Physiological Signals for Ability-Based Design

Claire L. Mitchell*, Jacob O. Wobbrock

The Information School | DUB Group, University of Washington, Seattle, United States of America

Abstract

Physiological signals can offer unique insights into how the human body functions. Recent advances in consumer-facing wearable technology enable physiological signals to act as an interface between the body and technology, and to improve human-technology interactions. This paper argues for how physiological signals can improve personalization with technology, specifically in support of ability-based design, where technology assumes the burden of better matching a user's abilities. For example, we offer a scenario in which an athlete's poor recovery, as measured through elevated resting heart rate, affects his ability to remember his schedule. His devices adapt to his state by pushing earlier and more frequent notifications to ensure meetings are not missed. In another scenario, we convey how sensing a user's limited fine motor control can be used to adapt on-screen keyboards for more accurate texting. In yet another scenario, we describe how physiological signals can be used to detect fatigue and recommend alternative input techniques. We argue that by obtaining a direct window to the physiological state of a user, interactive systems can precisely measure and adapt to a user's abilities.

Keywords

Ability-based design, accessibility, physiological signals, electromyography, adaptive user interfaces, personalization.

1. Introduction

Consumer-facing systems that utilize physiological signals offer unprecedented access to track human health and performance. These systems include at-home versions of clinical systems such as a blood pressure monitor or pulse oximeter, as well as wearable electronics such as smartwatches or rings. With these systems one can easily monitor individual physiological signals such as heart rate, blood oxygenation, temperature, blood pressure, as well as more comprehensive physiological indicators such as quality of sleep, heart rate irregularities, cycle tracking, recovery, and stress. While these systems offer consumers approachable methods to monitor and even modify behaviors from this information, these systems do little to utilize these signals to improve people's interactions with technology itself. We envision a future in which these physiological signals can be used to inform interactive systems when personalizing user interfaces in ability-based design, enabling systems to better match their users' abilities.

Ability-based design [1, 2] is a design methodology that prioritizes creating accessible systems that are designed to match the abilities of the user. This means that the burden of adaptation, or of being adaptable, falls to the system as opposed to the user. However, individual implementations

PhysioCHI: Towards Best Practices for Integrating Physiological Signals in HCI, May 11, 2024, Honolulu, HI, USA
*Corresponding author.
clairelm@uw.edu (C. L. Mitchell); wobbrock@uw.edu (J. O. Wobbrock)
https://clairem2520.github.io/ (C. L. Mitchell); https://faculty.washington.edu/wobbrock/ (J. O. Wobbrock)
0000-0001-8670-1761 (C. L. Mitchell); 0000-0003-3675-5491 (J. O. Wobbrock)

of ability-based design utilize disparate methodologies to measure ability, which represent how the user interacts with the system, as opposed to using direct physiological measurements of the user. For example, ability-based systems might measure how a user points, clicks, or drags with a mouse in order to optimize interface layouts for greater accuracy [3, 4]. While this approach provides useful information, we envision that separately, physiological signals can provide useful insights into a user's abilities not available from merely sensing technology usage itself. For example, a measurement of heart rate can be used to infer stress, which might lead to simplifying an automotive interface.

In this paper, we describe how physiological signals can support ability-based design and technology personalization more broadly. We detail related work that utilizes physiological signals in human-computer interaction, describe our own expertise in physiological computing and ability-based design, and present our view for the integration of the two.

2. Related Work

Here we provide a brief review of how physiological signals have been used in human-computer interaction, focusing on how physiological signals can be used for accessibility and personalization.

Recent advances in consumer-facing technology have allowed for physiological signals to be used as input modalities. For example, the Apple Watch allows for double-tap gestures that can be customized to a variety of actions through the use of a gyroscope, accelerometer, and optical heart sensor [5]. Meta has described their electromyography (EMG) wristband that can be used to perform simple gestures or more complex interactions such as typing without using a keyboard through the use of personalized typing models [6].

Yamagami et al. [7] highlighted the diversity of information that comes from physiological signals for individuals with disabilities and explains that this necessitates personalization for inclusive gesture recognition. SilentSpeller [8] used electropalatography to create a system that decodes letters from tongue movements with the goal of promoting a hands-free speech system that protects the privacy of individuals with limited ability to type. FingerSpeller [9] utilized smart rings to decode American Sign Language through the use of onboard accelerometers.

With wearables enabling easier access to physiological signals than ever before, the opportunity to utilize these signals in human-computer interaction (HCI) is ripe, especially given that many of them have been studied extensively in fields outside HCI. Eddy et al. [10] described this for EMG, detailing a framework and call to action for EMG in HCI. The authors note how much of the research surrounding EMG comes from a long history of prosthetics research.

