

EMGFlow: A Python package for pre-processing and feature extraction of electromyographic signals

William L. Conley¹ and Steven R. Livingstone¹

¹ Department of Computer Science, Ontario Tech University, Oshawa, Canada ¶ Corresponding author

DOI: [10.xxxxxx/draft](https://doi.org/10.xxxxxx/draft)

Software

- [Review](#)
- [Repository](#)
- [Archive](#)

Editor: [Open Journals](#)

Reviewers:

- [@openjournals](#)

Submitted: 01 January 1970

Published: unpublished

License

Authors of papers retain copyright and release the work under a Creative Commons Attribution 4.0 International License ([CC BY 4.0](#)).

Summary

Surface electromyography (sEMG) is increasingly used to study human physiology and behaviour, spurred by advances in deep learning and wearable sensors. Here, we introduce *EMGFlow*, an open-source Python package that streamlines preprocessing and feature extraction for sEMG signals. Tailored for batch processing, *EMGFlow* handles large datasets typical in machine learning, extracting a comprehensive set of 33 statistical features across time and frequency domains. The package supports flexible file selection with regular expressions and uses Pandas DataFrames end-to-end to facilitate interoperability. An interactive dashboard visualises signals at each preprocessing stage to aid user decisions. *EMGFlow* is distributed under the GNU General Public License v3.0 (GPL-3.0) and is available on PyPI. Documentation with guides, API references, and runnable examples is available at <https://wiiison.github.io/EMGFlow-Python-Package/>.

Statement of Need

Although several packages process physiological and neurological signals, support for sEMG has remained limited. Many lack a comprehensive feature set for sEMG, forcing researchers to use a patchwork of tools. Others focus on event detection with GUI-centric workflows that suit continuous recordings of a single participant, but complicate batch feature extraction common in machine learning (Abadi et al., 2015; Chen et al., 2022; Koelstra et al., 2012; Schmidt et al., 2018; Sharma et al., 2019; Zhang et al., 2016).

EMGFlow, a portmanteau of EMG and Workflow, fills this gap by providing a flexible pipeline for extracting a wide range of sEMG features, with a scalable design suited for large datasets. An overview of package metadata is presented in Table 1.

Metadata	Description
License	GPLv3
Implementation	Python >= 3.9
Code repository	https://github.com/Willson/EMGFlow-Python-Package
Documentation	https://wiiison.github.io/EMGFlow-Python-Package
PyPI installation	<code>pip install EMGFlow</code>

Table 1: *EMGFlow* package metadata.

Comparison to Other Packages

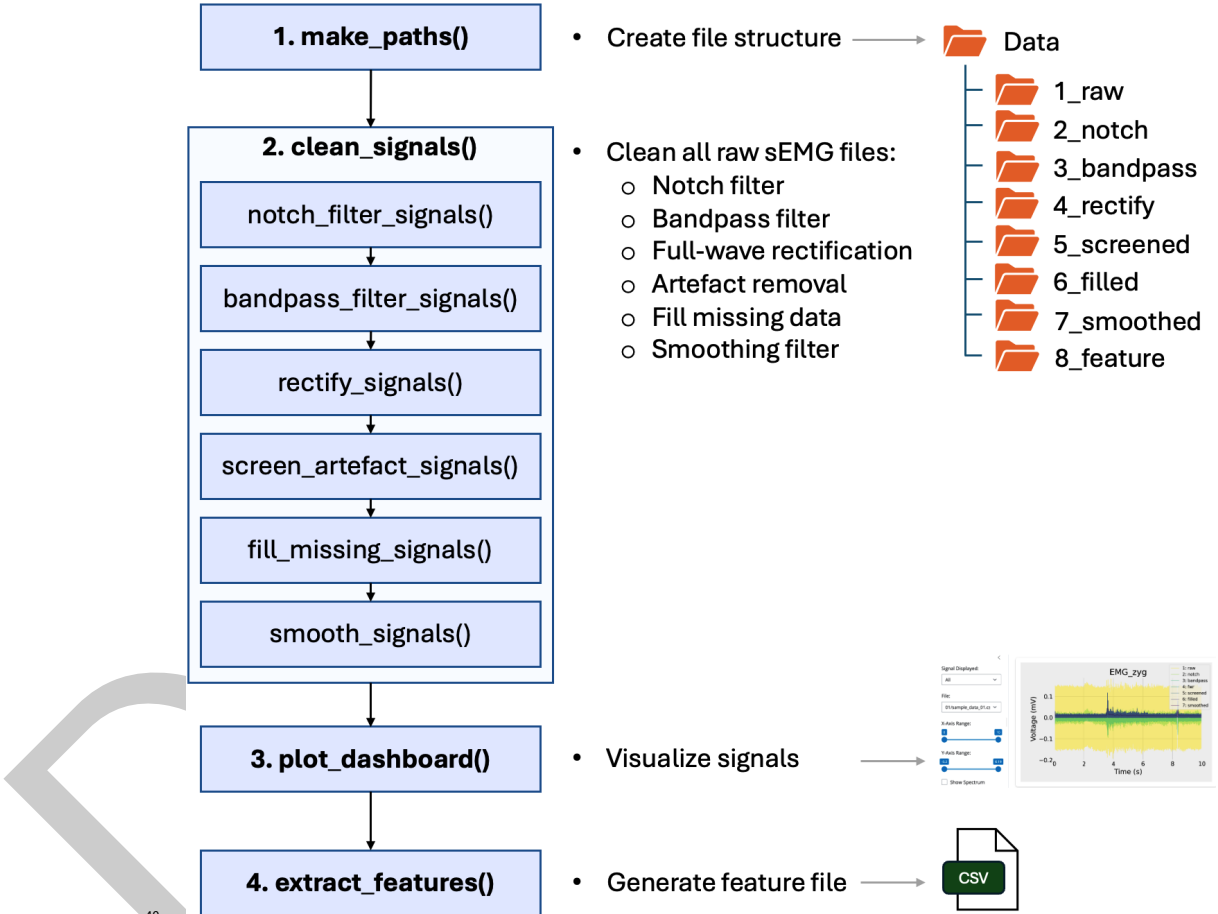
Compared to existing toolkits, *EMGFlow* provides a broader, sEMG-specific library of 33 features (Bizzego et al., 2019; Bota et al., 2024; Makowski et al., 2021; Sjak-Shie, n.d.;

