What if the "I" in HCI stands for Integration?

Pedro Lopes
University of Chicago
Chicago, Illinois, USA
pedrolopes@uchicago.edu

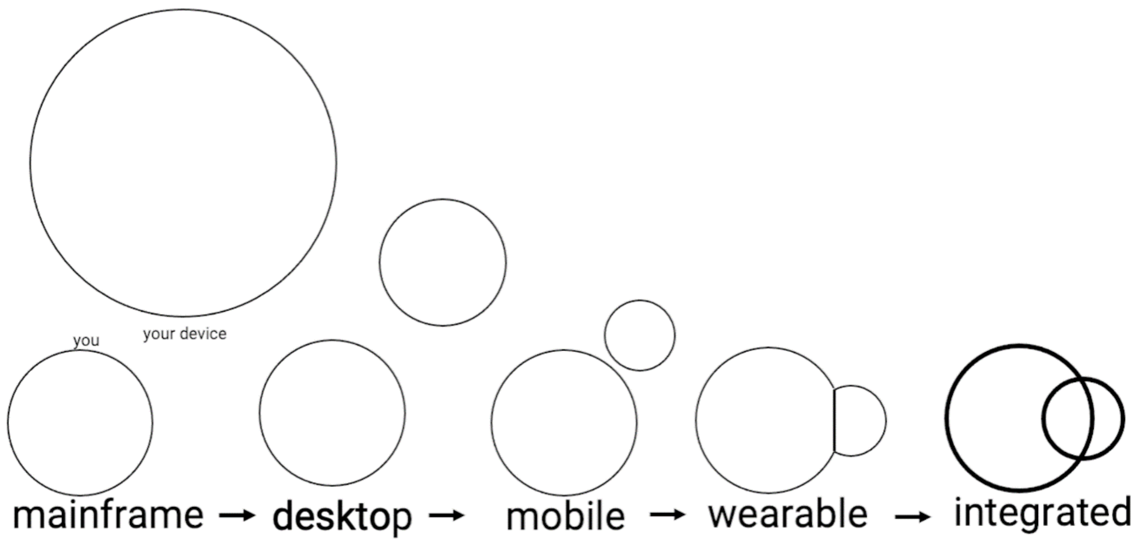

Figure 1: Evolutionary trends in interface paradigms reveal (1) devices getting smaller, and (2) devices closer to the user's physiology & cognition. This begs the HCI community to ask what I think is the most important question: *what comes next?*

Abstract

I explore the future of Human-Computer Interaction (HCI) by rethinking the "I" in HCI as standing for "Integration" rather than "Interaction." Analyzing the evolution of computing interfaces, from desktop computers to wearables, reveals a trend toward miniaturization and closer integration with the human body. I posit a new generation of devices that integrate AI-interfaces with brain or muscle stimulation to provide cognitive or physical assistance in a way that does not feel disempowering, since the user's body is *deeply integrated.* This provides a shift towards integrated interfaces that directly assist users' bodies rather than replacing them with external robots. This challenges us to envision a new type of AI interfaces that *integrate* with humans, enabling new physical modes of reasoning and self-expression. To this end, I argue the main challenges are (1) preserving the user's sense of agency (e.g., keep users in control); (2) avoiding device-dependency (e.g., devices that teach rather than automate); and (3) mapping its societal implications.

CCS Concepts

• **Human-centered computing** → Human computer interaction (HCI); HCI theory, concepts and models; Human computer interaction (HCI); Interaction devices; Haptic devices.

Keywords

Human-Computer Integration, Integration, Evolution of HCI, AI-Integration, Haptics

ACM Reference Format:
Pedro Lopes. 2025. What if the "I" in HCI stands for Integration?. In *The 38th Annual ACM Symposium on User Interface Software and Technology (UIST Adjunct '25), September 28–October 01, 2025, Busan, Republic of Korea.* ACM, New York, NY, USA, 5 pages. https://doi.org/10.1145/3746058.3762829

UIST Adjunct '25, Busan, Republic of Korea

ACM ISBN 979-8-4007-2036-9/2025/09
https://doi.org/10.1145/3746058.3762829

1 BACKGROUND: EVOLUTION OF INTERFACES

When we look back to the early days of computing, user and device were distant, often located in separate rooms. In the 70s, personal computers moved in with users. In the 90s, mobile devices moved computing into users' pockets. Recently, wearables brought computing into physical contact with the user's skin. These transitions proved extremely useful: moving closer to users allowed interactive devices to sense more of their users and act more personal & expressive.

