Data Article

Data acquired by wearable sensors for the evaluation of the flexion-relaxation phenomenon

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\textbf{A B S T R A C T}

The relationship between flexibility and the pattern formed by the surface electromyography activity of the back muscles while performing a dynamic trunk flexion-extension task is not yet thoroughly understood, although many previous studies have adopted it as their focus in the literature. Additionally, several studies have proposed technologies and algorithms to analyse the flexion-relaxation phenomenon, which is defined by myoelectric silence that occurs when the subject’s torso exceeds a certain flexion angle. Before participating in the flexion-relaxation test, subjects involved in the data collection underwent medical examinations, in which their physical condition, perceived pain, and level of disability were reported in their anamnesis. During the flexion-relaxation test, which was conducted with 25 subjects with and without low back pain, subjects wore four surface electromyography electrodes positioned over the back muscles, as well as an inertial sensor to estimate trunk inclination.

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Specifications Table

| Subject                          | Electrical and Electronic Engineering |
|---------------------------------|--------------------------------------|
| Specific subject area           | Wearable sensors to evaluate the flexion-relaxation phenomenon |
| Type of data                    | Data acquired via wearable sensors (text files) |
|                                  | Medical history of the subjects involved in the acquisition process (Portable Document Format files) |
| How data were acquired          | The data were acquired using a wireless inertial sensor (x-IMU, X-Io Technologies Limited) and a wireless electromyography (EMG) system (ZeroWire, Cometa srl) comprising surface electromyography (sEMG) sensors and a force sensitive resistor (FSR) sensor. |
| Data format                     | Raw and processed |
| Parameters for data collection  | Data were acquired from a total of 25 subjects (12 with low back pain and 13 without low back pain) who wore inertial and sEMG sensors. The flexion-extension test was carried out in a climate-controlled laboratory to ensure a time-invariant procedure that was unaffected by external factors, such as the environment. |
| Description of data collection  | The subjects wore the inertial sensor above their first lumbar vertebrae and the electrodes of the four sEMG sensors were positioned along the longissimus left, longissimus right, multifidus left, and multifidus right muscle fibres of the back. During the flexion-extension test, each subject was asked to repeat the research protocol four times, which comprised the following: (I) maintain a vertically upright position for approximately four seconds; (II) bend forward to naturally achieve the full flexion position; (III) maintain the position for approximately four seconds; (IV) return to the vertically upright position. |
| Data source location            | Santo Stefano Rehabilitation Institute, 62,018 Porto Potenza Picena, Italy |
|                                 | Latitude and longitude: 43.37076471, 13.6922881 |
| Data accessibility              | Repository name: Mendeley Data |
|                                 | Data identification number: 10.17632/g7pdm5prvp.1 |
|                                 | Direct URL to data: |
|                                 | https://data.mendeley.com/datasets/g7pdm5prvp/draft?a = c374fdea-5885-4446-ac87-bf579c61d472 |
| Related research article        | Paoletti, M.; Belli, A.; Palma, L.; Vallasciani, M.; Pierleoni, P. A Wireless Body Sensor Network for Clinical Assessment of the Flexion-Relaxation Phenomenon. Electronics 2020, 9, 1044. [1] |
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Value of the Data

- The data are useful in investigating the flexion-relaxation phenomenon and its relationship with low back pain and related disabilities.
- Researchers and medical staff can benefit from these data to propose new systems and methodologies for evaluating the flexion-relaxation phenomenon (FRP), which may overcome the limitations of the traditional visual inspection method.
- Future studies could examine the data that were collected to observe different patterns and draw connections between the patterns and physical conditions.
- Data were acquired simultaneously by two different sensors to examine the following signals: electromyography and subjects' trunk inclination.

Data description

The proposed dataset contains elements collected during the research protocol that was conducted to evaluate the FRP, as it relates to the back muscles of subjects with and without low back pain (LBP) [2]. The measurement system used during the data collection is illustrated in Fig. 1.
Fig. 1. Practical application of the wireless body sensor network (WBSN). The pair of electrodes for each channel is connected to the wireless sensor. An inertial measurement unit (IMU) is placed at the centre of the back and the FSR is connected to the wireless sensor directly above. LSX = left longissimus, LDX = right longissimus, MSX = left multifidus, MDX = right multifidus.

The dataset is organised into two folders: Raw and Supplementary Data.