31 Soleymani et al., 2017). Its dashboard visualises batch-processed files rather than single
32 recordings, enabling inspection of preprocessing effects across datasets (Gabrieli et al., 2020).
33 Adjustable filters and smoothing support international mains standards (50 vs 60 Hz), a subtle
34 detail some packages omit.

35 **Features**

36 **A Simplified Workflow**

37 Extracting features from large datasets is fundamental in machine learning and quantitative
38 analysis. *EMGFlow* supports batch-processing, enabling fully or semi-automated treatment of
39 sEMG recordings. Figure 1 outlines the pipeline.



40
41 **Figure 1:** An overview of the processing pipeline.

42 Example 1 demonstrates end-to-end preprocessing and feature extraction. We create project
43 paths with `make_paths()` and load bundled sample data with `make_sample_data()` (adapted
44 from PeakAffectDS (Greene et al., 2022)). Next, we run automated preprocessing via
45 `clean_signals()` using sensible, literature-based defaults, and then write a plaintext CSV of
46 33 features per file with `extract_features()`.

```
# %% Example 1: Quick start (full pipeline)
import EMGFlow

# Create project paths
path_names = EMGFlow.make_paths()

# Load sample data
EMGFlow.make_sample_data(path_names)

# Preprocess signals
EMGFlow.clean_signals(path_names, sampling_rate=2000, notch_f0=50)

# Extract features to disk "Features.csv"
EMGFlow.extract_features(path_names, sampling_rate=2000)
```

47 Tailored Preprocessing

48 Example 2 shows how advanced users can tailor low-level preprocessing. After setup, Step 1
49 applies a notch filter to remove AC mains interference. Most functions use common sense
50 defaults, which can be modified task-wide or for select cases. For instance, the sample data
51 were recorded in New Zealand (200-240 VAC 50Hz), so we set the notch frequency and quality
52 factor accordingly.

```
# %% Example 2: Tailored preprocessing
import EMGFlow

# Setup workspace
path_names = EMGFlow.make_paths()
EMGFlow.make_sample_data(path_names)

# Data sampling rate
sampling_rate = 2000

# Notch filter for mains hum (Hz, Q-score)
notch_main = [(50, 5)]

# Columns names containing sEMG (Zygomaticus major, Corrugator supercilii)
muscles = ['EMG_zyg', 'EMG_cor']

# Step 1. Apply notch filter to all files in 1_raw, writing output to 2_notch
EMGFlow.notch_filter_signals(path_names['raw'], path_names['notch'],
                             muscles, sampling_rate, notch_main)

53 EMGFlow preserves the raw directory structure and mirrors it at each pipeline stage. All
54 preprocessing functions accept an optional regular expression to target specific files. In Step 1b,
55 we apply an additional notch filter at 150 Hz (the 3rd harmonic) only to files in subfolder /01.

# Custom notch settings
notch_custom = [(150, 25)]
path_pattern = '^01/'

# Step 1b. Apply custom notch filter all to files in subfolder "/01"
EMGFlow.notch_filter_signals(path_names['notch'], path_names['notch'],
                             muscles, sampling_rate, notch_custom,
                             expression=path_pattern)
```