Our above review of prior research highlights the opportunities that physiological signals present for personalization and accessible computing; and yet, these opportunities are just starting to be explored in HCI.

3. Our Backgrounds and Prior Work

Our own work has engaged with both physiological computing and accessibility in HCI, which has informed our vision for more tightly integrating the two. The first author's work is in biomechanics, having spent time working for a wearable sensor company for four years prior to pursuing her Ph.D. During this time, her work focused on electromyography (EMG) as a biomarker, input signal, and means for personalization for augmentative and alternative communication (AAC) [11, 12, 13].

The second author was the original creator of ability-based design [1, 2] and has developed systems exemplifying ability-based design for desktop and mobile platforms [3, 14, 4, 15, 16, 17]. He has also worked on the methodology of ability-based design itself [18]. He has worked in accessibility for nearly 25 years.

A primary research interest of ours, and the subject of our ongoing work, is to bring together physiological and wearable signals to improve accessibility through ability-based design. For example, we have explored how signals from EMG and inertial sensors (IMUs) can be used to design keyboards personalized to a user's range of motion and muscle strength [11, 12].

4. Our Vision for Physiological Signals and Ability-Based Design

Here we describe our vision for how physiological signals can support ability-based design and improve technology personalization. Furthermore, we offer scenarios illustrating how physiological sensing can be used in ability-based design.

Ability-based design lays out seven principles that fall under three categories [1, 2]. The "designer's stance" encompasses the principles of *ability*, *accountability*, and *availability*. The "adaptive or adaptable interface" category contains *adaptability* and *transparency*. And the "sensing and modeling" category comprises *performance* and *context*. Physiological signals fall most obviously under the "sensing and modeling" category, where *performance* refers to systems that monitor and model a user's actions and state, and *context* refers to systems that are aware of and responsive to a user's situation, activities, and environment. We envision commodity wearables and mobile devices that can sense the abilities, actions, activities, and environments of their user, make intelligent decisions about issues including their user's fatigue, situational impairments [19], fine motor abilities, stress levels, or affective states, and then improve interface usability and accessibility.

Furthermore, the other principles of ability-based design speak to the methodologies that a designer should employ when utilizing physiological signals for ability-based design. The designer should choose to use physiological signals that engage with a user's abilities (*ability*), ensure that systems are robust with respect to sensor noise and unpredictability (*accountability*), and which are readily available on target users' devices (*availability*). In addition, systems must make visible how they are employing users' physiological signals, giving users the ability to control whether or how they want to adopt any interface adaptations (*transparency*), and enable such adaptations to match users' needs over time (*adaptability*). Full guidelines for how to integrate physiological signals while considering each principle of ability-based design are offered in Table 1.

Alongside utilizing physiological signals for sensing and modeling a user's abilities, we envision directly incorporating physiological signals as inputs that additionally drive personalization. We envision that these systems adapt their interfaces as a user switches between input modalities—often because of fatigue or context changes. For example, as a user moves into a

Table 1
Guidelines for the integration of physiological signals within ability-based design.

Ability-Based Design Principle	Guideline
Ability	Systems sense physiological signals that are indicators of ability and only utilize these signals to adapt the interface unless otherwise given permission by the user.
Accountability	Systems are robust to sensor noise, motion artifacts, and general unpredictability, not requiring users to adapt themselves to accommodate technology limitations.
Availability	Systems utilize sensors that are readily available on a user's device or that are low-cost, easy to procure add-ons.
Adaptability	Systems are flexible to trends in the user's physiological signals as well as the user's preferences, adapting interfaces accordingly.
Transparency	Systems reveal to the user what kinds of physiological signals are sensed, monitored, collected, and stored; and how such signals are used, giving the user options to make adjustments.
Performance	Systems employ physiological signals to measure the user's behavior over time.
Context	Systems utilize physiological signals to sense the user's context, situation, environment, and activities.

scenario where eye-tracking may be less feasible, the user can easily adopt an alternative input mechanism and the system will adapt to the user's expressed abilities.

Although certain systems have utilized physiological signals, rarely have such systems incorporated such signals for adaptation to users' abilities. Incorporating these physiological signals is an important first step in achieving ability-based design, but *how* these signals are handled by systems is crucial. It is not enough for systems to receive these inputs and adapt once to them. User fatigue, stress, learning, and situational changes all can impact a user's abilities. Therefore, systems must continually engage with both the user, context, and system state to accommodate a user's changing abilities over time.

Below, we offer three scenarios that communicate our vision of how physiological signals might be leveraged to support ability-based design.

