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Materials, methods, and optimized designs for soft wearable electronics with significantly reduced motion artifacts.

micromachines
MDPI

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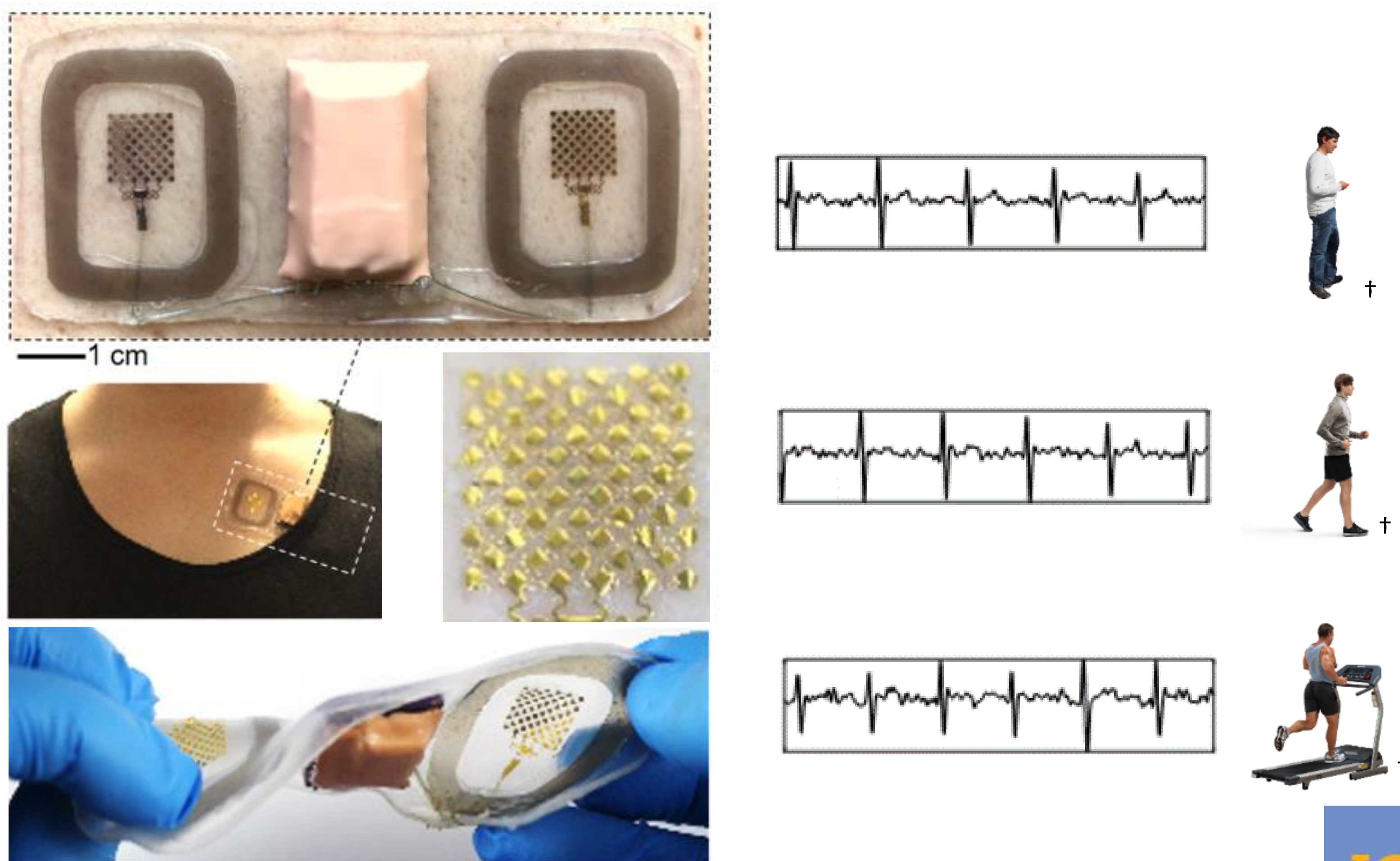
IEN Center for Human-Centric Interfaces and Engineering (CHCIE)

Materials, methods, and optimized designs for soft wearable electronics with significantly reduced motion artifacts.



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Abstract: Wearable electronics are changing healthcare and increasing possibilities for human-machine interfaces. Soft electronics, directly mounted on the skin, can monitor long-term heart rate trends or direct smart prosthetics' motion. However, these capabilities are only as good as the signal quality obtained. These wearable devices are worn in the real world, often suffering from motion artifacts not previously found when measured in a stationary setting such as a clinic or laboratory. Motion artifacts can mimic many biosignals by having a similar amplitude and frequency range, making them hard to filter out. A significant source of motion artifacts is from relative motion between the sensor and the signal source. Given human tissue's elastic nature, most body-mounted sensors undergo more relative motion than on a comparable rigid machine.