56 Interference Attenuation

57 Surface EMG is susceptible to multiple sources of interference that affect the signal with
 58 distinct spectral signatures (Boyer et al., 2023). Band-pass filtering is typically performed
 59 in Step 2 to isolate the frequency spectrum of human muscle activity. Common passbands
 60 are 10-500 Hz (Livingstone et al., 2016; McManus et al., 2020; Sato et al., 2021; Tamietto
 61 et al., 2009), though precise edges vary by domain (Abadi et al., 2015). Step 3 performs
 62 full-wave rectification, converting negative values to positive (Dakin et al., 2014; Rutkowska et
 63 al., 2024).

```
# Passband edges (low, high)
passband_edges = [20, 450]
```

```
# Step 2. Apply band-pass filter
```

```
EMGFlow.bandpass_filter_signals(path_names['notch'], path_names['bandpass'],
                                muscles, sampling_rate, passband_edges)
```

```
# Step 3. Apply full-wave rectifier
```

```
EMGFlow.rectify_signals(path_names['bandpass'], path_names['fwr'], muscles)
```

64 Signal artefacts are another source of contamination and span a diverse range of phenomenon
 65 including thermal noise, eyeblinks, and random noise bursts (Boyer et al., 2023). These can
 66 be mitigated with screen_artefacts(), which applies a Hampel filter (default), or Wiener
 67 filter, both reported as robust denoisers (Allen, 2009; Bhowmik et al., 2017; Jarrah et al.,
 68 2022). Because artefact profiles vary across projects, we recommend visual inspection
 69 with the interactive dashboard to tune n_sigma (Hampel) and window_ms (Bhowmik et al.,
 70 2017; Pearson et al., 2016). In Step 4 we target /02/sample_data_04.csv which contains an
 71 artificial, band-limited noise pulse, and copy other files forward untouched.

```
screen_pattern = r'^02/sample_data_04\.csv$'
```

```
# Step 4. Apply Hampel artefact filter to 02/sample_data_04.csv
```

```
EMGFlow.screen_artefact_signals(path_names['fwr'], path_names['screened'],
                                muscles, sampling_rate,
                                expression=screen_pattern, copy_unmatched=True)
```

72 Missing data consisting of brief gaps or NaNs can be filled with fill_missing_signals(),
 73 which defaults to Piecewise Cubic Hermite Interpolating Polynomial (method=pchip). PCHIP
 74 is shape-preserving, monotonicity-respecting, and avoids overshoot - properties desirable for
 75 sEMG (SciPy Community, 2025). Cubic spline is also available (Shin et al., 2021). In Step 5,
 76 we address artificially injected gaps with PCHIP.

77 In Step 6, optional smoothing removes residual high-frequency noise before feature extraction.
 78 The default smoother RMS, equal to the square root of the total power, estimates signal
 79 amplitude and is commonly used in sEMG (McManus et al., 2020). Boxcar, Gaussian, and
 80 LOESS alternatives are also provided.

```
# Step 5. Fill missing data
```

```
EMGFlow.fill_missing_signals(path_names['screened'], path_names['filled'],
                              muscles, sampling_rate)
```

```
# Step 6. Apply smoothing filter
```

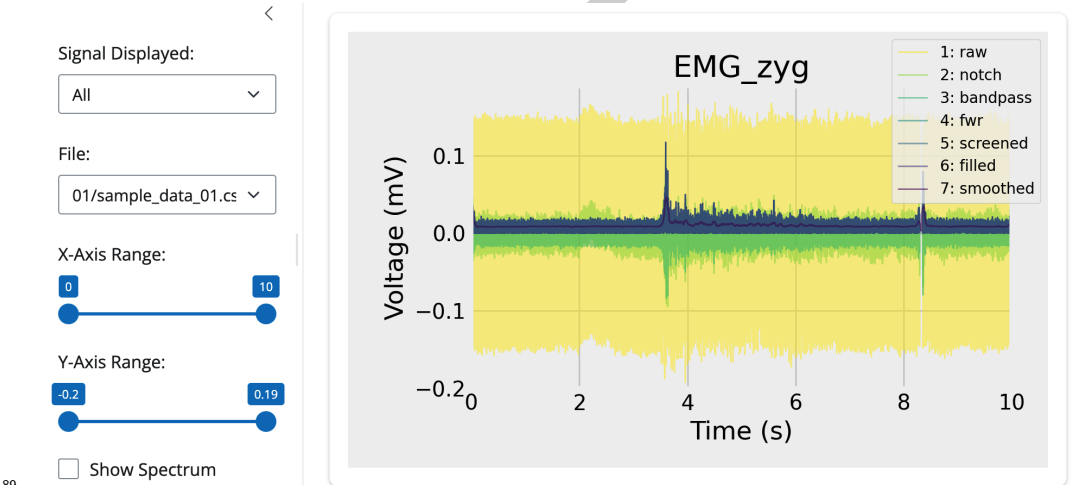
```
EMGFlow.smooth_signals(path_names['filled'], path_names['smooth'],
                        muscles, sampling_rate)
```

