Measuring osteoarthritis knee nociception using physiological and movement responses and a defined thermal stimulus: A proof-of-concept study.

Rebecca I. Hamilton[1], Cathy Holt[1], Jake Bowd[1], Ashly Alava Garcia[1], Dionne Shillabeer[1], Ryan Jones[1], Mark Elliott[4], Jan Herman Kuiper[5], Valerie Sparkes[1], Sharmila Khot[2], David Hamilton[3], Deborah Mason[1]

[1]Cardiff University, Biomechanics and Bioengineering Research Centre Versus Arthritis
[2]Cardiff University, Brain Research Imaging Centre
[3]Edinburgh Napier University, School of Health and Social Care
[4]University of Warwick, Institute of Digital Healthcare, WMG, International Digital Library
[5]The Robert Jones and Agnes Hunt Orthopaedic Hospital, Keele University

01 Background

Mechanical loading of joints with osteoarthritis (OA) results in pain-related functional impairment, altered joint mechanics and physiological nociceptor interactions leading to an experience of pain (Syx et al., 2018). Current tools to measure intervention efficacy are largely patient scores. Direct measures of nociception are needed as an objective indicator (Chen et al., 2021).

AIM: To analyse whether integrated biomechanical and physiological sensor datasets could display linked and quantifiable responses to a nociceptive stimulus.

02 Method

Participants: 14 healthy volunteers were consented to participate following ethical approval. An additional 4 participants were tested on a secondary protocol.

Task & Conditions: 5 movement and stationary activities (Fig. 1, right) were performed under control conditions or after a thermal pain stimulus applied to their right knee (40 - 0°, Fig. 2c, below).

Equipment & Measures: Inertial measurement unit (IMU) and electromyography (EMG) sensors were attached to the lower body (Fig 2b, below) and synchronised with ground reaction force (GRF) data. Galvanic skin response (GSR) electrodes for skin temperature and conductivity and photoplethysmography (PPG) sensors for heart rate were attached to the finger (Fig 2a, below) and manually timestamped to the integrated system. Visual Analogue Scale (VAS) scores were taken for each activity.

Analysis: GSR signal pre-processing was conducted for electrodermal activity (EDA) using MATLAB for statistical analysis on participant summary data, i.e., skin conductance (SC) and skin conductance response (SCR). Extra exploratory analysis on a case study and secondary protocol were incorporated using continuous decomposition analysis (CDA) (Benedek & Kaernbach, 2010) with Ledalab and Isokinetic Dynamometer exercises.
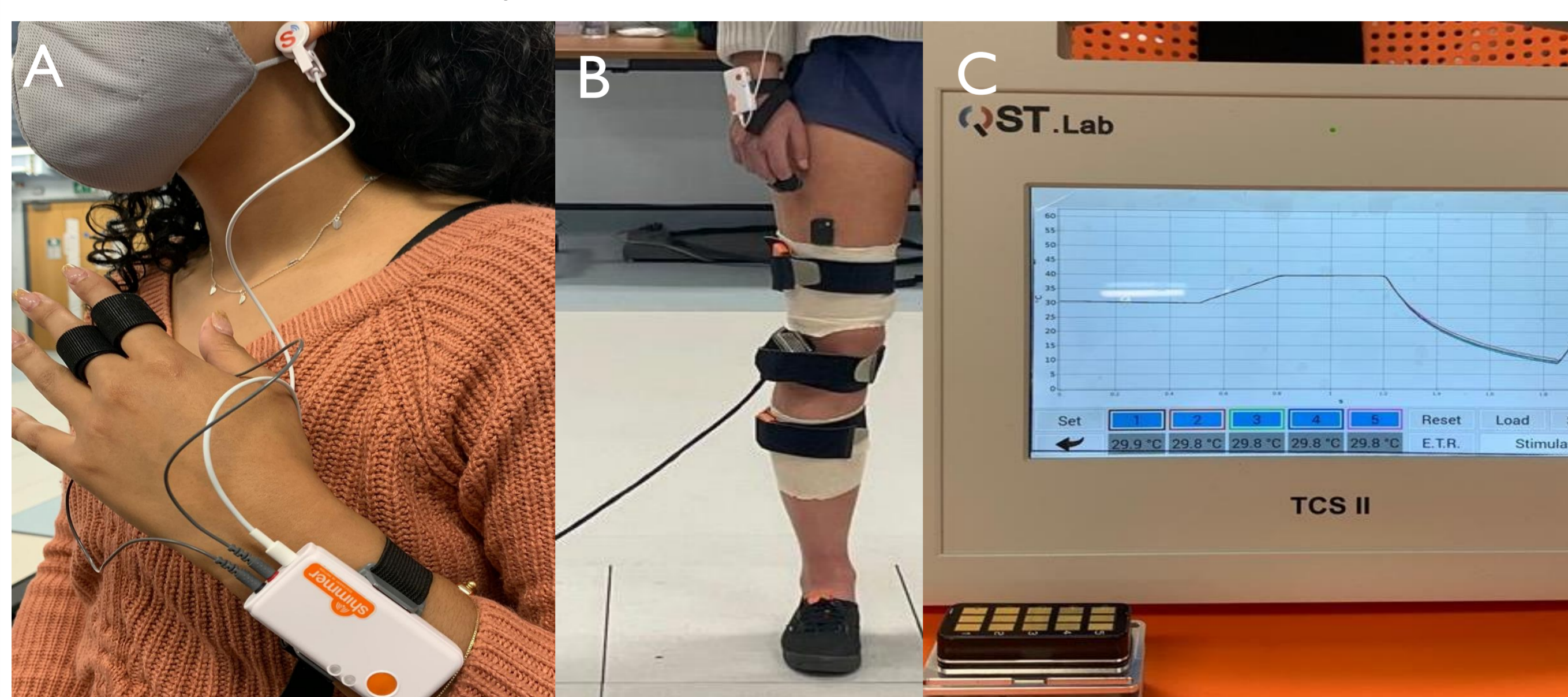
03 Results