Each folder, which includes the raw data and identified by 'IDx' (where x = 01, 02, ..., 25 indicates the subject’s identification number), contains three files: one Portable Document Format file with the subject’s anamnesis (IDx – Anamnesis.pdf) and two text files containing the data that were simultaneously acquired through an inertial sensor (IDx – Inertial.txt) and an sEMG sensor system (IDx – sEMG.txt):

- The 'IDx – Anamnesis.pdf' file contains data related to a subject’s physical condition, perceived pain, and level of disability [3,4,5,6].
- The 'IDx – Inertial.txt' file contains the wireless inertial sensor measurements acquired during the test. This record comprises one column indicating the acquisition time (sampling frequency = 128 Hz) and nine columns representing the data collected from the triaxial gyroscope, accelerometer, and magnetometer, all of which were incorporated into the inertial sensor. The 'IDx – Inertial.txt' file is organised into ten columns as follows:

1. Time series (s): inertial acquisition time.
2. Gyroscope x (°/s): angular velocity on the x axis of the gyroscope.
3. Gyroscope y (°/s): angular velocity on the y axis of the gyroscope.
4. Gyroscope z (°/s): angular velocity on the z axis of the gyroscope.
5. Acc x (g): acceleration on the x axis of the accelerometer.
6. Acc y (g): acceleration on the y axis of the accelerometer.
7. Acc z (g): acceleration on the z axis of the accelerometer.
8. Magn x (G): magnitude on the x axis of the magnetometer.
9. Magn y (G): magnitude on the y axis of the magnetometer.
10. Magn z (G): magnitude on the z axis of the magnetometer.
Table 1

Red colour identifies subjects with low back pain (are patients that typically have LBP but that during the test could have or not LBP). Green colour identifies subjects without low back pain called control subjects.

| ID  | GENDER | AGE | GROUP         | NRS-11 | BACKILL |
|-----|--------|-----|---------------|--------|---------|
| 01  | Female | 51  | LBP PATIENT   | 8      | 39/52   |
| 02  | Female | 40  | CONTROL       | 0      | 52/52   |
| 03  | Female | 34  | CONTROL       | 0      | 52/52   |
| 04  | Male   | 57  | LBP PATIENT   | 5      | 43/52   |
| 05  | Male   | 30  | LBP PATIENT   | 9      | 38/52   |
| 06  | Male   | 31  | CONTROL       | 0      | 52/52   |
| 07  | Male   | 35  | CONTROL       | 0      | 52/52   |
| 08  | Male   | 25  | CONTROL       | 0      | 52/52   |
| 09  | Male   | 58  | LBP PATIENT   | 3      | 49/52   |
| 10  | Female | 52  | LBP PATIENT   | 3      | 46/52   |
| 11  | Female | 46  | LBP PATIENT   | 3      | 41/52   |
| 12  | Female | 40  | CONTROL       | 0      | 52/52   |
| 13  | Male   | 49  | LBP PATIENT   | 2      | 39/52   |
| 14  | Female | 49  | LBP PATIENT   | 6      | 39/52   |
| 15  | Female | 51  | LBP PATIENT   | 2      | 38/52   |
| 16  | Female | 60  | CONTROL       | 0      | 52/52   |
| 17  | Female | 36  | CONTROL       | 0      | 52/52   |
| 18  | Male   | 22  | CONTROL       | 0      | 52/52   |
| 19  | Male   | 52  | LBP PATIENT   | 1      | 45/52   |
| 20  | Female | 22  | CONTROL       | 0      | 52/52   |
| 21  | Male   | 60  | CONTROL       | 0      | 52/52   |
| 22  | Female | 51  | CONTROL       | 0      | 52/52   |
| 23  | Male   | 60  | LBP PATIENT   | 8      | 34/52   |
| 24  | Male   | 61  | LBP PATIENT   | 3      | 52/52   |
| 25  | Male   | 52  | CONTROL       | 0      | 52/52   |

- ‘IDx – sEMG.txt’ contains the measurements acquired by the sEMG sensor system worn by each subject during the test. The record comprises one column indicating the acquisition time (sampling frequency 2 kHz) and four columns representing the electromyographic signal acquired by each sEMG sensor. The ‘IDx – sEMG.txt’ files are organised into five columns as follows:

1. Time series (s): sEMG acquisition time.
2. sEMG1 (uV): sEMG signal acquired from the electrodes on the left longissimus muscle.
3. sEMG2 (uV): sEMG signal acquired from the electrodes on the right longissimus muscle.
4. sEMG3 (uV): sEMG signal acquired from the electrodes on the left multifidus muscle.
5. sEMG4 (uV): sEMG signal acquired from the electrodes on the right multifidus muscle.