81 **An Interactive Dashboard**

82 *EMGFlow* includes a Shiny dashboard for visualising preprocessing effects. Pipeline steps can
83 be overlaid or shown individually, and files are selected from a drop-down menu. A checkbox
84 toggles between a time-domain amplitude view and a spectral view that displays the Power
85 Spectral Density (PSD). The amplitude view exposes transients and drift, guiding selection of
86 passband edges and confirming that filtering preserves waveform shape. The PSD highlights
87 mains peaks and harmonics, guiding the choice of notch parameters (f_0 , Q). Below we generate
88 a dashboard for the Zygomaticus major channel.

```
# Column and measurement units to plot
show_muscle = 'EMG_zyg'
units = 'mV'

# Plot data for the "EMG_zyg" column
EMGFlow.plot_dashboard(path_names, show_muscle, units)
```



89 **Figure 2:** *EMGFlow*'s interactive dashboard visualizing effects of different preprocessing steps
90 on batch processed files.
91

92 **An Extensive Feature Library**

93 After preprocessing, files are ready for feature extraction. Surface EMG records voltage
94 differences at the skin arising from the summed motor-unit action potentials (Fridlund &
95 Cacioppo, 1986), yielding an interference signal whose amplitude (time domain) and spectrum
96 (frequency domain) reflect motor-unit recruitment, discharge rates, and muscle-fiber conduction
97 velocity (De Luca, 2008; McManus et al., 2020). *EMGFlow* extracts 33 features across time
98 and frequency domains, as listed in Table 2.

Domain	Feature
Temporal	minV, maxV, meanV, stdV, skewV, kurtosisV, maxF, IEMG, MAV, MMAV1, MMAV2, SSI, VAR, VOrder, RMS, WL, WAMP, LOG
Spectral	MFL, AP, SpecFlux, MDF, MNF, TwitchRatio, TwitchIndex, TwitchSlope, SC, SF, SS, SDec, SEntropy, SRoll, SBW

99 **Table 2:** Features extracted from sEMG signals.
100 We conclude Example 2 by extracting features and previewing the first rows.

```
# Step 7. Extract features and save results in "Features.csv"
df = EMGFlow.extract_features(path_names, muscles, sampling_rate)

# Inspect features
df.round(4).head()

"""
      File_Path  EMG_zyg_Min  ...  EMG_cor_SB  EMG_cor_Spectral_PCT_Missing
0  01/sample_data_01.csv    0.0031  ...    543.1803                    0.0050
1  01/sample_data_02.csv    0.0050  ...    346.9988                    0.0002
2  02/sample_data_03.csv    0.0001  ...    2183.3999                    0.0153
3  02/sample_data_04.csv    0.0024  ...    1051.9444                    0.0000

[4 rows x 71 columns]
"""
```

101 Temporal Feature Extraction

102 The set of 18 time-domain features include statistical moments (mean, variance, skew, kurtosis)
 103 and sEMG-specific measures. Examples include Willison amplitude, a proxy for motor unit
 104 firing that counts threshold crossings, and log-detector, an estimator of muscle force (Tkach
 105 et al., 2010). Time-domain features can be computed after the first three preprocessing steps
 106 (notch, band-pass, rectify); Steps 4-6 are optional.

107 Spectral Feature Extraction

108 The 15 frequency-domain features characterise power-spectrum shape and distribution. Median
 109 frequency (Phinyomark et al., 2009) tracks changes in conduction velocity and is used in
 110 muscle fatigue assessments (Boxtel et al., 1983; Lindstrom et al., 1977; McManus et al., 2020).
 111 Standard measures include spectral centroid, flatness, entropy, and roll-off. We also introduce
 112 Twitch Ratio, adapted from speech analysis (Eyben et al., 2016), defined as the ratio of upper-
 113 to lower-band energy with a 60 Hz boundary between slow- and fast-twitch muscles fibres
 114 (Hegedus et al., 2020).