Figure 3 (Below): A) Demonstration data for stationary standing test with synchronised event markers (red vertical lines) for thermal stimulation with corresponding GRF (Newtons, blue line data) fluctuations and B) same test demonstrating synchronised EMG (microvolts, green line data) within 0.5 seconds of stimuli.
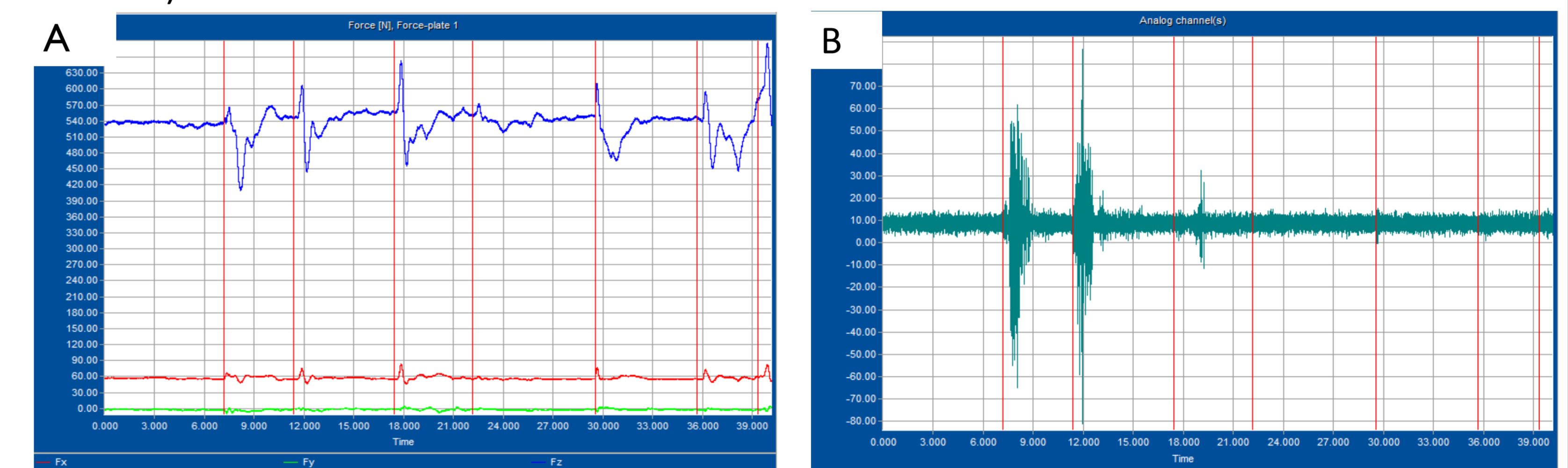