2 EACH EVOLUTION-STEP HAS IDIOSYNCRATIC GAINS

At every evolutionary step, as we switched from one interface paradigm to another, new societal benefits emerged. For instance, while the emergence of interactive maps did not immediately change society when accessed via desktop interfaces, it drastically sparked new markets once it was interactable via mobile interfaces (e.g., ride-sharing, food delivery, freelance gig work, local economies, and so forth). Similarly, while the inclusion of accelerometer data in mobile devices led to some early explorations in health-tracking, it was when this type of sensor data was acquired via on-skin wearables that new modes of interaction exploded (e.g., interactions based on physiological signals, such as fitness or mindfulness apps; and, activity recognition, such as irregular heart rhythms, handwashing, or fall/accident detection).

3 WHAT COMES NEXT IN THE EVOLUTION OF HCI?

I want to challenge us to consider the following question: What is the next interface paradigm that supersedes wearables?

A systematic investigation of this question should consider as many evolutionary interface factors as possible: hardware substrate (e.g., reduction in the size of components), processing capabilities (e.g., the increase in processing speed), user's physical abilities (e.g., load capacity of a joint, fatigue, accuracy, dexterity), user's psychological abilities (e.g., the hotly debated "bandwidth" of the human brain [53]), usability factors (e.g., how well each machine capability is matched with the user's abilities), societal factors (e.g., societal perception/adoption, ethical and moral norms).

4 WHAT IF THE "I" STANDS FOR INTEGRATION?

I have examined many of these evolutionary factors to extrapolate how the evolution of interfaces might play out [36] The rapid evolution of these factors points to two key aspects that help determine what might come next: (1) *devices getting smaller* (e.g., fitness trackers, earbuds, and so forth); and (2) *devices are getting closer to the human body*. In other words, as depicted in Figure 1, the interface is being **integrated** with the user (i.e., the circles representing the user and the device *overlap*). This integration with the user's body leads to a generation of interactive devices that mimic human capabilities (e.g., AI interfaces attempt to match the user's reasoning abilities, haptics interfaces attempt to match the user's dexterity, etc.).

I posit that many factors contribute to my extrapolation, namely the rapid evolution of hardware (e.g., Moore's law, Bell's Law of computer classes, or Dennard's Law), decades of insights from psychology & neuroscience that allowed HCI to create a tight coupling between user's abilities and device interface (e.g., inventions such as pointing/GUIs, touch/NUIs, conversational UIs), and the evolution of societal norms (e.g., the postmodern moral shift).

5 WHY INTEGRATION MATTERS

1. Integration = miniaturization. A first advantage of *user-device integration* is that it puts forward a new generation of miniaturized devices, circumventing constraints that often cause devices to end up larger than ideal. For example, towards providing users' bodies with *physical assistance* (i.e., force-feedback [15]), we see how *user-device integration* has proved beneficial in generating new solutions. Engineering haptic devices based on electrical muscle stimulation (as of 2025, over 100 of these muscle-devices have been explored in HCI [13]) allows achieving force-feedback & physical assistance comparable to that of larger and more cumbersome robotic exoskeletons [30]. This trend is idiosyncratic as it breaks away traditional engineering constraints (e.g., large motors are required to produce large forces [40], large batteries are required for large physical effects [5], etc.). I posit that this novel form of miniaturization via *user-device integration* underlies not just recent haptics research (e.g., in VR haptic actuators can be miniaturized by instead stimulating the user's brain [48, 49]), but also other domains, from implantable devices [19, 46] to software tools where user(s) and device collaborate to achieve functionality that would otherwise require a supercomputer (e.g., crowdsourcing, AI-assistants, and more [4, 7, 20, 35, 43]).

2. Integration = user-centric design. A second advantage of *user-device integration* is that it allows for interactions to emerge without encumbering the body with external tools—in this paradigm, the *body becomes the interactive device.* Using these interfaces, users would not need to hold devices if their hands could temporarily act as the input/output device [16, 42], or would not need to look at screens to get directions if their visual cortex is stimulated to "generate images" depicting directional cues [11, 17]. While nascent and provocative, these interfaces give rise to new meaning to "user-centered design"—in the sense that the device's design is *physically* centered in the user's body and must be designed to respect biological constraints as much as the usability constraints of typical user-centered design [41, 52].

