Load Informed Kinematic Evaluation (LIKE) protocols for the simulation of daily activities in the intervertebral disc (IVD)

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Current spine test standards simplify loads (e.g. ASTM F2789-10, ISO 18192), and IVD culture systems generally focus on axial compression, despite research showing that multi-axis loading effects cell viability[1]. In-vivo load data from instrumented vertebral replacements (IVBR)[2] combined with spine simulators could help understand how different activities, populations and lifestyles affect IVD health. However, the load-coupling and large range in load rates across different activities make the real-time replication of these complex loads in-vitro extremely challenging.

This study outlines the development of a Load Informed Kinematic Evaluation (LIKE) protocol for the replication of 20 unique activities to represent the average daily activity profile of a UK young adult population (25-44y) based on the Harmonised European Time Use Surveys (HETUS)[3] A six-axis bioreactor was used to replicate Orthoload data obtained from IVBRs in a bovine IVD specimen (n=1), with loads scaled based on cross-sectional area (Figure 1). All activities were slowed down to allow for a stable load replication. The kinematics measured during load control tests were then used to replicate the activities using kinematic control at the reduced test rate, and in real-time. However, axial compression was maintained in load control across all tests to accurately simulate changes in disc height over time. The rms error (RMSE) between desired and applied loads were used to evaluate the LIKE protocol (Table 1).

Preliminary results demonstrate that the LIKE protocol provides a novel method to replicate and stably control dynamic, complex physiological loads in real-time. Further tests are being completed to include more specimens and additional daily activities to create 24h kinematic activity profiles, which cannot currently be achieved. This provides a valuable method to complete long-term assessments of IVD treatments, investigations into how different activities effect cell viability, and in providing a greater understanding of the mechanisms of disc degeneration.

References:

1. Chan, et al., 2013. PLoS One,**8** (8), e72489.
2. Bergmann, 2008. "OrthoLoad". Retrieved Apr. 1 2021 from http://www.OrthoLoad.com
3. Lazaro-Pacheco, et al. In Philadelphia Spine Research Society (PSRS): Skytop, PA, 2022.

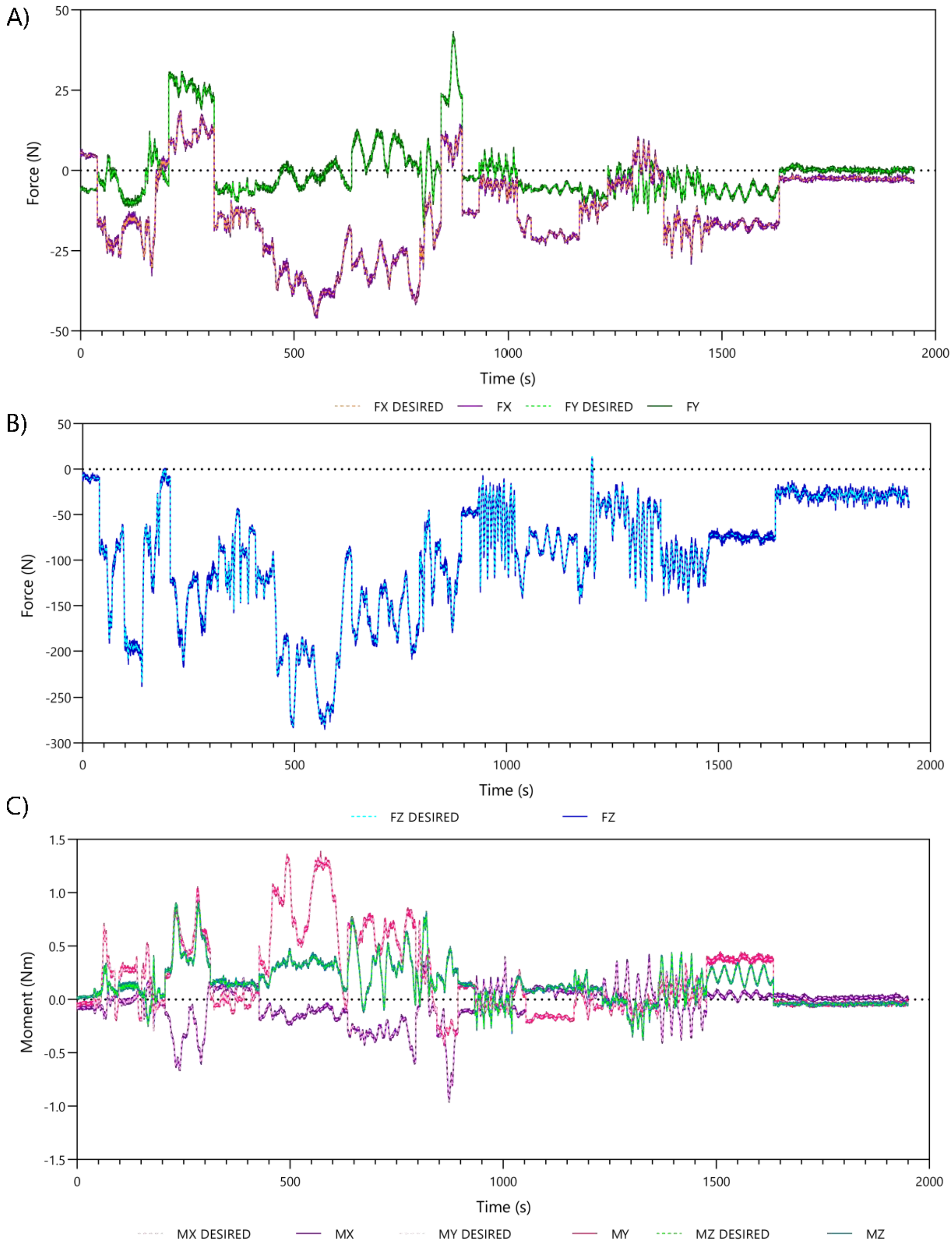

Figure 1. Example of desired and applied six-axis loads for a range of daily activities using load control for shear forces (A),axial compression (B) forces and moment (C).

Table 1. RMSE between the desired load (scaled Orthoload data), and the applied load in slowed six-axis load control, slowed kinematic control, and real-time kinematic control shows that the test system is capable of applying complex loads representative of daily activities, and that these loads are also well replicated using the more stable kinematic control method.

Axis	Load control (slowed)	Kinematic control (slowed)	Kinematic control (real-time)
Anterioposterior shear (N)	0.47	2.51	4.51
Lateral shear (N)	0.44	4.19	7.22
Axial Compression (N)	2.21	2.45	16.12
Lateral bending (Nm)	0.01	0.22	0.59
Flexion-extension (Nm)	0.01	0.11	0.45
Axial rotation (Nm)	0.01	0.09	0.17