4.1. Scenario 1: Fluctuating Abilities

Paul is in the midst of marathon training; yesterday, he had one of his last long runs before the marathon. He was hoping to get a good night's rest to aid in his recovery, but he had trouble sleeping due to stress about work. His smart ring measured his poor sleep, and also found other indicators of poor recovery, such as elevated resting heart rate. When Paul is not well rested, he often forgets things on his calendar and gets headaches, especially when he is looking at high contrast screens with bright colors. He has communicated these issues to the personalization settings in his phone and given his phone permission to adapt as it sees fit. Sensing Paul's poor exercise recovery, his phone provides early and more frequent notifications to his calendar in advance of important appointments, increases the calendar widget size on his home screen, and turns the phone colors to gray scale.

4.2. Scenario 2: Limited Fine Motor Control

Ann has received a video from her granddaughter learning how to kick a soccer ball. Ann wants to respond to her, but she has trouble texting a response due to limited fine motor control resulting from Parkinson's disease. Her tablet and smartwatch have measured Ann's tremor levels through her everyday phone use, especially movements when tapping, gesturing, and holding the phone. In addition, Ann's smartwatch has modeled patterns of how her symptoms change, especially in relationship to medication. The smartwatch has identified that Ann has high text entry error rates, specifically striking neighboring keys while texting. Given this, Ann's tablet has created a personalized keypress interaction model. Using this model, along with a language model, the tablet predicts intended keypresses when Ann strikes keys. The system also adapts to provide increased key sizes where necessary.

4.3. Scenario 3: Navigating Multiple Forms of Alternative Input

Ruth uses multiple forms of alternative access for her tablet, switching between two input techniques as she fatigues or environmental conditions change. The first technique is a combined EMG and IMU input that controls clicks and cursor movements, respectively. The second technique is eye-tracking. Ruth wears a smartwatch that monitors her fatigue, which is additionally monitored through her input devices. With either input technique, as Ruth fatigues, her tablet adjusts its sensitivity to selections and cursor movements to prevent accidental clicks and extraneous movements. Her tablet also provides suggestions regarding when to switch input techniques, taking into account Ruth's location, time of day, available devices, and other contextual factors that might impact the effectiveness of the suggested technique.

5. Conclusion

With the advent of consumer-focused physiological sensing systems like watches, rings, and wristbands, physiological signals can become more than just biomarkers for self-tracking; indeed, they represent an opportunity for improving accessibility by providing insights into a user's situation and abilities. With proper precautions in place to ensure security and privacy, systems utilizing physiological signals can enable a future in which technology can be adapted directly to users' abilities, whether automatically or by offering to the user appropriate customizations. We believe that physiological signals can support novel interaction techniques, interface optimizations, and user models for ability-based design, improving human-technology interactions for all.

Acknowledgments

The authors thank Momona Yamagami for discussions about this work. This work was supported in part by a National Science Foundation Graduate Research Fellowship and the University of

Washington Center for Research and Education on Accessible Technology and Experiences (CREATE). Any opinions, findings, conclusions or recommendations expressed in our work are those of the authors and do not necessarily reflect those of any supporter.

References

[1] J. O. Wobbrock, S. K. Kane, K. Z. Gajos, S. Harada, J. Froehlich, Ability-based design: Concept, principles and examples, ACM Transactions on Accessible Computing 3 (2011). doi:10.1145/1952383.1952384.

[2] J. O. Wobbrock, K. Z. Gajos, S. K. Kane, G. C. Vanderheiden, Ability-Based Design, Communications of the ACM 61 (2018) 62–71. doi:10.1145/3148051.

[3] K. Z. Gajos, J. O. Wobbrock, D. S. Weld, Automatically generating user interfaces adapted to users' motor and vision capabilities, in: Proceedings of the 20th annual ACM symposium on User interface software and technology, UIST '07, ACM Press, New York, NY, USA, 2007, pp. 231–240. doi:10.1145/1294211.1294253.

[4] K. Z. Gajos, J. O. Wobbrock, D. S. Weld, Improving the performance of motor-impaired users with automatically- generated, ability-based interfaces, in: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '08), ACM Press, 2008, pp. 1257–1266. doi:10.1145/1357054.1357250.

[5] Apple Watch double tap gesture now available with watchOS 10.1, 2023. URL: https://www.apple.com/newsroom/2023/10/apple-watch-double-tap-gesture-now-available-with-watchos-10-1/.

[6] Inside Facebook Reality Labs: Wrist-based interaction for the next computing platform, 2021. URL: https://tech.facebook.com/reality-labs/2021/3/inside-facebook-reality-labs-wrist-based-interaction-for-the-next-computing-platform/.

[7] M. Yamagami, A. A. Portnova-Fahreeva, J. Kong, J. O. Wobbrock, J. Mankoff, How Do People with Limited Movement Personalize Upper-Body Gestures? Considerations for the Design of Personalized and Accessible Gesture Interfaces, in: The 25th International ACM SIGACCESS Conference on Computers and Accessibility, ACM, New York NY USA, 2023, pp. 1–15. doi:10.1145/3597638.3608430.