Here, this work introduces a comprehensive study of materials, methods, and optimized designs that can significantly reduce motion artifacts via strain isolation, increased adhesion, and enhanced breathability for long-term recordings. Skin strain is another source of motion artifacts that can disturb electrodes' contact impedance and temporarily change the biopotential within the skin. We present a prototype electrocardiogram (ECG) device that uses a strain isolating layer to reduce skin strain at the electrode. This strategic integration of soft and hard materials reduces motion artifacts by stabilizing the electrode, while allowing freedom of movement elsewhere to maintain gentle contact with the skin. These solutions are demonstrated for long-term ECG collection but have application for any skin-mounted wearable device.

Keywords: wearable electronics; soft electronics; motion artifacts; electrocardiogram (ECG); strain isolation; skin strain; form factor; breathability;

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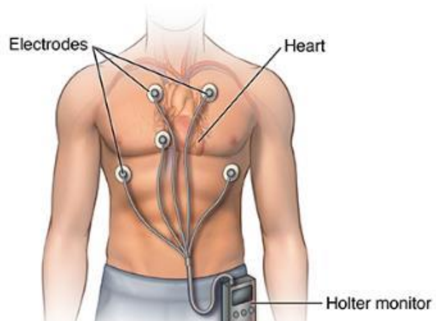
Introduction

Wearable electronics are only as good as the signals they measure.



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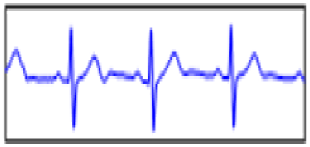
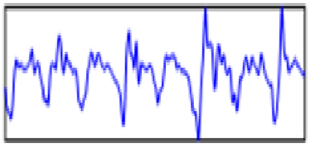
Measured in clinic



Measured while jogging



Robot Arm


‡

- Single system
- Rigid mounting

Smart Prosthetic


‡

- Human/Machine interface
- Soft deformable skin

† https://www.hopkinsmedicine.org/health/treatment-tests-and-therapies/holter-monitor

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Motion Artifact

artifact also **artefact** (är′tə-făkt′) [1]
n.
A phenomenon or feature not originally present or expected and caused by an interfering external agent, action, or process, as an unwanted feature in a microscopic specimen after fixation, in a digitally reproduced image, or in a digital audio recording.

Included for this study
Sensor deformation or movement caused by direct patient movement.
- Walking, jogging, stretching, coughing, electromyographic (EMG) noise, vibration from vehicle, strain on sensor, change in connection.

Not included for this study
Noise caused by movement of external influences.
- Powerline interference, change in electrical/magnetic field.

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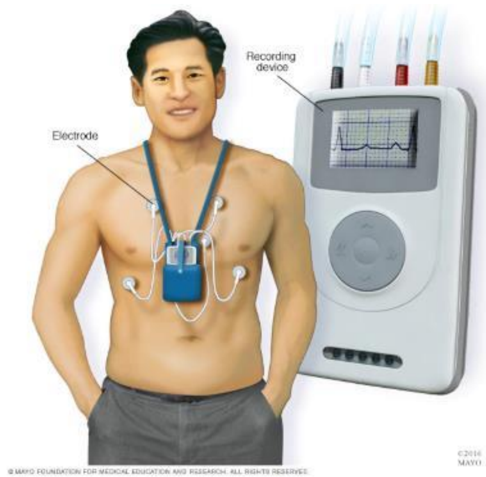
Results

Investigate the major sources of motion artifacts

- Relative motion between sensor and signal source
- Skin strain
- Change in contact impedance

Relative Motion

Small form factor reduces motion of entire system.



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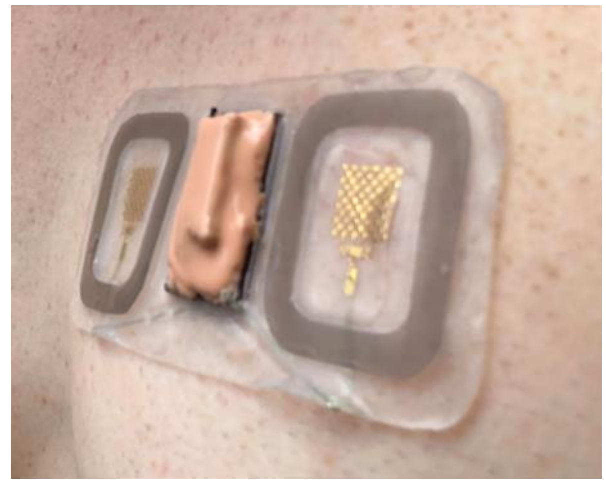
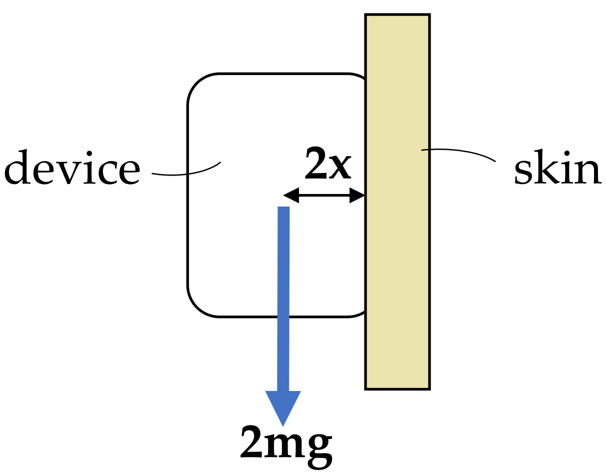
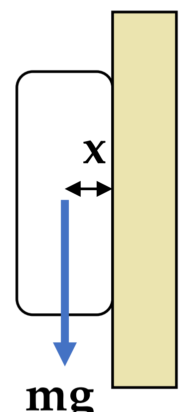