115 Spectral features are computed by converting the Step 2 band-limited signal into a PSD. To
 116 avoid discarding otherwise valid Welch frames due to isolated dropouts, we perform constrained
 117 interpolation for micro-gaps <5 samples (2.5–5 ms at 1–2 kHz) and leave longer gaps as
 118 NaN so affected frames are rejected (Jas et al., 2017). This limits interpolation bias, which
 119 increases with gap size and density (Clifford & Tarassenko, 2005; Munteanu et al., 2016). We
 120 do not apply Steps 3–6 before PSD: rectification is non-linear and distorts spectra (Farina et
 121 al., 2013; McClelland et al., 2014; Neto & Christou, 2010); artefact-replacement filters can
 122 violate stationarity assumptions for FFT-based PSD; and smoothing suppresses high-frequency
 123 content. We estimate PSD with Welch's method using Hann windows, 50% overlap, and
 124 rejection of segments with remaining invalid samples, and mean averaging of retained spectra
 125 to form a long-term spectrum (Welch, 1967).

126 Missing Data Reporting

127 EMGFlow reports the percentage of missing data in the final temporal and spectral series
 128 as _Temporal_PCT_Missing and _Spectral_PCT_Missing in the extracted feature DataFrame,
 129 enabling downstream exclusion criteria where appropriate.

130 Documentation and Testing

131 The documentation site (<https://wiiison.github.io/EMGFlow-Python-Package>) is built with
 132 VitePress. It provides a Quick-Start, an example gallery from minimal to advanced pipelines,

an API reference with executable snippets, and a detailed catalogue of all mathematical feature definitions. Mermaid diagrams give a high-level view of the module structure.

Code reliability is enforced via an automated *unittest* suite run on every commit via GitHub Actions. The same tests can be executed locally; instructions and examples are provided on the documentation site. This ensures that changes remain reliable across platforms.

Community Guidelines

Contributions are welcome via issues or pull requests. Suggestions for features, usage tips, and questions can also be raised through GitHub Discussions.

AI Usage Disclosure

- Source code: All EMGFlow source code and test cases were written manually by the authors.
- Manuscript: The authors used GPT-5 to edit a final draft of the manuscript for flow, tone, and grammatical correctness. The authors reviewed and edited the content as needed and take full responsibility for the content of the publication.
- Documentation: The documentation website was created manually by the authors. The authors used GPT-5 to edit the “About electromyography” page. The authors reviewed and edited the content of this page and take full responsibility for the content of the page. All remaining documentation content was written manually by the authors.

Acknowledgements

We acknowledge the support of the Natural Sciences and Engineering Research Council of Canada (NSERC, #2023-03786) and the Faculty of Science, Ontario Tech University.

Author contributions

S.R.L. conceptualised the project. W.L.C. and S.R.L. designed the toolbox functionality. W.L.C. wrote the toolbox code and maintains the GitHub repository. W.L.C. and S.R.L. maintain the documentation website. S.R.L. prepared manuscript figures; W.L.C. prepared repository and documentation figures. S.R.L. and W.L.C. prepared the manuscript and approved the final version.

References

- Abadi, M. K., Subramanian, R., Kia, S. M., Avesani, P., Patras, I., & Sebe, N. (2015). DECAF: MEG-Based multimodal database for decoding affective physiological responses. *IEEE Transactions on Affective Computing*, 6(3), 209–222. <https://doi.org/10.1109/TAFFC.2015.2392932>
- Allen, D. P. (2009). A frequency domain hampel filter for blind rejection of sinusoidal interference from electromyograms. *Journal of Neuroscience Methods*, 177(2), 303–310. <https://doi.org/10.1016/j.jneumeth.2008.10.019>
- Bhowmik, S., Jelfs, B., Arjunan, S. P., & Kumar, D. K. (2017). Outlier removal in facial surface electromyography through hampel filtering technique. *2017 IEEE Life Sciences Conference (LSC)*, 258–261. <https://doi.org/10.1109/LSC.2017.8268192>