Videos 1 and 2 in the Supplementary Data folder are demonstration videos that explain the flexion-extension test, while Table 1 summarises information pertaining to the subjects involved in the data collection and is organised into six columns as follows:

1. ID - subject’s identification number (for privacy reason).
2. GENDER - subject’s gender.
3. AGE - subject’s age.
4. GROUP - group to which the subject belongs: control group (subjects without LBP) or patient group (subjects with LBP).
5. NRS-11 - mean pain value typically perceived, evaluated using the Numeric Rating Scale (NRS-11 scale).
6. BACkILL - disability perceived in everyday life and measured using the Backill questionnaire.

Table 2 shows the specific pain level perceived by each subject on an ongoing basis. The first value (typical mean value) is the same as that represented in Table 1 and indicates whether the subject is designated as part of the control or patient group. The other values more specifically detail the level of perceived pain during the flexion-relaxation test (before/during/after).

Experimental design, materials, and methods

It is interesting to observe the results pertaining to different subjects when they bend forward (during the flexion-relaxation test), to evaluate the surface electromyography patterns and identify the presence or absence of FRP [7,8]. This physiological phenomenon is defined by myoelectric silence, which occurs when a subject’s torso exceeds a certain flexion angle: it can be observed in most healthy subjects but is typically absent in patients with LBP. Unfortunately, FRP is not present in all healthy subjects, nor is it always absent in subjects with LBP; some subjects do not manifest FRP despite being healthy, while others do manifest FRP in addition to having LBP. This is the primary reason this phenomenon is still studied today.

A series of techniques and algorithms used to quantify FRP have been developed and studied over time [9]. Each method is characterised based on its ability to successfully identify the FRP presence/absence.

The sEMG signals measured must be correlated with the data related to the subject’s inclination, which were acquired during the same flexion-relaxation test. The dataset comprises the surface electromyography and inertial sensor measurements to study the FRP on the back muscles of different subjects. The collected data were then compared with the anamnestic information that was acquired during the visit [2].

The participants signed an informed written consent before the data collection, which was carried out in accordance with the Declaration of Helsinki. Potential participants underwent a medical examination to determine their eligibility for inclusion in the research protocol. The subjects involved in the data collection were identified by an ID number and divided into two groups: the control group (subjects without LBP) and patient group (subjects with LBP). The data collection comprised 25 case studies (12 female and 13 male): 13 in the control group and 12 in the patient group, as reported in Table 1.

Below, the inclusion and exclusion criteria for the research protocol are shown as follows:

A. exclusion criteria

- Severe structural deformities (e.g. kyphoscoliosis).
- Systemic diseases (a disease that affects multiple apparatuses or organs, often related to rheumatic diseases, or rare diseases such as genetic disorders) or neoplastic diseases (tumours).
- Significant psychiatric diseases.
- Pregnancy.
- Any other medical condition that could interfere with the correct execution of the protocol.

B. inclusion criteria for individuals in the control group

- Aged between 18 and 65 years old.
- No history of musculoskeletal or abdominal pain.
- Not under medical treatment.
Table 2
The table shows what happens in pain perception, for each cycle (1°, 2°, 3°, 4°) and each phase (S=STANDING, F=FLEXION, FF=FULL FLEXION, E=EXTENSION), during the flexion-relaxation test.

