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Utilising electrodermal activity sensor signals to quantify nociceptive response during movement activities.

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Abstract

Objective

With an increasingly ageing population and osteoarthritis prevalence, the quantification of nociceptive signals responsible for painful movements and individual responses could lead to better treatment and monitoring solutions. Changes in electrodermal activity (EDA) can be detected via changes in skin conductance (SC) and measured using finger electrodes on a wearable sensor, providing objective information for increased physiological stress response.

Results

To provide EDA response preliminary data, this was recorded with healthy volunteers on an array of activities while receiving a noxious stimulus. This provides a defined scenario that can be utilised as protocol feasibility testing. Raw signal extraction, processing and statistical analysis was performed using mean SC values on all participant data. Extra exploratory analysis on a case study was incorporated using various decomposition tools. The application of the stimuli resulted in a 35% average increase in mean SC with considerable gender differences in SC and self-reported pain scores. Though EDA parameters are a promising tool for nociceptive response indicators, limitations including motion artifact sensitivities and lack of previous movement-based EDA published data result in restricted analysis understanding. Refined processing pipelines with signal decomposition tools will be necessary to incorporate into a protocol that quantifies nociceptive response clinically meaningfully.

Introduction

Mechanical loading of osteoarthritic joints results in pain-related functional impairment, causing alterations in joint mechanics, tissue structure and physiological nociceptor interactions. Nociceptive signals are concluded to be the major cause of pain from early to late-stage osteoarthritis (OA) (6). At present, there are limited options for objective markers of pain experienced by the patient. This consequently affects diagnosis and treatment decisions. Better understanding of pain utilising nociceptive stimuli and response monitoring could lead to better treatment and monitoring solutions (2).

An EPSRC OATech NetworkPlus [EP/N027264/1] funded Sandpit Proof-of-Concept study aimed to develop this notion using currently available technologies resulting in exploratory sensor data results for nociceptive measures (4). Findings demonstrated linked datasets and a noticeable response to a defined thermal stimulus during a stationary standing test. Further exploration to specifically investigate electrodermal (EDA) was carried out, to contribute to the development of a protocol pipeline to quantify nociceptive response during movement activities.

Changes in EDA can occur due to the activation of the sympathetic nervous system by a noxious stimulus, such as temperature. EDA can be observed as a change in skin conductance (SC), measured in

micro siemens (µS). This is composed of skin conductance level (SCL) - background activity of the nervous system, and skin conductance response (SCR) - the activity related to a stimulus. The aim of this project work was to investigate the significance of SC variations in healthy volunteers in which to provide preliminary data for wider project work investigating a range of wearable sensor data available for detection of nociceptive response.

Method

SC was recorded for 14 volunteers while performing 5 activities (stationary standing, sit-to-stand, squat, lunge and 2-step walk) in the Musculoskeletal Biomechanics Research Facility, School of Engineering, Cardiff University. Written informed consent to participate in the study was obtained from all participants. Tests were performed 3 times during a control condition with no stimuli and a test condition with a thermal stimulus applied (rapid thermal change in temperature of 40-0° within a 2 second loop). This was applied to the participants' right knee using a thermal electrode (Thermal Cutaneous Stimulator, QST.Lab, Strasbourg, France) to define and standardise the nociceptive stimulus. A Visual Analogue Scale (VAS) was used to record self-reported pain scores during each activity.

The SC signal was captured using a galvanic skin response (GSR) sensor (Shimmer3 GSR+ Unit, Shimmer, Dublin, Ireland). Further data was collected on added participants (n=4) to test movements while maintaining the GSR sensor stationary due to observations on motion artifact effects on the sensor. This secondary protocol was achieved with a sit-to-stand while keeping the wrist placed sensor on a table and flexion/extension resistance exercises with participants seated in an Isokinetic Dynamometer (System 4 Pro, Biodex Medical Systems, New York, USA).

A battery of exploratory tests was performed on the EDA signals produced. Raw data extraction and pre-processing was conducted using MATLAB. Mean and maximum SC values were used to perform statistical analysis on all participant data. Ledalab, a signal decomposition tool based on non-negative deconvolution, was used to separate SCR and SCL from raw SC data for further analysis (1). This method was used to conduct standard trough-to-peak (TTP) analysis, to measure significant SCRs above 0.01 µS, and continuous decomposition analysis (CDA), to extract event related parameters. Data extraction and processing via MATLAB scripts (code available in supplementary documentation) was used to extract summary SC values for comparison.

Results

The application of the thermal stimuli resulted in a 35% average increase in mean SC values across initial 14 participants (Females: n=8, Males: n=6) during all exercises (Table 1), with a significant increase identified using non-parametric statistical testing and denoted by *. A significant increase in SC was observed during the stationary standing activity (Z = -3.3, p <0.001). Considerably higher male SC in comparison to females for both conditions and greater female VAS scores compared to males were revealed (Figure 1).

Table 1. Mean skin conductance comparison during different activities with significant increase in the static stationary standing test in the test condition compared to the control.

