ANALYSIS OF CERVICAL SPINE LOADING IN RUGBY SCRUMMAGING: A COMPUTER SIMULATION APPROACH

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Musculoskeletal modelling is widely used in biomechanics for the analysis and simulation of human motion. A modelling approach allows estimates of the internal load on specific anatomical structures, and the individual muscle forces that govern movement execution. Within the analysis of impact events in rugby union, modelling can help the understanding of the mechanisms of acute and chronic cervical spine injuries, starting from experimental measures of external load on the player, and progressing to the estimation of stresses acting on the internal cervical structures. During this part of the applied session, we will use a novel musculoskeletal model and previously collected experimental data (forces and kinematics) to analyse the cervical spine loading experienced during a rugby scrum. An open-source biomechanical software (OpenSim 3.2) will be used to set up and run inverse and forward dynamics pipelines to calculate joint moments and joint reaction forces, and to analyse "what if…" scenarios.

KEY WORDS: impact, musculoskeletal modelling, darionics, inverse dynamics, forward dynamics, injury prevention.

Scrummaging is a fundamental phase of Rugby Union. Due to its physical nature, the scrum is associated with approximately 6 to 8% of all injuries, and 40% of catastrophic injuries (Trewartha et al., 2015). Previous studies provided an overall description of the biomechanical load experienced at the front row interface during machine (Preatoni et al., 2015) and contested scrums (Cazzola et al., 2015), and proposed alternative scrum engagement processes to de-emphasise the initial engagement and decrease injury risk (Trewartha et al., 2015). However, in order to provide a better understanding of the mechanisms related to cervical spine injuries (Dennison et al., 2012), and propose further viable routes for injury prevention, there is the need to translate the external forces and movements measured during experimental tests into the corresponding internal stresses acting on cervical spine anatomical structures.

The characterisation of this load transfer is made difficult by the impossibility to take *in-vivo* measures of joint loads unobtrusively, and it is further complicated by the limited information available upon individual players' movements during a scrum. Musculoskeletal modelling is widely used in biomechanics for the analysis and simulation of human motion (Delp et al., 2007), especially when direct measures on internal anatomical structures are not practicable through an *in vivo* experimental design.

Musculoskeletal models that include subject-specific anthropometrics and muscle characteristics can provide an accurate estimation of the internal load applied on individual anatomical structures and the force generated by individual muscles. However, computer models need to be validated against *in vivo* or cadaveric dynamics measurements, in order to provide reliable analysis and simulation outcomes that are relevant for understanding real-word problems. Currently, most of the full body musculoskeletal models are used in gait analysis and locomotion simulations, whilst the ones specifically focused on upper limbs or spine movements (Vasavada et al., 1998) do not include lower limbs and, therefore, are limited in their potential applications. For this reason a novel OpenSim '*Rugby Model*' (Figure 1a) was developed. The model includes: i) the inertial properties of all its anatomical segments from DEXA scans of a rugby player, and ii) custom scapuloclavicular joints to model the coupled motion of scapula and clavicle with respect to humeral elevation.

During this part of the applied session the '*Rugby Model*' (Cazzola et al., 2014; available at https://simtk.org/home/csibath) will be employed to analyse cervical spine loading in a rugby scrum. An open-source biomechanical software (OpenSim 3.2, SimTk, USA) will be used to set up and run an inverse dynamics pipeline driven by *in-vivo* data of a front-row rugby player scrummaging against an instrumented scrum machine (Figure 1b). The experimental data will consist of 3D motion of the body segments and the external forces applied to the body (i.e. ground reaction forces and scrum machine forces). The pipeline will allow us to calculate the joint moments and joint reaction forces during a machine scrummaging trial, and will include i) scaling, ii) inverse kinematics, iii) residual reduction analysis (RRA), and iv) inverse dynamics procedures. We will briefly discuss the limitations and the validity of a musculoskeletal approach for impact events (Figure 1c). Finally, a forward dynamics pipeline will be set up and run in OpenSim demonstrating how to exploit musculoskeletal models to analyse "*what if…*" scenarios from an injury prevention perspective.

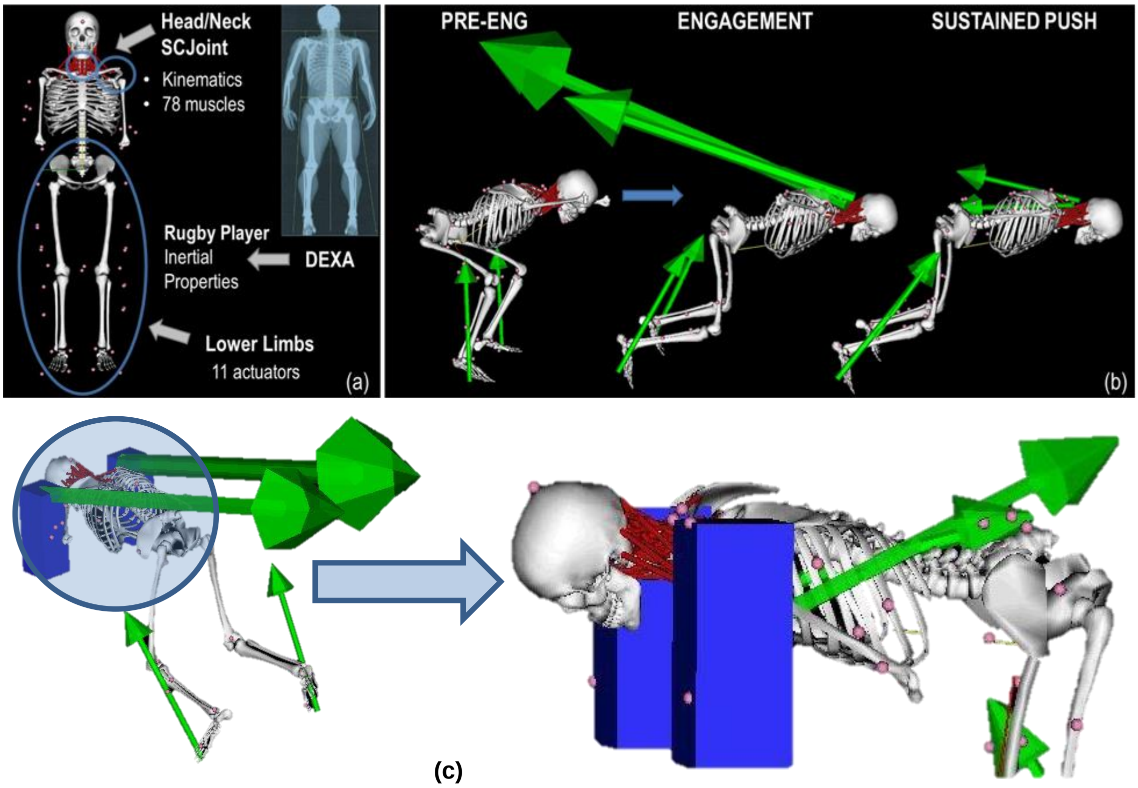

Figure 1. (a) The full body 'Rugby Model', specifically optimised for rugby activities dynamic analysis. (b) Full body motion and external load application of an individual player scrummaging, divided in the main three phases of a rugby scrum: pre-engagement, engagement and sustained push. (c) Inclusion of the scrum pads in the model in order to minimise experimental inaccuracies.

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