3. Integration = new ways of thinking. A third facet of this *user-device integration* is that it allows new physical modes of reasoning with computers to arise, going beyond symbolic thinking (the primary mode of working with computers since the era of visual interfaces took hold [21]). This lines up with important paradigms in HCI where interfaces allow users to explore data using their bodies [14, 27, 28], via tangible representations [34], or even via interoceptive signals (e.g., internal sensations like gut-feelings [37]).

4. Integration = new abilities. A final facet of *user-device integration* is that it enables us to probe the boundaries of human perception, cognition, and action. I argue for a trend in recent HCI where interfaces endow users with new physical abilities (i.e., not just regaining lost abilities as in sensory restoration [1, 2]). Examples of such interfaces include devices that: allow users to locate odors by smelling in stereo [6], steer users to safety by accelerating their reaction time using muscle stimulation [22], or add biologically implausible senses, like feeling Wi-Fi signals via the skin [14].

6 DO WE LOSE OURSELVES IF DEVICES INTEGRATE?

While this integration between humans and computers can be implemented as beneficial (e.g., faster reaction time [22], improved skill acquisition [8, 38, 51], new sensorium [6, 14, 50]), it also touches on a deep philosophical question: *Do we still feel human when we integrate with an interface?*

Agency. I argue that the question of agency (i.e., exerting & feeling control over an interface) is probably the most important in technology, both from a standpoint of the evolution of interfaces, but also when considering novel forms of AI interfaces (including any forms closer to general intelligence, known as AGI). To answer this, I posit that we need HCI, ethicists, and neuroscientists[1] to work together to rigorously understand what gives rise to our conscious feeling of control, evaluate the impact that automated interfaces have on our sense of agency, and map the boundaries of our moral understanding of *user-device integration.* I argue for a recent trend in HCI leveraging insights from neuroscience, regarding agency, to improve the design of this new type of integrated interfaces [3, 10, 22, 23, 47, 48].

Device dependency. Probing deeper, another question emerges: *When we integrate with devices, do we become dependent on them?* One way to tackle this is by exploring types of user-*device integration* that impart bodily knowledge rather than impose dependency. Some clues are on the horizon: in accelerated reaction time via muscle stimulation, users can become faster even after removing the device (if the device was designed to preserve some of their sense of agency) [23]. This is akin to how some tools are helpful even in their absence, such as maps, which provide a simplified representation of a space that we mentally store for later retrieval. We should strive for designing *user-device integrations* that work even when they are turned off (e.g., no battery, removed, etc.).

7 WHAT OTHER EVOLUTIONARY ROUTES ARE THERE?

While Figure 1 depicts one possible evolution, in which users and devices integrate, I posit that there are more shapes this evolution might take. An important step is to map possible paths and celebrate their idiosyncrasies. To illustrate this, I depict some different visions I have gathered over the years. In my classes & talks, I show the diagram of Figure 1 (while hiding the last interface paradigm) and ask for attendees' interpretation of what will happen to the two circles (i.e., user & interface). It is inspiring to see how different visions people have when primed to think about "what's the next interface"—Figure 2 shows one example.

8 COULD EVOLUTION BE CYCLICAL? WHERE IS AI?

One critical question in this is how Artificial Intelligence (AI) fits into this evolution of interfaces. Since the primary interface between users and AI is textual commands, the interaction style is similar to that of early command-line interfaces (CLI). As such, one could argue that this evolution of HCI is cyclical and that we are in the first "grand reset" of interface paradigms—did AI bring interfaces back to the 60s?

However, I'd argue this cyclical argument (Figure 3) can be deceiving, as we are not just seeing a return to the CLI but, instead, the first integration with humans' cognitive capabilities. Large-language models (LLMs) are a type of conversational interface able to integrate with a key facet of human biology: our ability to communicate in language. Moreover, AI interfaces are rapidly adopting all other paradigms: point-and-click, touch, mobile cameras, and