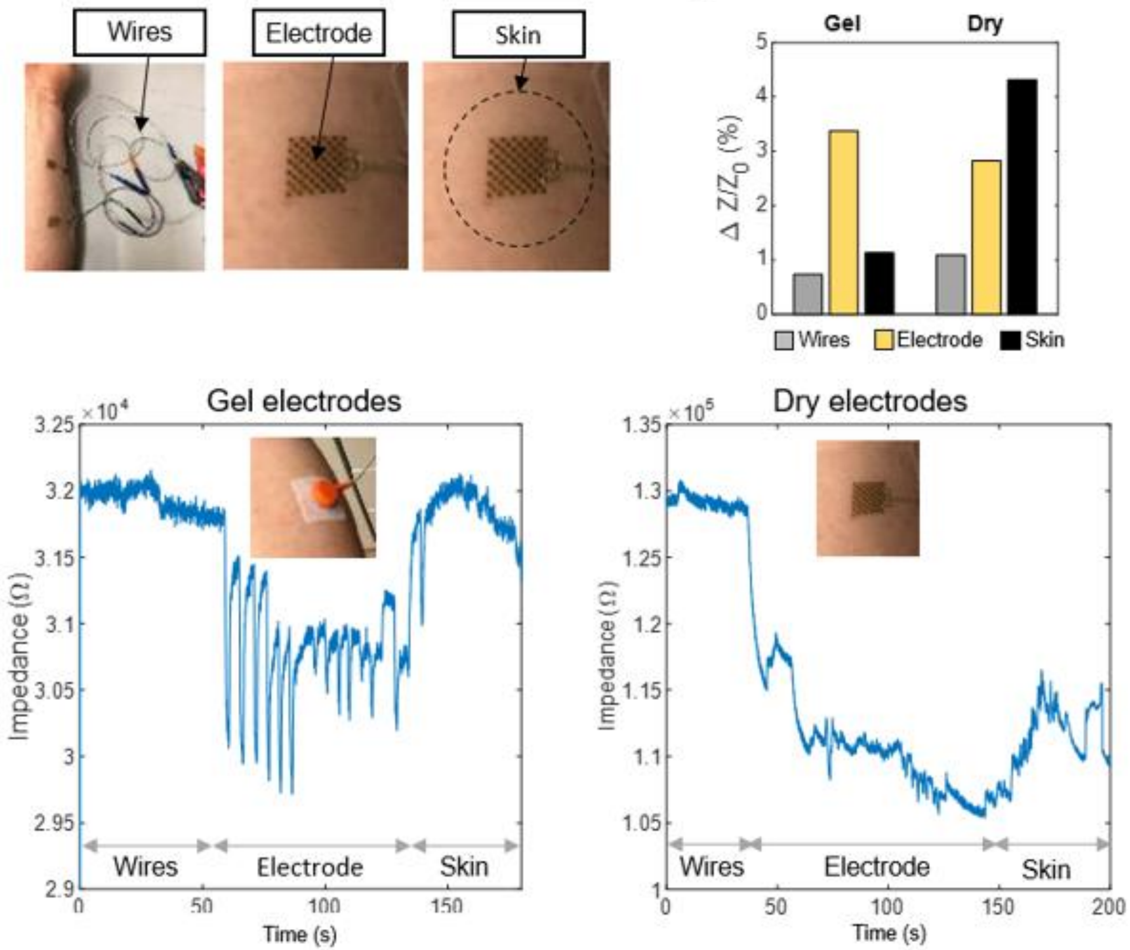




† https://www.mayoclinic.org/

Relative Motion

Disturbance of the electrode and surrounding skin produces large noise.