Activity	Mean skin conductance (µS)				
	Static	Sit-to-stand	Squat	Lunge	Walk
Test condition	2.70 (SD=2.07)*	3.86 (SD=2.74)	4.70 (SD=3.35)	4.56 (SD=3.16)	4.86 (SD=3.46)
Control condition	5.93 (SD=3.97)*	6.19 (SD=4.07)	6.13 (SD=3.90)	7.13 (SD=4.56)	6.21 (SD=4.55)

A rapid exploratory analysis using Ledalab was performed on a sample participant case study with CDA analysis on the full testing session (Figure 2). CDA analysis showed that the overall mean SCRs for the control condition (mean=1.4 ± 1) was significantly lower than the test condition (mean=3 ± 0.7, $t(4) = -4$, $p = 0.016$) within the primary protocol.

Exploratory standard TTP analysis on a smaller sample of participants (n=9) showed that the overall mean SCRs for the no stimuli condition (mean=2 ± 1.2) was significantly lower than for stimuli condition (mean=5.8 ± 3.5, $t(8) = -2.9$, $p = 0.0018$).

Data observations on the secondary protocol reducing motion artifact on the GSR sensor revealed maximum SC values increasing by 52% (n=4) during the test condition compared to control in a sit-to-stand test and 19% increase (n=2) in Biodex flexion/extension resistance movements.

Discussion

Results on all types of analysis revealed increases in SC parameters with the application of a noxious stimulus when compared to a control, providing a compelling case for utilising EDA measures as an indicator for nociceptive response. The results should, however, be interpreted with caution based on the study limitations and exploratory nature, and utilised rather as preliminary data and feasibility testing to build a developed protocol with an EDA data processing pipeline, than as a direct interpretation of EDA results.

Changes in EDA measures can be analysed using mean and maximum SC values, number of significant SCRs when conducting TTP and CDA analysis on Ledalab and comparison to a VAS score when the stimuli is not applied. Analysing differences between the two conditions and different exercises revealing a significant increase in mean SC during a stationary activity, demonstrates a potential indicator when the sensor is not affected by motion artifact. Descriptive differences reveal high increases in maximum SC values when accounting for this in the secondary protocol (52% and 19% increase). These results warrant further investigation in a protocol accounting for both the sensitivities of the sensor and maintaining movement activities within the protocol.

A rapid exploratory analysis (Figure 2) allows the interpretation of signal changes over time and patterns of signal change. Although incorporated into just a single case study, significant differences in these results also justify incorporating the use of signal decomposition tools such as Ledalab as part of a data processing pipeline. Equally, significant differences in results for TTP analysis for SCR exploration also suggest further exploration for data processing to be incorporated in larger number of participants' data, whereas Ledalab is more time consuming to process SCRs on each participant dataset.

With many EDA signal outputs referring to SC changes as indicators of stress and pain in stationary situations, there is a clear lack of investigation into GSR sensor data collection during movement and the data processing pipelines in which to do this effectively. Fujita et al. (3) however previously studied changes in SC during different activities, via monitoring with skin impedance electrodes with an OA population and found reductions in response to painful movement, equating to a reduction in skin ability to resist electrical flow and subsequently an increase in SC. Gender differences in EDA were revealed with higher SC values in males and lower pain reporting (Figure 1); a factor known to have an impact in pain perception yet to be established (5).

While there is a clear relationship between the applied thermal stimuli and changes in SC, quantifiyng the change and utilising effective signal processing techniques is a considerable challenge due to the difficulty in differentiating between event related activity and baseline activity of the nervous system. More investigation into signal decomposition software tools for a more in-depth analysis could help meet this challenge.

Conclusion

The above findings indicate that nociceptive responses induced by a known pain stimulus can likely be quantified using parameters such as mean SC and number of significant SCR with optimisation techniques. The key findings are: (1) Noticeable increase in mean SC and SCRs during the application of stimuli were observed. (2) Higher values of SC were observed in male participants in comparison to female participants for both conditions. (3) Further analysis and techniques should be explored to optimise and refine data collection and signal processing to select key features for nociceptive response across subject cohort groups.

Limitations

Interpretation of sensor data is limited by the sensor sensitivity to motion artifact. Incorporating measures such as those within the secondary protocol or decomposition tools that account for this to determine the true EDA values and their level of change due to the noxious trigger. There is limited previous published data on GSR sensor outputs during movement activities and therefore no pipeline or protocols for this currently exist for comparison. Thus, all data collected in this field is exploratory and novel. Different processing tools may arise in many ways of interpreting data, decreasing options of standardising data outputs. There are feasibility limitations incorporating this sensor data exploration

into a nociceptive response protocol due to the limited technology available and therefore incorporating into clinically meaningful analysis.