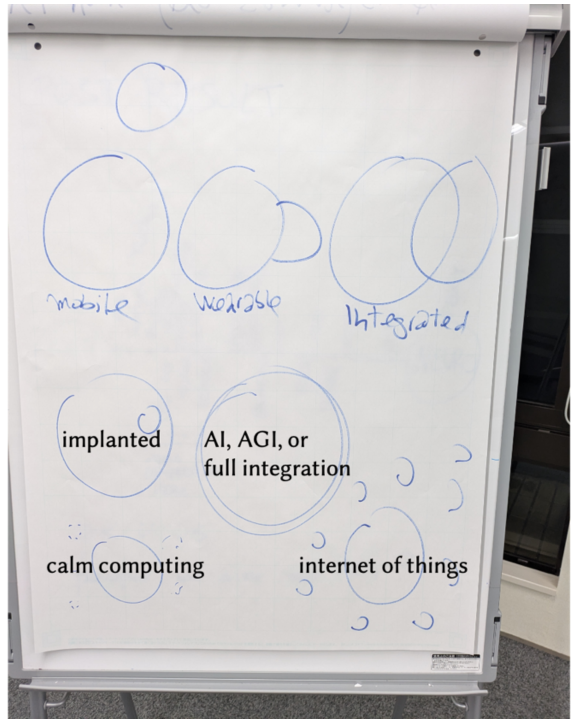

Figure 2: The lower sketches are ideas for the future of interfaces, drawn by attendees of keynotes/classes. (I annotated each drawing with comments on what their sketches imply).

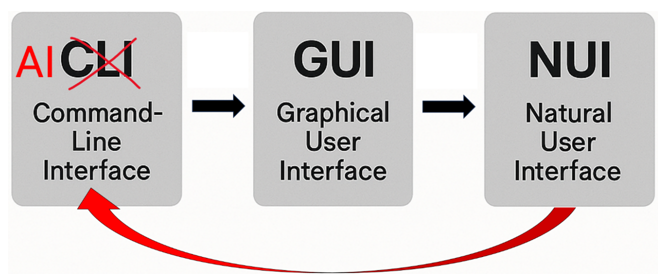

Figure 3: The popular portrait of the evolution of interfaces (CLI to GUI to NUI). But could interactions with AI (via LLMs) be resetting us back to the CLI?

[1]Unique to my argument is calling for joint work across Neuroscience *and* Human-Computer Interaction—more on this in [29].

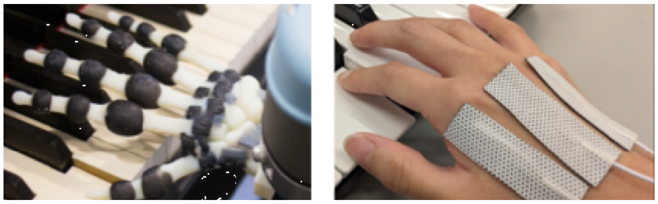

Figure 4: The current vision of AI (left) is that robotics will automate tasks. Instead, via the lens of human-computer integration (right), we can envision a new type of AI that assists the user's body rather than replacing it. This begs a key question: what is at the core of being human? In other words, do we want a robot to play for us or teach us? (Image on the left by Josie Hughes, in Creative Commons at flickr.com/cambridgeuniversity-engineering; right side by Yun Ho [8]).

wearable sensors. Seeing AI move through the evolution of interfaces begs the question: *How might the next generation of AI interfaces connect more physically to the user?*

9 INTEGRATION TO ENVISION A DIFFERENT AI-WORLD

The closest that contemporary AI comes to assisting users with physical tasks is through robotic automation. While this is indeed a way to "assist" with physical challenges (e.g., a robot that does the dishes), decades of research in HCI, cognitive/learning sciences suggest that automating a task is not synonymous with learning it (i.e., instead creates a physical dependency on these devices). Moreover, while we might decide as a society that some tasks warrant automation (e.g., those involving hazards), from a humanistic lens there are tasks at the core of being human (e.g., self-expression through dance/painting/music, meaning making through discovery & curiosity), which might not be desirable to be automated with robots.

Thinking of HCI as in "Integration" rather than "Interaction" opens up a new type of AI that *integrates* the user's body, rather than *removing* the user from the task (as with AI-based robotics). I argue for a trend in which recent HCI research on force-feedback devices (e.g., exoskeletons [26, 44], muscle stimulation [24, 25, 28, 31], or brain stimulation [48, 49]) conjures a new type of *embodied AI* that moves the user's body to provide feedback for learning physical tasks. One example is a system, by Nith & Ho et al., that assists users in performing challenging tasks not via "textual instructions" (as typical of LLMs) but by electrically stimulating the user's body to act out the task—a form of embodied-AI assistance [18]. This idea that an AI could act internally, rather than externally, is illustrated by the provocation in Figure 4 would we rather design AI-interfaces that play piano *for* us or that *teach* us how to play piano?

Acknowledgments

This vision keynote at UIST would not be possible without my students at the Human-Computer Integration Lab[2]. It is their work that led to many of these thoughts.

This material is supported by the National Science Foundation Grant No. 2047189. Any opinions, findings, conclusions, or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the National Science Foundation.