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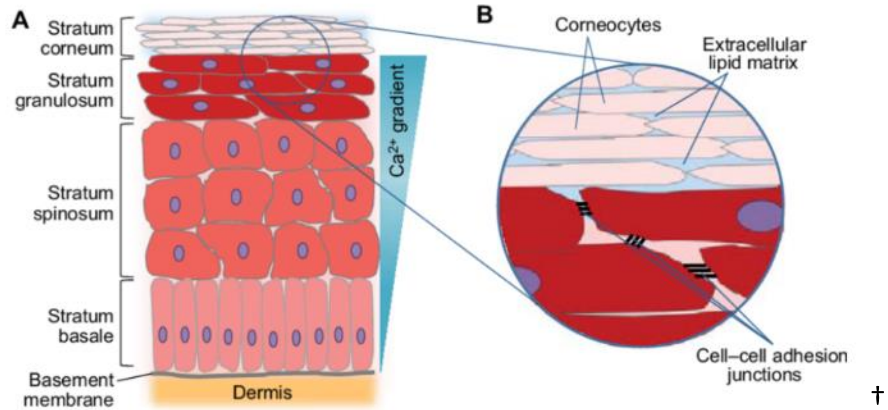
Skin Strain

Skin strain is the underlying mechanism of many motion artifacts for skin mounted sensors.

Skin strain changes the half-cell potential within the epidermis[2].



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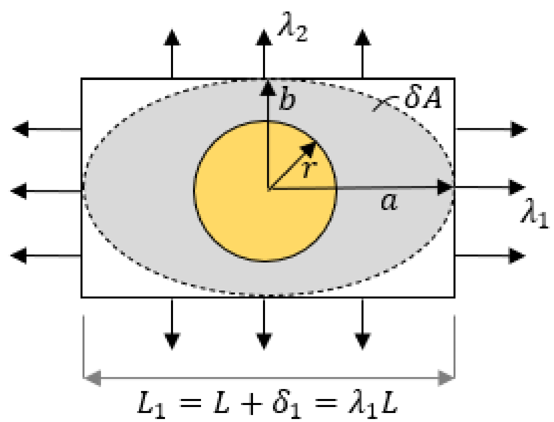
Even flexible sensors lose contact with the skin during stretching.



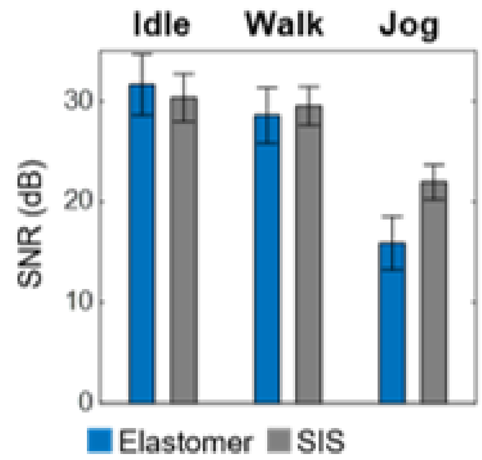
$$\delta A = \pi r^2(\lambda_1 \lambda_2 - 1)$$

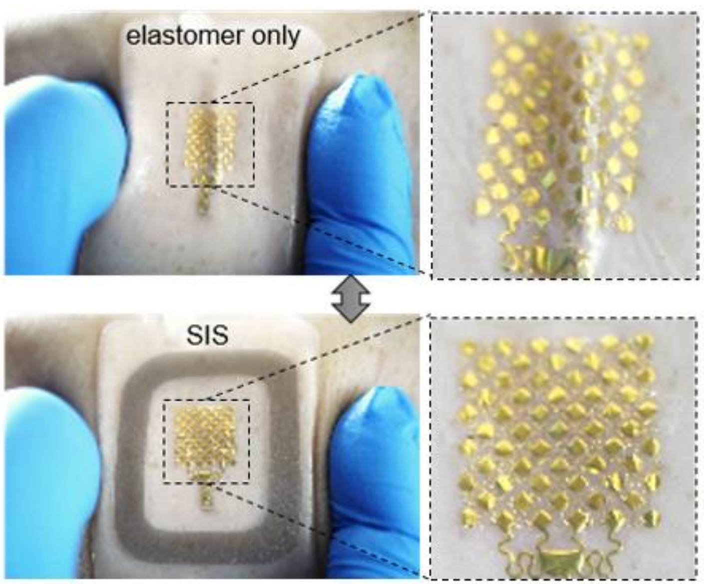
† D. C. Blaydon and D. P. Kelsell, "Defective channels lead to an impaired skin barrier," *J Cell Sci,* vol. 127, no. Pt 20, pp. 4343-50, Oct 15 2014, doi: 10.1242/jcs.154633

