorders, as well as issues associated with usability, comfort, organisational design, etc. To achieve these goals, it is often critical to understand human physical capabilities, including range of motion, muscle strength, and fatigue, and individual and environmental factors that affect these capabilities. Such knowledge is also important for rehabilitation science and athletic performance. In recent decades, and resulting from developments of advanced, multi-joint kinematic theories and methods, there has been a substantial increase in our abilities to solve problems related to range of motion, such as simulating and/or predicting reaching ability. On the other hand, existing knowledge regarding muscle strength and fatigue, while extensive, remains limited in several respects, and is often restricted to single-joint and task-specific levels. In general, evidence to support realistic, applied problems is lacking, largely a result of the inherent complexity of muscle strength and fatigue, and current limitations in theories and methods for assessing and modelling these aspects of human capabilities.

The purpose of this special issue is to report on some of the frontiers of research on muscle strength and fatigue, including theories, modelling techniques, and assessment methods. We, the guest editors, sincerely thank the authors who contributed to the special issue and the referees who provided their valuable feedback (and do so promptly!). We hope the special issue can stimulate further research in the fields of muscle strength and fatigue. Below is a brief summary of the goals and contributions of each paper.

Muscle strength, when described at the joint level, is a function of joint angle and angular velocity, and as such can be represented as a 3D joint strength ‘surface’. Looft and Frey-Law propose a novel approach to modelling joint strength as a function of joint kinematics, using logistic equations to model the 3D joint strength surface. Their modelling approach provides equal or better representations of 3D joint strength surfaces for the elbow and knee joints when compared to a more conventional approach using polynomial equations. The advantages of using logistic equations in modelling are that this approach demonstrates less extreme curvatures at the endpoints of motion and is better in predicting physiologically consistent (non-negative) torque values through the full range of joint motion. The authors concluded that muscle strength modelling using logistic equations could provide modern digital human models with more accurate strength predictions, ultimately resulting in better assessments of task performance and injury risk.

It is noteworthy that the approach proposed by Looft and Frey-Law is population-orientated (i.e., normative muscle strength surfaces). Oomen et al., in contrast, describe a rule-based strength scaling method for muscle strength modelling that is specifically intended to facilitate individualised musculoskeletal models. They assessed isometric strength in knee extension and fitted, using multiple linear regression, a strength model based on a set of demographic and anthropometric variables for each individual. The model was then validated by comparing predicted isometric knee extension strength to values collected from a second group of participants. The model performance was also assessed by comparison to existing individualised musculoskeletal modelling methods. Their work indicates that, overall, a rule-based strength scaling method provided better estimates of knee extension strength than existing methods, though more work is suggested to further improve the model performance in individualised predictions.

Compared to major body joints such as the knee and elbow, the strength characteristics of the wrist joint are not well-described in the literature. Xia and Frey-Law assessed isometric and isokinetic wrist joint strength in flexion-extension and radio-ulnar deviation for both men and women. Additionally, forearm strength in supination-pronation was obtained. Finally, normative 3D strength surfaces corresponding to these six motion directions were modelled using the logistic equation approach proposed by Looft and Frey-Law (as described above). This study is the first to simultaneously assess wrist strength in multiple motion directions from the same group of participants, thus providing the most comprehensive description of the strength characteristics of the wrist joint.

The so-called ‘two-joint effect’ has long been known; when a biarticular muscle spans a given joint, the strength at that joint can be affected by the angle of the adjacent joint that shares the same muscle. Das et al. present results suggesting multi-joint influences on strength could extend beyond this classic two-joint effect. Specifically, they found that the orientation of the head could affect isometric wrist flexion strength in young adult females even though the two body parts (neck and wrist) do not share specific muscles. The authors attributed this phenomenon to the asymmetrical tonic neck reflex that was more prominent during infancy. It would be interest to see if such ‘distant’ multi-joint effects exist between other body parts and if such effects should be considered in muscle strength modelling.

Local muscle fatigue is a natural phenomenon occurring after muscle activity, yet is among the most complex and least quantitatively described aspect of human ability/performance. Rashedi and Nussbaum reviewed existing muscle fatigue models and concluded that these models, whether empirical or theoretical, are clearly promising yet require further development for real world ergonomic applications. Particularly for two ‘ergonomically-relevant’ muscle fatigue models examined in details, they found that substantial variations exist in model predictions. These differences, however, could elucidate a useful approach, both for developing testable hypotheses and in guiding subsequent model development or refinement, as the authors argued. They also suggested that expansion of model structure to account for individual differences (e.g., age, gender, and obesity), task related parameters, and variability in motor unit composition may further enhance the performance of such muscle fatigue models.

Based on a previous model developed by the same research group (and one of the two models examined in detail by Rashedi and Nussbaum), Sakka et al. proposed a new muscle fatigue model suitable for repetitive push/pull operations. In particular, isometric shoulder and elbow models that account for strength variability due to joint angle were incorporated into their upper extremity model. They used the model to simulate repetitive push/pull operations under quasi-static conditions (i.e., slow speed), and illustrated how different task configurations could impact fatigue at the shoulder and elbow and provide potential implications for repetitive task-related musculoskeletal disorders.

While these papers provide important new increments and/or directions for future research in the fields of muscle strength and fatigue, additional work is clearly needed. For example, one complexity inherent in muscle strength is its nature as a ‘vector’. The muscle strength models proposed in this special issue, as well as previous models, mainly consider muscle strength in the primary motion planes of a joint. Muscle strength in directions between these primary planes, however, is not well documented. Dependent on specific objectives and applications, one may expand strength modelling further to the muscle level (e.g., for joint load analysis). For fatigue, one area to be explored is the dynamics of fatigue recovery due to physiological regulation of blood flow in active muscles. This may be particularly important for modelling fatigue resulting from prolonged, low-moderate intensity tasks that are common in the workplace. Another potentially fruitful area is to develop and evaluate models of muscle fatigue for application to dynamic tasks. Of course there are many other hurdles in muscle strength and fatigue modelling. In the coming years, however, continued work in these areas can be expected to provide important contributions, such as tools for task configuration and planning, work shift, musculoskeletal disorder risk analysis, and accurate physical function evaluation in patients and populations with restricted abilities. Further developments in modern digital human models will also greatly benefit the knowledge gained.