[2]https://lab.plopes.org/

References

[1] Paul Bach-Y-Rita, Carter C. Collins, Frank A. Saunders, Benjamin White, and Lawrence Scadden. 1969. Vision Substitution by Tactile Image Projection. Nature 221, 5184: 963–964. https://doi.org/10.1038/221963a0
[2] Paul Bach-y-Rita and Stephen W. Kercel. 2003. Sensory substitution and the human–machine interface. Trends in Cognitive Sciences 7, 12: 541–546. https://doi.org/10.1016/j.tics.2003.10.013
[3] Joanna Bergström, Jarrod Knibbe, Henning Pohl, and Kasper Hornbæk. 2022. Sense of Agency and User Experience: Is There a Link? ACM Trans. Comput.-Hum. Interact. 29, 4: 28:1-28:22. https://doi.org/10.1145/3490493
[4] Jeffrey P. Bigham, Chandrika Jayant, Hanjie Ji, Greg Little, Andrew Miller, Robert C. Miller, Robin Miller, Aubrey Tatarowicz, Brandyn White, Samual White, and Tom Yeh. 2010. VizWiz: nearly real-time answers to visual questions. In Proceedings of the 23nd annual ACM symposium on User interface software and technology, 333–342. https://doi.org/10.1145/1866029.1866080
[5] Jas Brooks, Steven Nagels, and Pedro Lopes. 2020. Trigeminal-based Temperature Illusions. In Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems, 1–12. https://doi.org/10.1145/3313831.3376806
[6] Jas Brooks, Shan-Yuan Teng, Jingxuan Wen, Romain Nith, Jun Nishida, and Pedro Lopes. 2021. Stereo-Smell via Electrical Trigeminal Stimulation. In Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems (CHI '21), 1–13. https://doi.org/10.1145/3411764.3445300
[7] Ruei-Che Chang, Yuxuan Liu, and Anhong Guo. 2024. WorldScribe: Towards Context-Aware Live Visual Descriptions. In Proceedings of the 37th Annual ACM Symposium on User Interface Software and Technology, 1–18. https://doi.org/10.1145/3654777.3676375
[8] Siya Choudhary, Romain Nith, Yun Ho, Jas Brooks, Mithil Guruvugari, and Pedro Lopes. 2025. Adaptive Electrical Muscle Stimulation Improves Muscle Memory. In Proceedings of the 2025 CHI Conference on Human Factors in Computing Systems (CHI '25), 1–11. https://doi.org/10.1145/3706598.3713676
[9] Ashley Colley, Aki Leinonen, Meri-Tuulia Forsman, and Jonna Häkkilä. 2018. EMS Painter: Co-creating Visual Art Using Electrical Muscle Stimulation. In Proceedings of the Twelfth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '18), 266–270. https://doi.org/10.1145/3173225.3173279
[10] Patricia I. Cornelio Martinez, Emanuela Maggioni, Kasper Hornb a ek, Marianna Obrist, and Sriram Subramanian. 2018. Beyond the Libet Clock: Modality Variants for Agency Measurements. In Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18), 541:1-541:14. https://doi.org/10.1145/3173574.3174115
[11] Valdemar Munch Danry, Laura Chicos, Matheus Fonseca, Ishraki Kazi, and Pattie Maes. 2024. Synthetic Visual Sensations: Augmenting Human Spatial Awareness with a Wearable Retinal Electric Stimulation Device. In Proceedings of the Augmented Humans International Conference 2024 (AHs '24), 15–27. https://doi.org/10.1145/3652920.3652932
[12] Ayaka Ebisu, Satoshi Hashizume, Kenta Suzuki, Akira Ishii, Mose Sakashita, and Yoichi Ochiai. 2017. Stimulated Percussions: Method to Control Human for Learning Music by Using Electrical Muscle Stimulation. In Proceedings of the 8th Augmented Human International Conference (AH '17), 33:1-33:5. https://doi.org/10.1145/3041164.3041202
[13] Sarah Faltaous, Marion Koelle, and Stefan Schneegass. 2022. From Perception to Action: A Review and Taxonomy on Electrical Muscle Stimulation in HCI. In Proceedings of the 21st International Conference on Mobile and Ubiquitous Multimedia (MUM '22), 159–171. https://doi.org/10.1145/3568444.3568460
[14] Erik Grönvall, Jonas Fritsch, and Anna Vallg a arda. 2016. FeltRadio: Sensing and Making Sense of Wireless Traffic. In Proceedings of the 2016 ACM Conference on Designing Interactive Systems (DIS '16), 829–840. https://doi.org/10.1145/2901790.2901818
[15] Abhishek Gupta, Marcia K. O'Malley, Volkan Patoglu, and Charles Burgar. 2008. Design, Control and Performance of RiceWrist: A Force Feedback Wrist Exoskeleton for Rehabilitation and Training. The International Journal of Robotics Research 27, 2: 233–251. https://doi.org/10.1177/0278364907084261
[16] Shin Hanagata and Yasuaki Kakehi. 2018. Paralogue: A Remote Conversation System Using a Hand Avatar Which Postures Are Controlled with Electrical Muscle Stimulation. In Proceedings of the 9th Augmented Human International Conference (AH '18), 35:1-35:3. https://doi.org/10.1145/3174910.3174951
[17] Daiki Higuchi, Kazuma Aoyama, Masahiro Furukawa, Taro Maeda, and Hideyuki Ando. 2017. Position shift of phosphene and attention attraction in arbitrary direction with galvanic retina stimulation. In Proceedings of the 8th Augmented Human International Conference (AH '17), 1–6. https://doi.org/10.1145/3041164.