[8] N. Kimura, T. Gemicioglu, J. Womack, R. Li, Y. Zhao, A. Bedri, Z. Su, A. Olwal, J. Rekimoto, T. Starner, SilentSpeller: Towards mobile, hands-free, silent speech text entry using electropalatography, in: Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems, CHI '22, ACM Press, New York, NY, USA, 2022, pp. 1–19. doi:10.1145/3491102.3502015.

[9] D. Martin, Z. Leng, T. Gemicioglu, J. Womack, J. Heath, W. C. Neubauer, H. Kwon, T. Ploetz, T. Starner, FingerSpeller: Camera-Free Text Entry Using Smart Rings for American Sign Language Fingerspelling Recognition, in: Proceedings of the 25th International ACM SIGACCESS Conference on Computers and Accessibility, ASSETS '23, ACM Press, New York, NY, USA, 2023, pp. 1–5. doi:10.1145/3597638.3614491.

[10] E. Eddy, E. J. Scheme, S. Bateman, A Framework and Call to Action for the Future Development of EMG-Based Input in HCI, in: Proceedings of the 2023 CHI Conference on

Human Factors in Computing Systems, CHI ’23, Association for Computing Machinery, New York, NY, USA, 2023, pp. 1–23. doi:10.1145/3544548.3580962.

[11] C. Mitchell, G. Cler, S. Fager, P. Contessa, S. Roy, G. De Luca, J. Kline, J. Vojtech, Ability-Based Keyboards for Augmentative and Alternative Communication: Understanding How Individuals’ Movement Patterns Translate to More Efficient Keyboards: Methods to Generate Keyboards Tailored to User-Specific Motor Abilities, in: Extended Abstracts of the 2022 CHI Conference on Human Factors in Computing Systems, CHI EA ’22, ACM Press, New York, NY, USA, 2022. doi:10.1145/3491101.3519845, event-place: New Orleans, LA, USA.

[12] C. L. Mitchell, G. J. Cler, S. K. Fager, P. Contessa, S. H. Roy, G. De Luca, J. C. Kline, J. M. Vojtech, Ability-Based Methods for Personalized Keyboard Generation, Multimodal Technologies and Interaction 6 (2022) 67. doi:10.3390/mti6080067.

[13] J. M. Vojtech, C. L. Mitchell, L. Raiff, J. C. Kline, G. De Luca, Prediction of Voice Fundamental Frequency and Intensity from Surface Electromyographic Signals of the Face and Neck, Vibration 5 (2022) 692–710. doi:10.3390/vibration5040041, number: 4 Publisher: Multidisciplinary Digital Publishing Institute.

[14] K. Z. Gajos, D. S. Weld, J. O. Wobbrock, Automatically generating personalized user interfaces with SUPPLE, Artificial Intelligence 174 (2010) 910–950. URL: www.elsevier.com/locate/artint. doi:10.1016/j.artint.2010.05.005.

[15] A. Mariakakis, S. Parsi, S. N. Patel, J. O. Wobbrock, Drunk User Interfaces: Determining Blood Alcohol Level through Everyday Smartphone Tasks, in: Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems, ACM, Montreal QC Canada, 2018, pp. 1–13. doi:10.1145/3173574.3173808.

[16] M. E. Mott, R.-D. Vatavu, S. K. Kane, J. O. Wobbrock, Smart Touch: Improving Touch Accuracy for People with Motor Impairments with Template Matching, in: Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems, CHI ’16, ACM Press, New York, NY, USA, 2016, pp. 1934–1946. doi:10.1145/2858036.2858390, event-place: San Jose, California, USA.

[17] J. O. Wobbrock, Improving Pointing in Graphical User Interfaces for People with Motor Impairments Through Ability-Based Design, in: G. Kouroupetroglou (Ed.), Assistive Technologies and Computer Access for Motor Disabilities:, Advances in Medical Technologies and Clinical Practice, IGI Global, 2014. doi:10.4018/978-1-4666-4438-0.

[18] A. Nolte, J. Wobbrock, T. Volkmann, N. Jochems, Implementing Ability-Based Design: A Systematic Approach to Conceptual User Modeling, ACM Transactions on Accessible Computing 15 (2022) 1–26. doi:10.1145/3551646, place: New York, NY, USA Publisher: Association for Computing Machinery.

[19] J. O. Wobbrock, Situationally-Induced Impairments and Disabilities, in: Y. Yesilada, S. Harper (Eds.), Web Accessibility: A Foundation for Research, Human–Computer Interaction Series, Springer London, London, 2019. doi:10.1007/978-1-4471-7440-0.