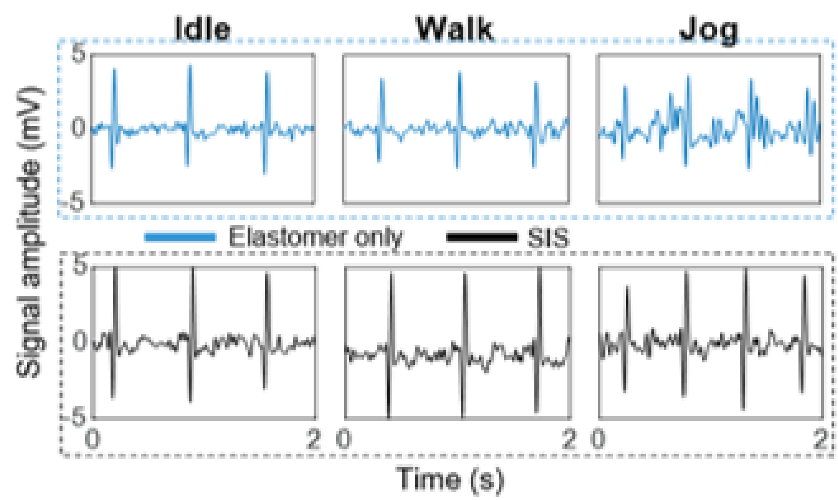
Skin Strain

We developed a Strain Isolation System (SIS) to reduce skin strain at the electrode/skin interface.

- Hard/soft material integration







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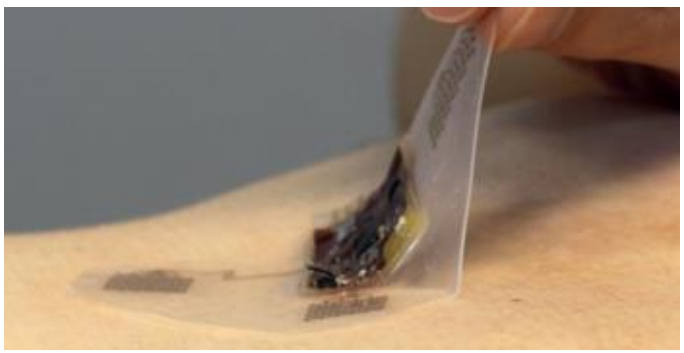
Contact Impedance

Additional factors that help maintain contact for stable signal.

- Elastomer adhesion
- Substrate breathability



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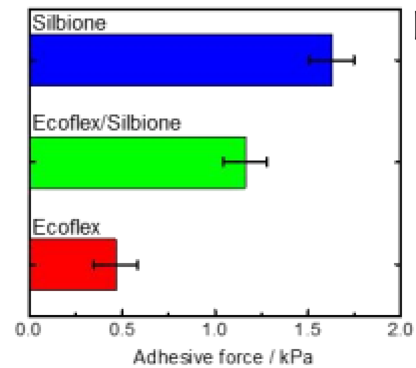

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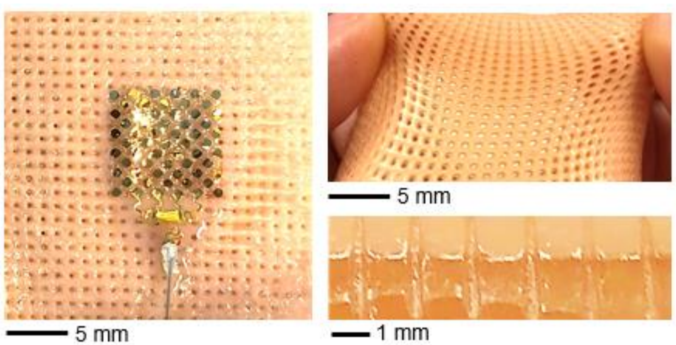

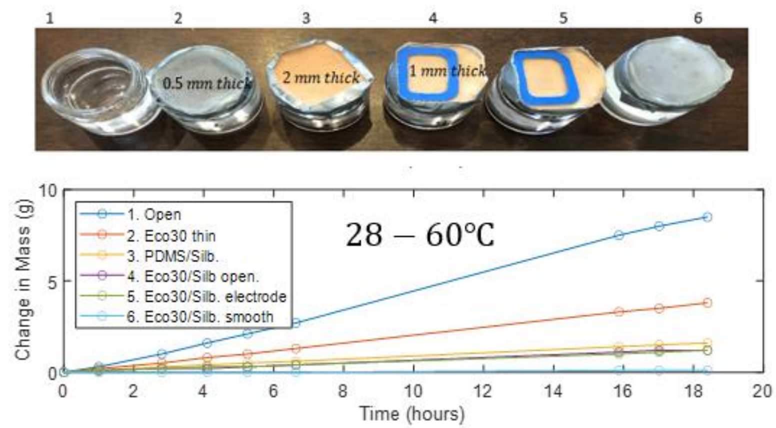

† Y.-S. Kim *et al.*, All-in-One, Wireless, Stretchable Hybrid Electronics for Smart, Connected, and Ambulatory Physiological Monitoring. *Advanced Science* **6**, (2019)