3041179
[18] Yun Ho, Romain Nith, Peili Jiang, Shan-Yuan Teng, and Pedro Lopes. 2025. Generative Muscle Stimulation: Physical Assistance by Constraining Multimodal-AI with Biomechanical Knowledge. https://doi.org/10.48550/arXiv.2505.10648
[19] Christian Holz, Tovi Grossman, George Fitzmaurice, and Anne Agur. 2012. Implanted user interfaces. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, 503–512. https://doi.org/10.1145/2207676.2207745
[20] Scott Horowitz, Brian Koepnick, Raoul Martin, Agnes Tymieniecki, Amanda A. Winburn, Seth Cooper, Jeff Flatten, David S. Rogawski, Nicole M. Koropatkin, Tsinatkeab T. Hailu, Neha Jain, Philipp Koldewey, Logan S. Ahlstrom, Matthew R. Chapman, Andrew P. Sikkema, Meredith A. Skiba, Finn P. Maloney, Felix R. M. Beinlich, Zoran Popović, David Baker, Firas Khatib, and James C. A. Bardwell. 2016. Determining crystal structures through crowdsourcing and coursework. Nature Communications 7, 1: 12549. https://doi.org/10.1038/ncomms12549
[21] Hiroshi Ishii. 2008. Tangible bits: beyond pixels. In Proceedings of the 2nd international conference on Tangible and embedded interaction (TEI '08), xv–xxv. https://doi.org/10.1145/1347390.1347392
[22] Shunichi Kasahara, Jun Nishida, and Pedro Lopes. 2019. Preemptive Action: Accelerating Human Reaction Using Electrical Muscle Stimulation Without Compromising Agency. In Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI '19), 643:1-643:15. https://doi.org/10.1145/3290605.3300873
[23] Shunichi Kasahara, Kazuma Takada, Jun Nishida, Kazuhisa Shibata, Shinsuke Shimojo, and Pedro Lopes. 2021. Preserving Agency During Electrical Muscle Stimulation Training Speeds up Reaction Time Directly After Removing EMS. In Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems, 1–9. https://doi.org/10.1145/3411764.3445147
[24] Oliver Beren Kaul, Max Pfeiffer, and Michael Rohs. 2016. Follow the Force: Steering the Index Finger Towards Targets Using EMS. In Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA '16), 2526–2532. https://doi.org/10.1145/2851581.2892352
[25] Mohamed Khamis, Nora Schuster, Ceenu George, and Max Pfeiffer. 2019. ElectroCutscenes: Realistic Haptic Feedback in Cutscenes of Virtual Reality Games Using Electric Muscle Stimulation. In 25th ACM Symposium on Virtual Reality Software and Technology (VRST '19), 1–10. https://doi.org/10.1145/3359996.3364250
[26] P. Letier, M. Avraam, S. Veillerette, M. Horodinca, M. De Bartolomei, A. Schiele, and A. Preumont. 2008. SAM: A 7-DOF portable arm exoskeleton with local joint control. In 2008 IEEE/RSJ International Conference on Intelligent Robots and Systems, 3501–3506. https://doi.org/10.1109/IROS.2008.4650889
[27] Lian Loke and Toni Robertson. 2013. Moving and making strange: An embodied approach to movement-based interaction design. ACM Trans. Comput.-Hum. Interact. 20, 1: 7:1-7:25. https://doi.org/10.1145/2442106.2442113
[28] Pedro Lopes. 2016. Proprioceptive Interaction: The User's Muscles As Input and Output Device. In Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA '16), 223–228. https://doi.org/10.1145/2851581.2859014
[29] Lopes, Pedro. 2025. What happens at the intersection of Human-Computer Interaction and Neuroscience? Essays of the Human Computer Integration Lab. Retrieved from https://lab.plopes.org/essays/hcineuro.html
[30] Pedro Lopes and Patrick Baudisch. 2017. Immense Power in a Tiny Package: Wearables Based on Electrical Muscle Stimulation. IEEE Pervasive Computing 16, 3: 12–16. https://doi.org/10.1109/MPRV.2017.2940953