- 171 Bizzego, A., Battisti, A., Gabrieli, G., Esposito, G., & Furlanello, C. (2019). Pyphysio: A
172 physiological signal processing library for data science approaches in physiology. *SoftwareX*,
173 10, 100287. <https://doi.org/10.1016/j.softx.2019.100287>
- 174 Bota, P., Silva, R., Carreiras, C., Fred, A., & Silva, H. P. da. (2024). BioSPPy: A python
175 toolbox for physiological signal processing. *SoftwareX*, 26, 101712. [https://doi.org/10.](https://doi.org/10.1016/j.softx.2024.101712)
176 [1016/j.softx.2024.101712](https://doi.org/10.1016/j.softx.2024.101712)
- 177 Boxtel, A. van, Goudswaard, P., Molen, G. M. van der, & Bosch, W. E. van den. (1983).
178 Changes in electromyogram power spectra of facial and jaw-elevator muscles during fatigue.
179 *Journal of Applied Physiology*, 54(1), 51–58. <https://doi.org/10.1152/jappl.1983.54.1.51>
- 180 Boyer, M., Bouyer, L., Roy, J.-S., & Campeau-Lecours, A. (2023). Reducing noise, artifacts
181 and interference in single-channel EMG signals: A review. *Sensors*, 23(6). [https://doi.org/](https://doi.org/10.3390/s23062927)
182 [10.3390/s23062927](https://doi.org/10.3390/s23062927)
- 183 Chen, J., Ro, T., & Zhu, Z. (2022). Emotion Recognition With Audio, Video, EEG, and
184 EMG: A Dataset and Baseline Approaches. *IEEE Access*, 10, 13229–13242. <https://doi.org/10.1109/ACCESS.2022.3146729>
- 185 <https://doi.org/10.1109/ACCESS.2022.3146729>
- 186 Clifford, G. D., & Tarassenko, L. (2005). Quantifying errors in spectral estimates of HRV due
187 to beat replacement and resampling. *IEEE Transactions on Biomedical Engineering*, 52(4),
188 630–638. <https://doi.org/10.1109/TBME.2005.844028>
- 189 Dakin, C. J., Dalton, B. H., Luu, B. L., & Blouin, J.-S. (2014). Rectification is required to
190 extract oscillatory envelope modulation from surface electromyographic signals. *Journal of*
191 *Neurophysiology*, 112(7), 1685–1691. <https://doi.org/10.1152/jn.00296.2014>
- 192 De Luca, C. J. (2008). A practicum on the use of sEMG signals in movement sciences. *Delsys*
193 *Inc.*
- 194 Eyben, F., Scherer, K. R., Schuller, B. W., Sundberg, J., André, E., Busso, C., Devillers, L. Y.,
195 Epps, J., Laukka, P., Narayanan, S. S., & Truong, K. P. (2016). The Geneva Minimalistic
196 Acoustic Parameter Set (GeMAPS) for Voice Research and Affective Computing. *IEEE*
197 *Transactions on Affective Computing*, 7(2), 190–202. [https://doi.org/10.1109/TAFFC.](https://doi.org/10.1109/TAFFC.2015.2457417)
198 [2015.2457417](https://doi.org/10.1109/TAFFC.2015.2457417)
- 199 Farina, D., Negro, F., & Jiang, N. (2013). Identification of common synaptic inputs to motor
200 neurons from the rectified electromyogram. *The Journal of Physiology*, 591(10), 2403–2418.
201 <https://doi.org/10.1113/jphysiol.2012.246082>
- 202 Fridlund, A. J., & Cacioppo, J. T. (1986). Guidelines for human electromyographic research.
203 *Psychophysiology*, 23(5), 567–589. <https://doi.org/10.1111/j.1469-8986.1986.tb00676.x>
- 204 Gabrieli, G., Azhari, A., & Esposito, G. (2020). PySiology: A python package for physiological
205 feature extraction. In A. Esposito, M. Faundez-Zanuy, F. C. Morabito, & E. Pasero (Eds.),
206 *Neural approaches to dynamics of signal exchanges* (pp. 395–402). Springer Singapore.
207 https://doi.org/10.1007/978-981-13-8950-4_35
- 208 Greene, N., Livingstone, S. R., & Szymanski, L. (2022). *PeakAffectDS* (Version 1.0) [Data
209 set]. Zenodo. <https://doi.org/10.5281/zenodo.6403363>
- 210 Hegedus, A., Trzaskoma, L., Soldos, P., Tuza, K., Katona, P., Greger, Z., Zsarnoczky-Dulhazi,
211 F., & Kopper, B. (2020). Adaptation of fatigue affected changes in muscle EMG frequency
212 characteristics for the determination of training load in physical therapy for cancer patients.
213 *Pathology & Oncology Research*, 26(2), 1129–1135. [https://doi.org/10.1007/s12253-019-](https://doi.org/10.1007/s12253-019-00668-3)
214 [00668-3](https://doi.org/10.1007/s12253-019-00668-3)
- 215 Jarrah, Y. A., Asogbon, M. G., Samuel, O. W., Wang, X., Zhu, M., Nsugbe, E., Chen, S., &
216 Li, G. (2022). High-density surface EMG signal quality enhancement via optimized filtering
217 technique for amputees' motion intent characterization towards intuitive prostheses control.
218 *Biomedical Signal Processing and Control*, 74, 103497. [https://doi.org/10.1016/j.bspc.](https://doi.org/10.1016/j.bspc.2022.103497)