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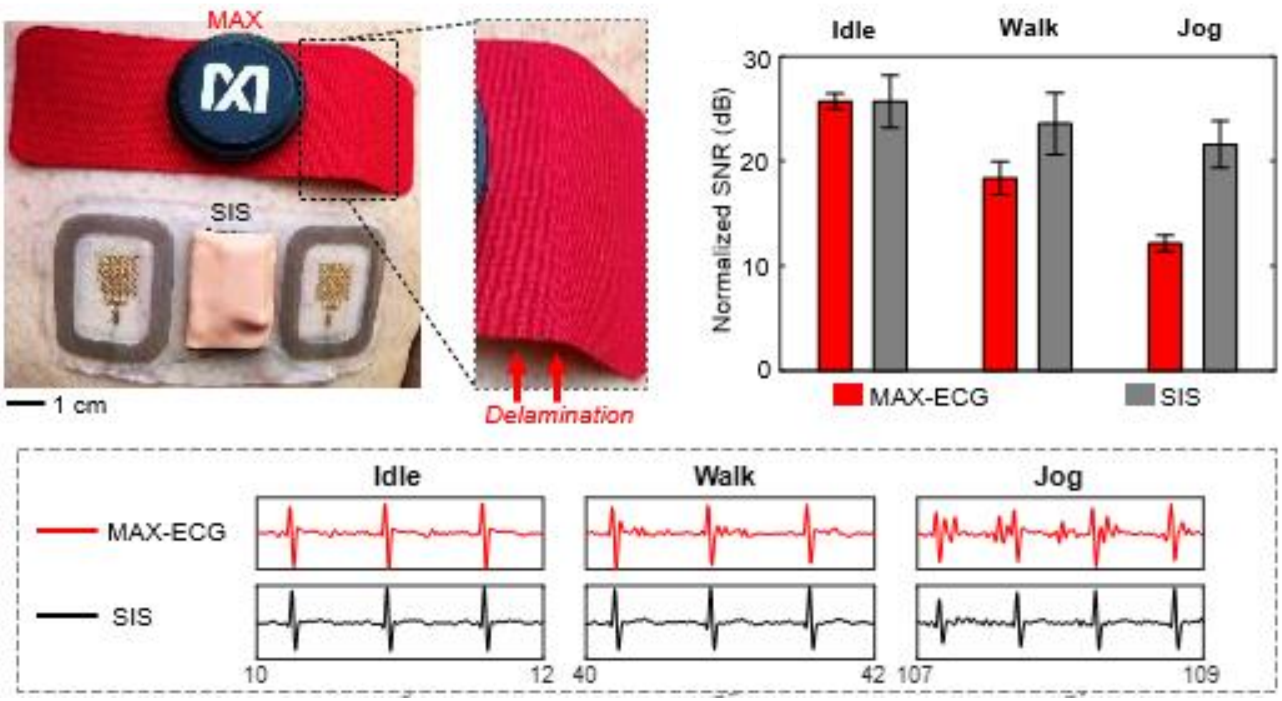
Discussion

Comparison with commercial devices.



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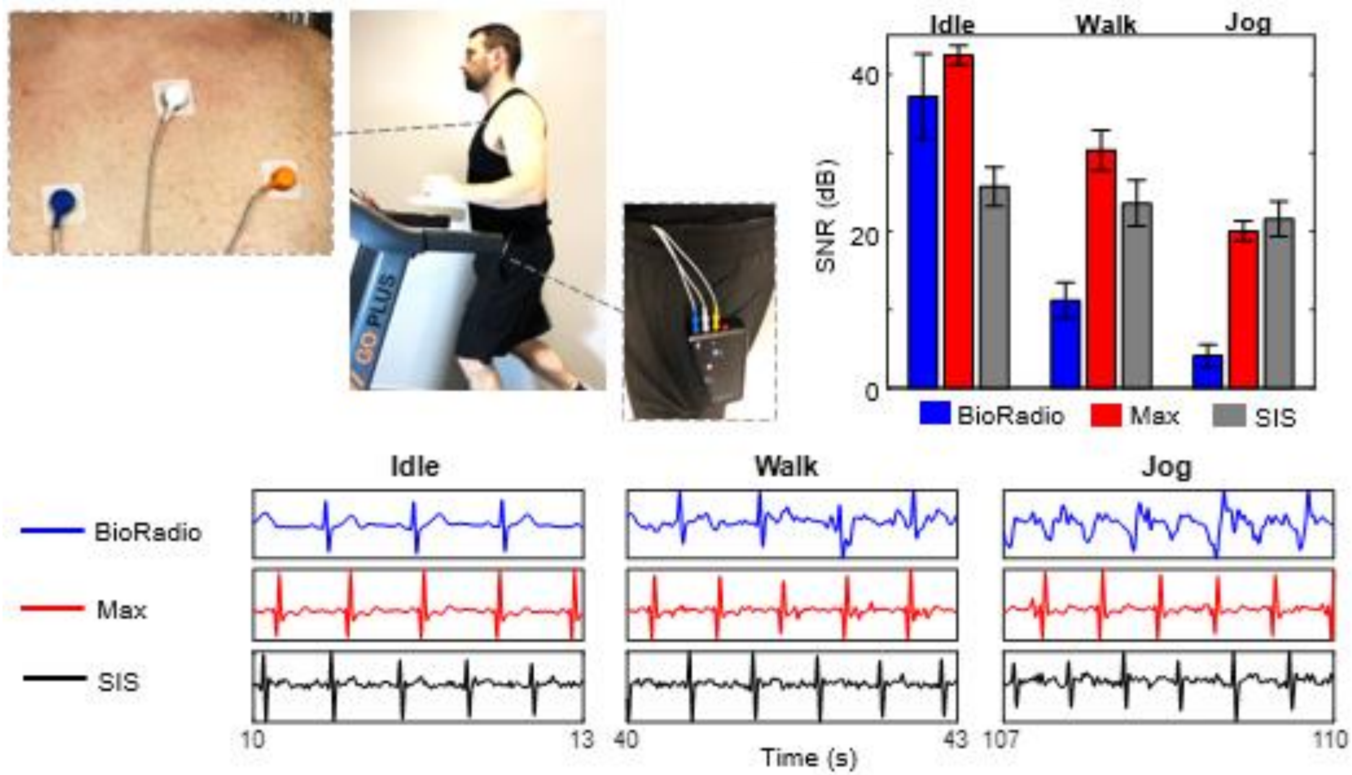
Device Comparison