[31] Pedro Lopes, Sijing You, Lung-Pan Cheng, Sebastian Marwecki, and Patrick Baudisch. 2017. Providing Haptics to Walls & Heavy Objects in Virtual Reality by Means of Electrical Muscle Stimulation. In Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI '17), 1471–1482. https://doi.org/10.1145/3025453.3025600
[32] Pedro Lopes, Doăa Yüksel, François Guimbretière, and Patrick Baudisch. 2016. Muscle-plotter: An Interactive System Based on Electrical Muscle Stimulation That Produces Spatial Output. In Proceedings of the 29th Annual Symposium on User Interface Software and Technology (UIST '16), 207–217. https://doi.org/10.1145/2984511.2984530
[33] Daito Manabe. electric stimulus to face – test (artwork). Retrieved August 21, 2025 from https://daito.ws/en/archive/electricstimulustoface_test/
[34] Andrew Manches, Claire O'Malley, and Steve Benford. 2009. Physical manipulation: evaluating the potential for tangible designs. In Proceedings of the 3rd International Conference on Tangible and Embedded Interaction (TEI '09), 77–84. https://doi.org/10.1145/1517664.1517688
[35] Jessica Marshall. 2012. Victory for crowdsourced biomolecule design. Nature: nature.2012.9872. https://doi.org/10.1038/nature.2012.9872
[36] Florian Floyd Mueller, Pedro Lopes, Paul Strohmeier, Wendy Ju, Caitlyn Seim, Martin Weigel, Suranga Nanayakkara, Marianna Obrist, Zhuying Li, Joseph Delfa, Jun Nishida, Elizabeth M. Gerber, Dag Svanaes, Jonathan Grudin, Stefan Greuter, Kai Kunze, Thomas Erickson, Steven Greenspan, Masahiko Inami, Joe Marshall, Harald Reiterer, Katrin Wolf, Jochen Meyer, Thecla Schiphorst, Dakuo Wang, and Pattie Maes. 2020. Next Steps for Human-Computer Integration. In Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems, 1–15. https://doi.org/10.1145/3313831.3376242
[37] Mia Huong Nguyen, Moritz Alexander Messerschmidt, Chitralekha Gupta, and Suranga Nanayakkara. 2025. GutIO: Toward Sensing and Inducing Gut Feelings with Abdominal Sounds. In Proceedings of the Extended Abstracts of the CHI Conference on Human Factors in Computing Systems (CHI EA '25), 1–9. https://doi.org/10.1145/3706599.3719826
[38] Arinobu Niijima and Shoichiro Takeda. 2025. Improving Putting Accuracy with Electrical Muscle Stimulation Feedback Guided by Muscle Synergy Analysis. In Proceedings of the 2025 CHI Conference on Human Factors in Computing Systems (CHI '25), 1–11. https://doi.org/10.1145/3706598.3713605
[39] Romain Nith, Yun Ho, and Pedro Lopes. 2024. SplitBody: Reducing Mental Workload while Multitasking via Muscle Stimulation. In Proceedings of the CHI Conference on Human Factors in Computing Systems (CHI '24), 1–11. https://doi.org/10.1145/3613904.3642629
[40] Romain Nith, Shan-Yuan Teng, Pengyu Li, Yujie Tao, and Pedro Lopes. 2021. DextrEMS: Increasing Dexterity in Electrical Muscle Stimulation by Combining it with Brakes. In The 34th Annual ACM Symposium on User Interface Software and Technology (UIST '21), 414–430. https://doi.org/10.1145/3472749.3474759
[41] Donald A. Norman. 1983. Design principles for human-computer interfaces. In Proceedings of the SIGCHI conference on Human Factors in Computing Systems - CHI '83, 1–10. https://doi.org/10.1145/800045.801571
[42] Siyou Pei, Alexander Chen, Jaewook Lee, and Yang Zhang. 2022. Hand Interfaces: Using Hands to Imitate Objects in AR/VR for Expressive Interactions. In Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems (CHI '22), 1–16. https://doi.org/10.1145/3491102.3501898