219 2022.103497

220 Jas, M., Engemann, D. A., Bekhti, Y., Raimondo, F., & Gramfort, A. (2017). Autoreject:
221 Automated artifact rejection for MEG and EEG data. *NeuroImage*, 159, 417–429. <https://doi.org/10.1016/j.neuroimage.2017.06.030>
222

223 Koelstra, S., Muhl, C., Soleymani, M., Lee, J.-S., Yazdani, A., Ebrahimi, T., Pun, T., Nijholt,
224 A., & Patras, I. (2012). DEAP: A database for emotion analysis using physiological signals.
225 *IEEE Transactions on Affective Computing*, 3(1), 18–31. [https://doi.org/10.1109/T-](https://doi.org/10.1109/T-AFFC.2011.15)
226 [AFFC.2011.15](https://doi.org/10.1109/T-AFFC.2011.15)

227 Lindstrom, L., Kadefors, R., & Petersen, I. (1977). An electromyographic index for localized
228 muscle fatigue. *Journal of Applied Physiology*, 43(4), 750–754. [https://doi.org/10.1152/](https://doi.org/10.1152/jappl.1977.43.4.750)
229 [jappl.1977.43.4.750](https://doi.org/10.1152/jappl.1977.43.4.750)

230 Livingstone, S. R., Vezer, E., McGarry, L. M., Lang, A. E., & Russo, F. A. (2016). Deficits
231 in the mimicry of facial expressions in parkinson's disease. *Frontiers in Psychology*, 7.
232 <https://doi.org/10.3389/fpsyg.2016.00780>

233 Makowski, D., Pham, T., Lau, Z. J., Brammer, J. C., Lespinasse, F., Pham, H., Schölzel,
234 C., & Chen, S. H. A. (2021). NeuroKit2: A Python toolbox for neurophysiological signal
235 processing. *Behavior Research Methods*, 53(4), 1689–1696. [https://doi.org/10.3758/](https://doi.org/10.3758/s13428-020-01516-y)
236 [s13428-020-01516-y](https://doi.org/10.3758/s13428-020-01516-y)

237 McClelland, V. M., Cvetkovic, Z., & Mills, K. R. (2014). Inconsistent effects of EMG
238 rectification on coherence analysis. *The Journal of Physiology*, 592(1), 249–250. <https://doi.org/10.1113/jphysiol.2013.265181>
239 <https://doi.org/10.1113/jphysiol.2013.265181>

240 McManus, L., De Vito, G., & Lowery, M. M. (2020). Analysis and Biophysics of Surface EMG
241 for Physiotherapists and Kinesiologists: Toward a Common Language With Rehabilitation
242 Engineers. *Frontiers in Neurology*, 11. <https://doi.org/10.3389/fneur.2020.576729>

243 Munteanu, C., Negrea, C., Echim, M., & Mursula, K. (2016). Effect of data gaps: Comparison
244 of different spectral analysis methods. *Annales Geophysicae*, 34(4), 437–449. <https://doi.org/10.5194/angeo-34-437-2016>
245 <https://doi.org/10.5194/angeo-34-437-2016>

246 Neto, O. P., & Christou, E. A. (2010). Rectification of the EMG signal impairs the identification
247 of oscillatory input to the muscle. *Journal of Neurophysiology*, 103(2), 1093–1103.
248 <https://doi.org/10.1152/jn.00792.2009>

249 Pearson, R. K., Neuvo, Y., Astola, J., & Gabbouj, M. (2016). Generalized hampel filters.
250 *EURASIP Journal on Advances in Signal Processing*, 2016(1), 87. [https://doi.org/10.](https://doi.org/10.1186/s13634-016-0383-6)
251 [1186/s13634-016-0383-6](https://doi.org/10.1186/s13634-016-0383-6)

252 Phinyomark, A., Limsakul, C., & Phukpattaranont, P. (2009). A novel feature extraction for
253 robust EMG pattern recognition. <https://arxiv.org/abs/0912.3973>