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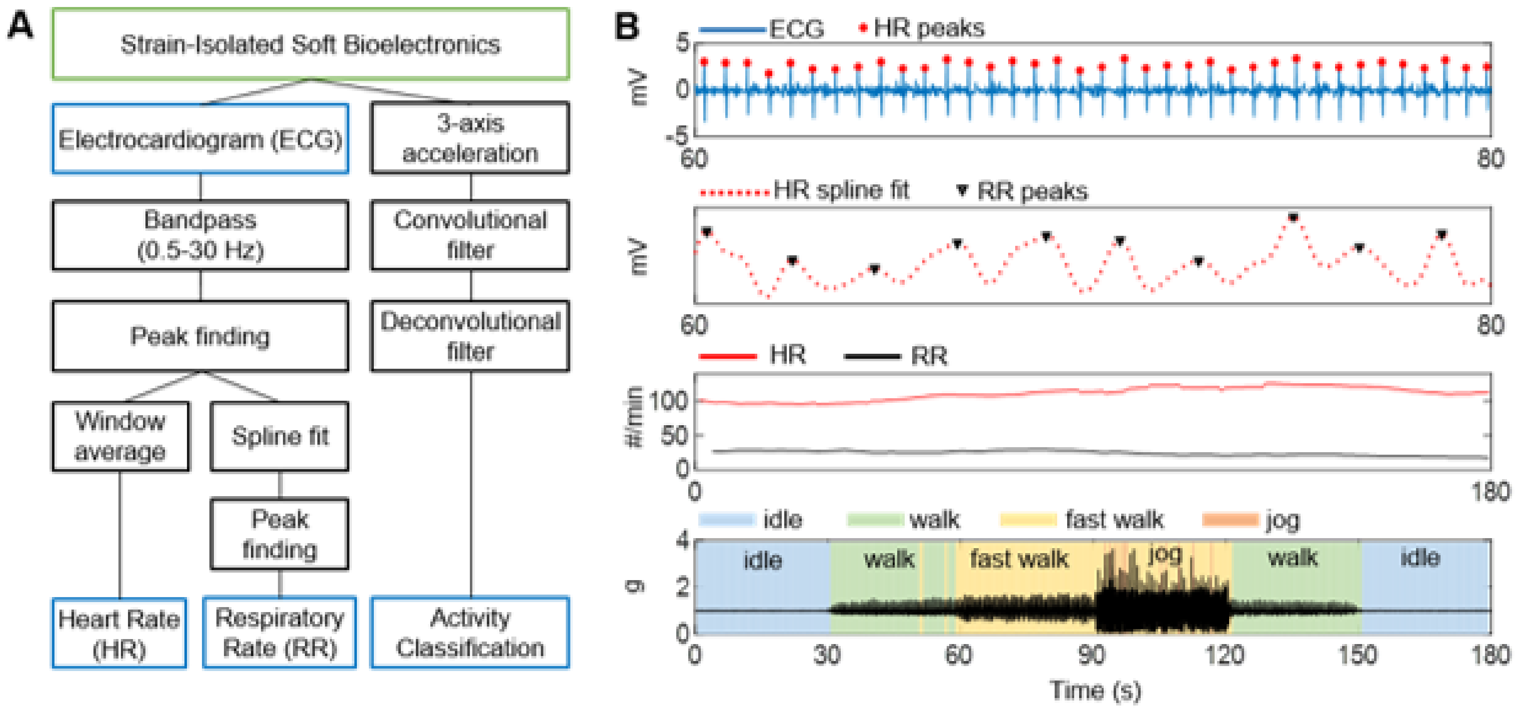
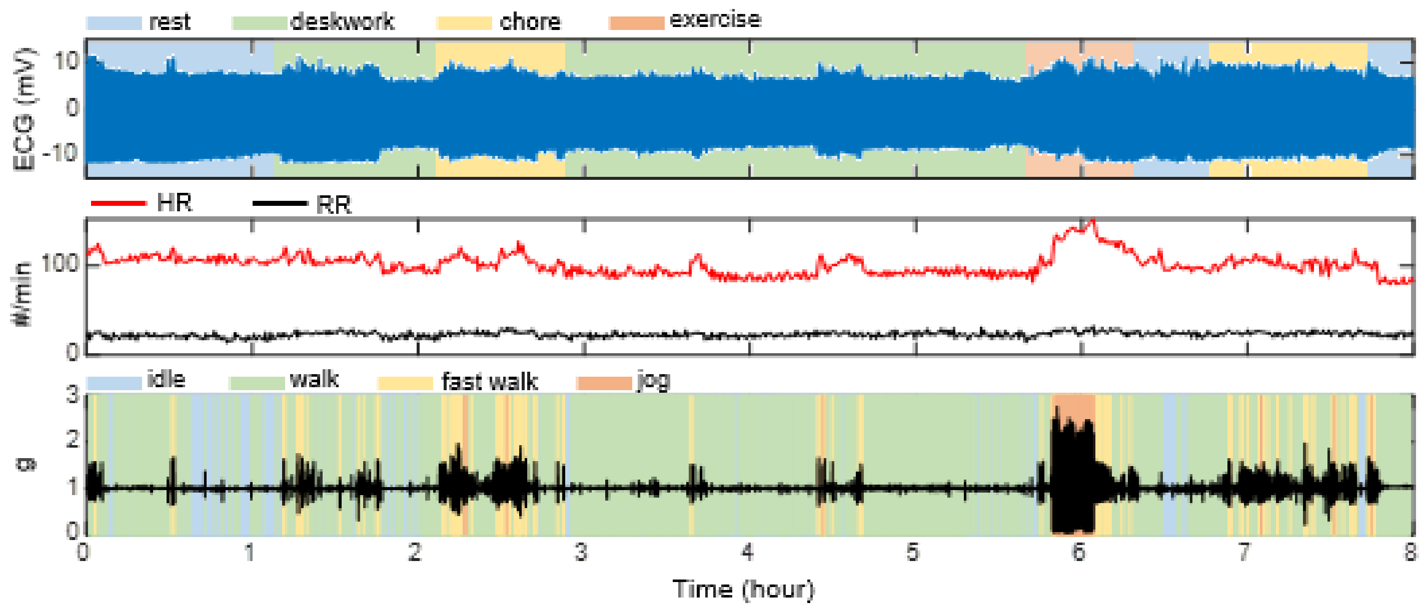
Additional Signal Processing