Declarations

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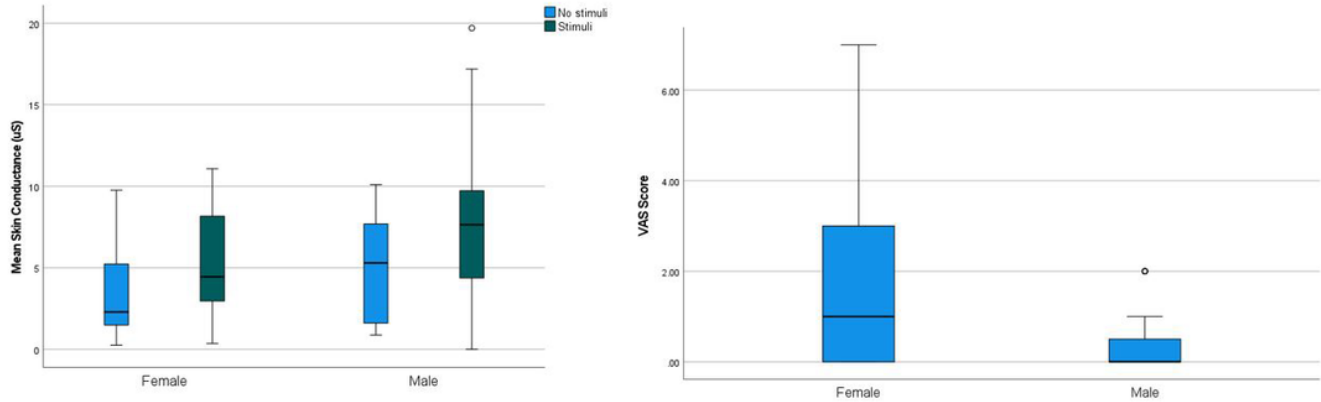
Figures

Figure 1. Male and female skin conductance comparison revealing higher values in males compared to females in both conditions (left) and females revealing higher overall VAS scores compared to males (right).

Figure 1
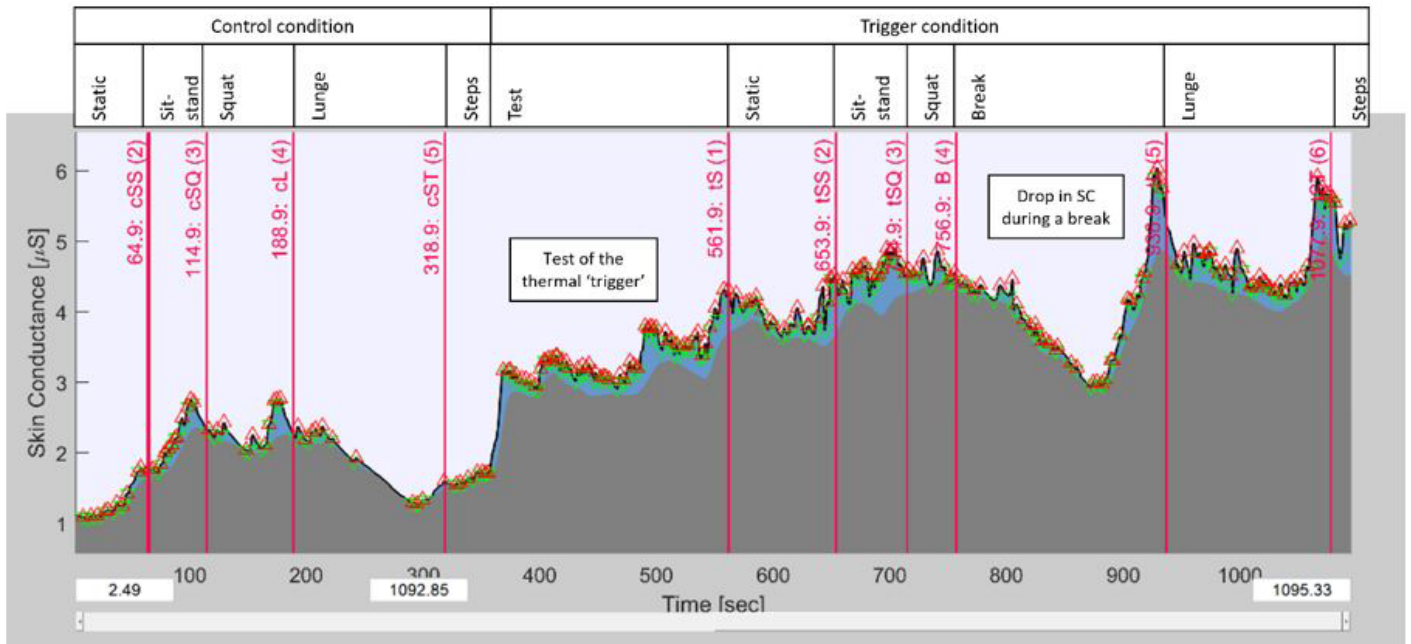
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Figure 2. Rapid CDA decomposition of sample participant EDA signal data for full testing session including both control and test condition using Ledalab.

Figure 2

See image above for figure legend

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementaryMaterial.docx