[43] Carlo Reverberi, Tommaso Rigon, Aldo Solari, Cesare Hassan, Paolo Cherubini, GI Genius CADx Study Group, Giulio Antonelli, Halim Awadie, Sebastian Bernhofer, Sabela Carballal, Mário Dinis-Ribeiro, Agnès Fernández-Clotett, Glòria Fernández Esparrach, Ian Gralnek, Yuta Higasa, Taku Hirabayashi, Tatsuki Hirai, Mineo Iwatate, Miki Kawano, Markus Mader, Andreas Maieron, Sebastian Mattes, Tastuya Nakai, Ingrid Ordas, Raquel Ortigão, Oswaldo Ortiz Zúñiga, Maria Pellisé, Cláudia Pinto, Florian Riedl, Ariadna Sánchez, Emanuel Steiner, Yukari Tanaka, and Andrea Cherubini. 2022. Experimental evidence of effective human–AI collaboration in medical decision-making. Scientific Reports 12, 1: 14952. https://doi.org/10.1038/s41598-022-18751-2
[44] Oscar Sandoval-Gonzalez, Ignacio Herrera Aguilar, Juan Jacinto Villegas, Carlo Avizzano, Jose Flores Cuautle, Paolo Tripicchio, and Otniel Portillo-Rodríguez. 2016. Design and Development of a Hand Exoskeleton Robot for Active and Passive Rehabilitation. International Journal of Advanced Robotic Systems 13: 1–12. https://doi.org/10.5772/62404
[45] Stelarc. THIRD HAND (artwork). Retrieved August 21, 2025 from http://stelarc.org/_activity-20265.php
[46] Paul Strohmeier and Jess McIntosh. 2020. Novel Input and Output opportunities using an Implanted Magnet. In Proceedings of the Augmented Humans International Conference, 1–5. https://doi.org/10.1145/3384657.3384785
[47] Daisuke Tajima, Jun Nishida, Pedro Lopes, and Shunichi Kasahara. 2022. Whose Touch is This?: Understanding the Agency Trade-Off Between User-Driven Touch vs. Computer-Driven Touch. ACM Trans. Comput.-Hum. Interact. 29, 3: 24:1-24:27. https://doi.org/10.1145/3489608
[48] Tanaka, Yudai, Mathews, Hunter, and Lopes, Pedro. 2025. Primed Action: Preserving Agency while Accelerating Reaction-time via Subthreshold Brain Stimulation. Proceedings of the 38th Annual ACM Symposium on User Interface Software and Technology (New York, NY, USA, 2025).: 1–9. https://doi.org/10.1145/3746059.3747634
[49] Yudai Tanaka, Jacob Serfaty, and Pedro Lopes. 2024. Haptic Source-Effector: Full-Body Haptics via Non-Invasive Brain Stimulation. In Proceedings of the 2024 CHI Conference on Human Factors in Computing Systems (CHI '24), 1–15. https://doi.org/10.1145/3613904.3642483
[50] Shan-Yuan Teng, Gene S-H Kim, Xuanyou Liu, and Pedro Lopes. 2025. Seeing with the Hands: A Sensory Substitution That Supports Manual Interactions. In Proceedings of the 2025 CHI Conference on Human Factors in Computing Systems, 1–15. https://doi.org/10.1145/3706598.3713419
[51] Steeven Villa, Finn Jacob Eliyah Krammer, Yannick Weiss, Robin Welsch, and Thomas Kosch. 2025. Understanding the Influence of Electrical Muscle Stimulation on Motor Learning: Enhancing Motor Learning or Disrupting Natural Progression? In Proceedings of the 2025 CHI Conference on Human Factors in Computing Systems (CHI '25), 1–17. https://doi.org/10.1145/3706598.3714183
[52] Karel Vredenburg, Ji-Ye Mao, Paul W. Smith, and Tom Carey. 2002. A survey of user-centered design practice. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, 471–478. https://doi.org/10.1145/503376.503460
[53] Jieyu Zheng and Markus Meister. 2025. The unbearable slowness of being: Why do we live at 10 bits/s? Neuron 113, 2: 192–204. https://doi.org/10.1016/j.neuron.2024.11.008