| ID | TYPICAL MEAN VALUE | BEFORE TEST | 1° CYCLE | 2° CYCLE | 3° CYCLE | 4° CYCLE | AFTER TEST |
|----|---------------------|-------------|----------|----------|----------|----------|------------|
|    |                     | S | F | FF | E | S | F | FF | E | S | F | FF | E | S | F | FF | E |
| 01 |                     | 6 | 7 | 7  | 7  | 7  | 8 | 7  | 7  | 7  | 8 | 7  | 7  | 7  | 8 | 7  | 7  | 7  | 8  |
| 02 |                     | 0 | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0  |
| 03 |                     | 0 | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0  |
| 04 |                     | 0 | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0  |
| 05 |                     | 0 | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0  |
| 06 |                     | 0 | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0  |
| 07 |                     | 0 | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0  |
| 08 |                     | 0 | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0  |
| 09 |                     | 0 | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0  |
| 10 |                     | 0 | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0  |
| 11 |                     | 0 | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0  |
| 12 |                     | 0 | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0  |
| 13 |                     | 0 | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0  |
| 14 |                     | 0 | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0  |
| 15 |                     | 0 | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0  |
| 16 |                     | 0 | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0  |
| 17 |                     | 0 | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0  |
| 18 |                     | 0 | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0  |
| 19 |                     | 0 | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0  |
| 20 |                     | 0 | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0  |
| 21 |                     | 0 | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0  |
| 22 |                     | 0 | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0  |
| 23 |                     | 0 | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0  |
| 24 |                     | 0 | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0  |
| 25 |                     | 0 | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0 | 0  | 0  | 0  | 0  |
• No episodes of LBP within the last six months.
• No consultation with a therapist or doctor regarding LBP problems.

C. inclusion criteria for patient group

• Aged between 18 and 65 years old.
• Available to participate in a pain management program.
• Actively suffering from LBP (LBP type should be specified, and it should also be clarified whether it is present when the test is executed).

Pain and disability, which were reported in each subject’s anamnesis, were identified using the numeric rating scale (NRS-11 scale) and the Backill questionnaire, respectively. To better evaluate and quantify the static or dynamic pain perceived by the subject, the NRS-11 scale was applied before, during, and after the execution of the flexion-relaxation test (Table 2). Some subjects in the patient group did not have LBP during the test (a pain-free period) but typically suffer from LBP; for this reason, a mean LBP value was introduced, as reported in Table 2, to better explain this aspect of the subjects’ condition.

Before starting the acquisition, the subjects were properly trained to ensure valid results and were given the following instructions:

1. Before the test, no movement can be performed.
2. At the point of maximum flexion, the knees must not be flexed.
3. The speed of movement is self-determined.

During the test, the subject began in a standing position, moved into the full flexion phase (typically between 85° and 95°), and then returned to the starting position. These movements define a cycle that can be divided into four phases: standing, flexion, full flexion, and extension. In the data collection, the flexion-relaxation test was deemed complete after the subject had repeated the cycle four times.

The sEMG system and the inertial measurement unit were used together to understand the subject’s muscular activation pattern during each phase of each cycle in the flexion-relaxation test. The sEMG sensor system acquired the surface electromyography signals from the subject’s back muscles and the inertial sensor collected data from which it is possible to estimate the angle of the back’s inclination. The flexion-extension speed, which is extracted from the inertial sensor, is another important parameter that is useful in evaluating whether the test was executed correctly, together with the range of motion. During the flexion-relaxation test, the subject wore the inertial sensor above the first lumbar vertebra and the four sEMG sensors were placed on the right longissimus, left longissimus, right multifidus, and left multifidus muscles, respectively. As depicted in Fig. 1, the FSR sensor of the wireless EMG system is positioned above the inertial sensor to allow the simultaneous acquisition of a physical event. Since the EMG system and the inertial sensor record data independently, a physical event is required to synchronise the two systems. The physical event was achieved by instructing the medical staff to tap the FSR sensor three consecutive times with their finger before starting the flexion-relaxation test. This physical event resulted in large acceleration spikes on the inertial sensor, which were also visible in the signal acquired by the FSR sensor of the EMG system. The synchronization was carried out in the post-processing stage using Matlab software.

CRediT author statement

Michele Paoletti: Methodology, Software, Formal analysis, Investigation, Validation, Data curation, Writing - Original Draft Alberto Belli: Conceptualization, Project administration, Supervision, Writing - Original Draft, Writing - Review & Editing Lorenzo Palma: Conceptualization,
Project administration, Supervision, Writing - Review & Editing Michele Paniccia: Conceptualization, Resources, Supervision Francesca Tombolini: Resources, Data curation, Investigation, Writing - Review & Editing Antonio Ruggiero: Resources, Data curation, Investigation Massimo Vallasciani: Resources, Supervision Paola Pierleoni: Conceptualization, Project administration, Supervision

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships which have, or could be perceived to have, influenced the work reported in this paper.

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