Figure 4 (Below): Thermal stimulation increased mean SC (Z = -3.3, P< 0.001), with SC and VAS score differences between genders. Data observations on the secondary protocol reducing motion artifact on the GSR sensor revealed maximum SC values increased by 52% (n=4) during the test condition compared to control in a sit-to-stand test and 19% increase (n=2) in Isokinetic Dynamometer flexion/extension resistance movements.
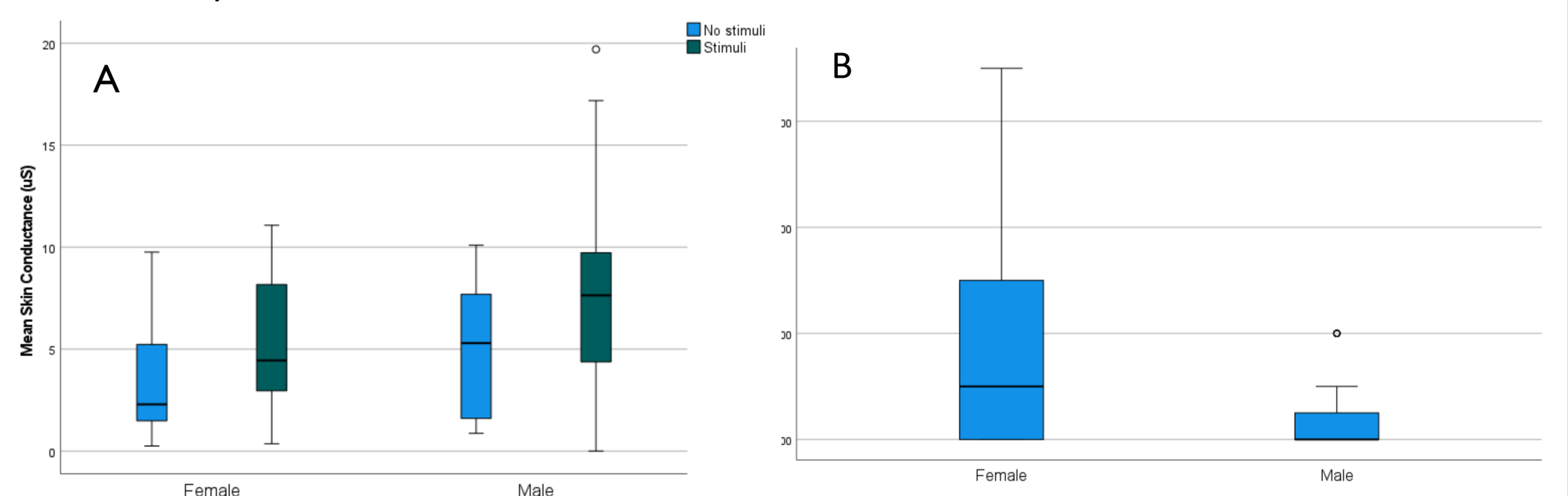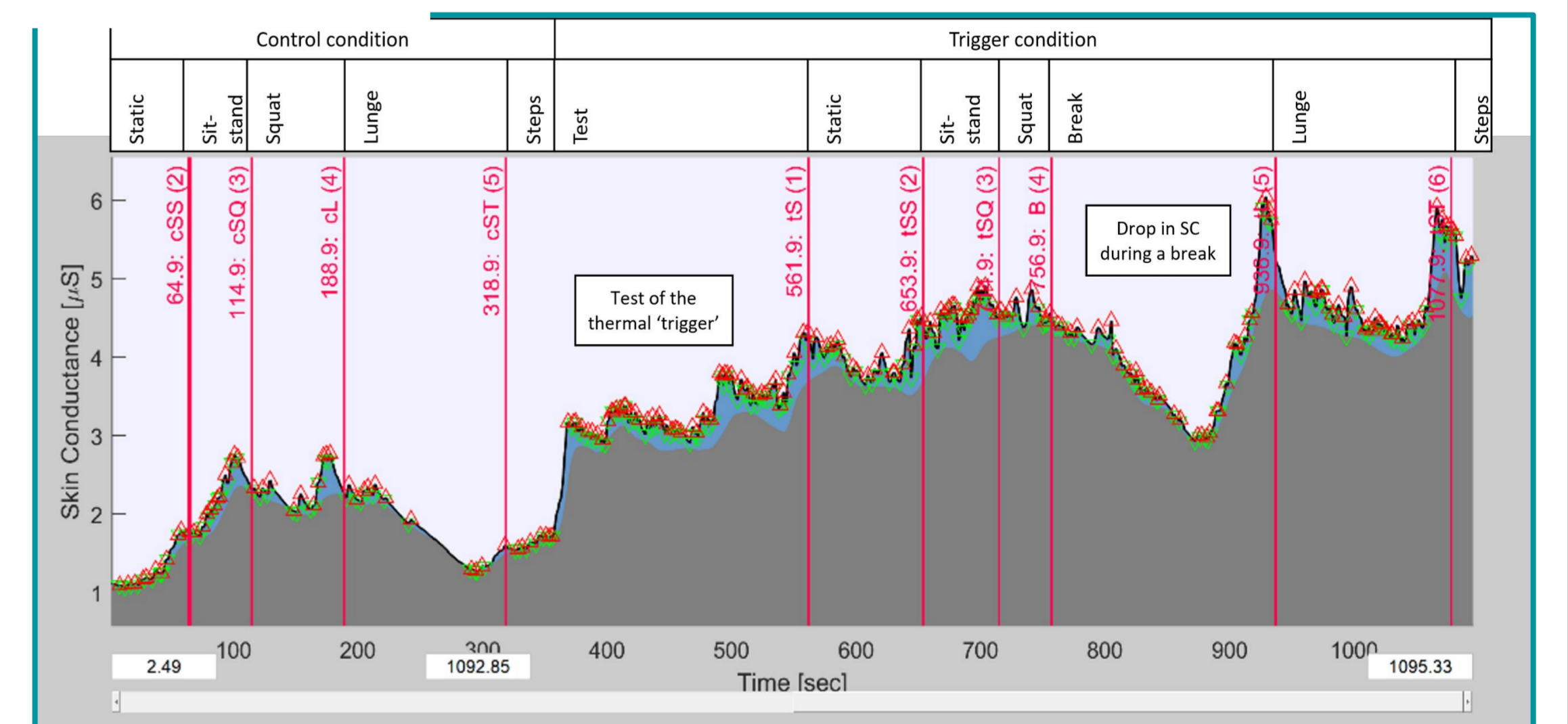