Long-term monitoring

Device performed well for over 8 hours of continuous monitoring.



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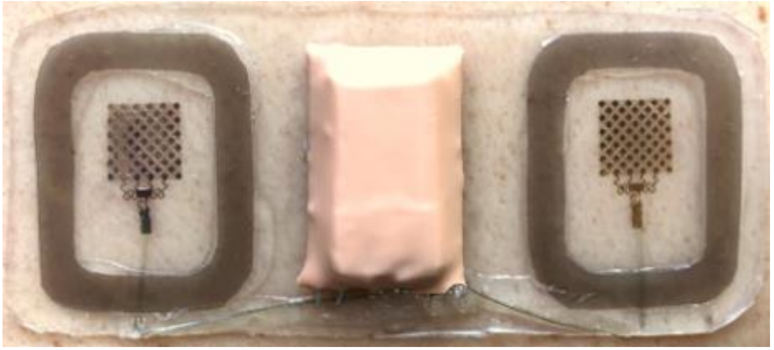
Conclusions

We have demonstrated accurate, long-term physiological monitoring. Soft electronics reduce motion artifacts using these design strategies:

- Small form factor to reduce relative motion
- Isolate sensors by reducing skin strain
- Gentle adhesion and breathable materials to maintain stable contact with skin.



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Supplementary Materials

[1] "artifact," in *The American Heritage® Medical Dictionary*, ed: Houghton Mifflin Company, 2007.

[2] Z. Zhang, I. Silva, D. Wu, J. Zheng, H. Wu, and W. Wang, "Adaptive motion artefact reduction in respiration and ECG signals for wearable healthcare monitoring systems," *Medical and Biological Engineering and Computing,* vol. 52, no. 12, pp. 1019-1030, 2014, doi: 10.1007/s11517-014-1201-7.

[3] Y. Liu *et al.*, "Epidermal mechano-acoustic sensing electronics for cardiovascular diagnostics and human-machine interfaces," *Sci Adv,* vol. 2, no. 11, pp. e1601185-e1601185, 2016, doi: 10.1126/sciadv.1601185.

Acknowledgments

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https://sites.google.com/view/yeogroup/home

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NSF

CDC
Centers for Disease Control and Prevention

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