254 Rutkowska, J. M., Ghilardi, T., Vacaru, S. V., Schaik, J. E. van, Meyer, M., Hunnius, S., &
255 Oostenveld, R. (2024). Optimal processing of surface facial EMG to identify emotional
256 expressions: A data-driven approach. *Behavior Research Methods*, 56(7), 7331–7344.
257 <https://doi.org/10.3758/s13428-024-02421-4>

258 Sato, W., Murata, K., Uraoka, Y., Shibata, K., Yoshikawa, S., & Furuta, M. (2021). Emotional
259 valence sensing using a wearable facial EMG device. *Scientific Reports*, 11(1), 5757.
260 <https://doi.org/10.1038/s41598-021-85163-z>

261 Schmidt, P., Reiss, A., Duerichen, R., Marberger, C., & Van Laerhoven, K. (2018). Introducing
262 WESAD, a multimodal dataset for wearable stress and affect detection. *Proceedings*
263 *of the 20th ACM International Conference on Multimodal Interaction*, 400–408. <https://doi.org/10.1145/3242969.3242985>
264 <https://doi.org/10.1145/3242969.3242985>

265 SciPy Community. (2025). *PchipInterpolator — SciPy v1.16.2 manual*. <https://docs.scipy>.

- 266 [org/doc/scipy/reference/generated/scipy.interpolate.PchipInterpolator.html](https://docs.scipy.org/doc/scipy/reference/generated/scipy.interpolate.PchipInterpolator.html). [https://docs.](https://docs.scipy.org/doc/scipy/reference/generated/scipy.interpolate.PchipInterpolator.html)
267 [scipy.org/doc/scipy/reference/generated/scipy.interpolate.PchipInterpolator.html](https://docs.scipy.org/doc/scipy/reference/generated/scipy.interpolate.PchipInterpolator.html)
- 268 Sharma, K., Castellini, C., Broek, E. L. van den, Albu-Schaeffer, A., & Schwenker, F. (2019).
269 A dataset of continuous affect annotations and physiological signals for emotion analysis.
270 *Scientific Data*, 6(1), 196. <https://doi.org/10.1038/s41597-019-0209-0>
- 271 Shin, S. Y., Kim, Y., Jayaraman, A., & Park, H.-S. (2021). Relationship between gait quality
272 measures and modular neuromuscular control parameters in chronic post-stroke individuals.
273 *Journal of NeuroEngineering and Rehabilitation*, 18(1), 58. [https://doi.org/10.1186/](https://doi.org/10.1186/s12984-021-00860-0)
274 [s12984-021-00860-0](https://doi.org/10.1186/s12984-021-00860-0)
- 275 Sjak-Shie, E. E. (n.d.). PhysioData toolbox (version 0.7.0). In *PhysioData Toolbox*. Retrieved
276 October 20, 2025, from <https://physiodatatoolbox.leidenuniv.nl/>
- 277 Soleymani, M., Villaro-Dixon, F., Pun, T., & Chanel, G. (2017). Toolbox for emotional
278 feAture extraction from physiological signals (TEAP). *Frontiers in ICT*, Volume 4 - 2017.
279 <https://doi.org/10.3389/fict.2017.00001>
- 280 Tamietto, M., Castelli, L., Vighetti, S., Perozzo, P., Geminiani, G., Weiskrantz, L., &
281 Gelder, B. de. (2009). Unseen facial and bodily expressions trigger fast emotional
282 reactions. *Proceedings of the National Academy of Sciences*, 106(42), 17661–17666.
283 <https://doi.org/10.1073/pnas.0908994106>
- 284 Tkach, D., Huang, H., & Kuiken, T. A. (2010). Study of stability of time-domain features for
285 electromyographic pattern recognition. *Journal of NeuroEngineering and Rehabilitation*,
286 7(1), 21. <https://doi.org/10.1186/1743-0003-7-21>
- 287 Welch, P. (1967). The use of fast fourier transform for the estimation of power spectra: A
288 method based on time averaging over short, modified periodograms. *IEEE Transactions on*
289 *Audio and Electroacoustics*, 15(2), 70–73. <https://doi.org/10.1109/TAU.1967.1161901>
- 290 Zhang, L., Walter, S., Ma, X., Werner, P., Al-Hamadi, A., Traue, H. C., & Gruss, S.
291 (2016). "BioVid emo DB": A multimodal database for emotion analyses validated by
292 subjective ratings. *2016 IEEE Symposium Series on Computational Intelligence (SSCI)*,
293 1–6. <https://doi.org/10.1109/SSCI.2016.7849931>