Figure 5: CDA of sample case study participant EDA signal data. Trough-to-peak analysis (n=9) showed mean SCRs for the control condition (M=2±1.2) was significantly lower than after thermal stimulation (M=5.8±3.5, t(8) = -2.9, p = 0.0018).

04 Conclusions

We have demonstrated that physiological and biomechanical data can be linked and quantified in response to a defined nociceptive stimulus (Fig. 3). Mean SC and SCR increased when the thermal stimulus was applied (Fig. 4). Limited literature exists on GSR and EDA data outputs, however, results are similar to Fujita et al. (2001) who used skin impedance electrodes in an OA population. Higher values of SC were observed in male participants in comparison to females for both conditions (Fig. 4), a factor known to have an impact in pain perception but yet to be stablished (Strehle & Gray, 2013). Future work will select key features for nociceptive response across OA patients facilitating development of wearable nociceptive sensors to measure disease progression and treatment effectiveness.

Chen J, Abbod M, Shieh JS. Pain and Stress Detection Using Wearable Sensors and Devices-A Review. Sensors (Basel). 2021 Feb 3;21(4):1030. doi: 10.3390/s21041030.

Benedek, M. and Kaernbach, C. 2010. Decomposition of skin conductance data by means of nonnegative deconvolution. Psychophysiology 47(4), pp. 647-658. doi: 10.1111/j.1469-8986.2009.00972.x

Fujita, T., Yoshio, F., Seiko F, O., Akimitsu, M. and Yasuyuki, T. 2001. Fall of skin impedance and bone and joint pain. Journal of Bone and Mineral Metabolism 19, pp. 175-179.

Strehle, E. M. and Gray, W. K. 2013. Comparison of skin conductance measurements and subjective pain scores in children with minor injuries. Acta Paediatr 102(11), pp. e502-506. doi: 10.1111/apa.12382

Syx, D., Tran, P. B., Miller, R. E. and Malfait, A. M. 2018. Peripheral Mechanisms Contributing to Osteoarthritis Pain. Curr Rheumatol Rep 20(2), p. 9. doi: 10.1007/s11926-018-0716-6