Full text available at: http://dx.doi.org/10.1561/1100000065

The Psychophysiology Primer: A Guide to Methods and a Broad Review with a Focus on Human–Computer Interaction

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Foundations and Trends® in Human-Computer Interaction

Published, sold and distributed by:
now Publishers Inc.
PO Box 1024
Hanover, MA 02339
United States
Tel. +1-781-985-4510
www.nowpublishers.com
sales@nowpublishers.com

Outside North America:
now Publishers Inc.
PO Box 179
2600 AD Delft
The Netherlands
Tel. +31-6-51115274

The preferred citation for this publication is

B. Cowley et al. *The Psychophysiology Primer: A Guide to Methods and a Broad Review with a Focus on Human–Computer Interaction.* Foundations and Trends® in Human-Computer Interaction, vol. 9, no. 3-4, pp. 151–308, 2015.

This Foundations and Trends® issue was typeset in LaTeX using a class file designed by Neal Parikh. Printed on acid-free paper.

ISBN: 978-1-68083-199-3

Full text available at: http://dx.doi.org/10.1561/1100000065

Foundations and Trends® in Human-Computer Interaction

Volume 9, Issue 3-4, 2015

Editorial Board

Full text available at: http://dx.doi.org/10.1561/1100000065

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Foundations and Trends® in Human-Computer Interaction, 2015, Volume 9, 4 issues. ISSN paper version 1551-3955. ISSN online version 1551-3963. Also available as a combined paper and online subscription.

Foundations and Trends® in Human-Computer Interaction
Vol. 9, No. 3-4 (2015) 151–308

DOI: 10.1561/1100000065

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The Psychophysiology Primer: A Guide to Methods and a Broad Review with a Focus on Human–Computer Interaction

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Contents

Abstract

Digital monitoring of physiological signals can allow computer systems to adapt unobtrusively to users, so as to enhance personalised 'smart' interactions. In recent years, physiological computing has grown as a research field, and it is increasingly considered in diverse applications, ranging from specialised work contexts to consumer electronics. Working in this emerging field requires comprehension of several physiological signals, psychophysiological states or 'indices', and analysis techniques. The resulting literature encompasses a complex array of knowledge and techniques, presenting a clear challenge to the practitioner.

We provide a foundational review of the field of psychophysiology to serve as a primer for the novice, enabling rapid familiarisation with the core concepts, or as a quick-reference resource for advanced readers. We place special emphasis on everyday human–computer interface applications, drawing a distinction from clinical or sports applications, which are more commonplace. The review provides a framework of commonly understood terms associated with experiential constructs and physiological signals. Then, 12 short and precisely focused review chapters describe 10 individual signals or signal sources and present two technical discussions of online data fusion and processing. A systematic review of multimodal studies is provided in the form of a reference table. We conclude with a general discussion of the application of psychophysiology to human–computer interaction, including guidelines and challenges.

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DOI: 10.1561/1100000065.

1

Introduction

The psychophysiological method uses measurements of physiology to form inferences about states of mind. The aim is to extract quantitative **indices** of essentially *qualitative* cognitive or affective states. Because the method does not impose restrictions on the physiological signals that are measurement sources, it has an extensive area of possible focus. Since the measurements are quantitative while cognitive and affective states are qualitative, there is an issue of establishing ground truth, and the choice of psychological model becomes important. Clearly, there are enormous challenges. Among the ways of addressing these challenges are accounting for the context of the individual during the recording and using multimodal data. However, the primary requirement is an effective working knowledge of the range of relevant signals and their application.

Human–computer interaction (HCI) is one domain wherein the psychophysiological method can be efficiently applied. In this application, human-facing software accesses psychophysiological indices from its user(s) in order to adapt via some internal logic and, for example, alter the information display so as to enhance the cognitive ergonomics. The vision is that, in conjunction with 'smart' software, the human

Figure 1.1: An example of an ambulatory psychophysiological set-up with an EEG amplifier plus mobile and fixed devices. Image reproduced with permission from Neuroelectrics SLU (Barcelona, Spain).

user performs the tasks that humans carry out best and is aided by software that automates other types of tasks.

As in other psychophysiology applications, such as clinical or sports uses, it is important to link the task and environment context with physiology signals such that user-facing systems, systems in the environment, and sensors all contribute to the same end, as illustrated in Figure 1.1.

We present a reference guide and primer to the concepts and methods of psychophysiology, along with its uses in HCI, thereby enabling rapid familiarisation with the core concepts across a broad swath of the field of psychophysiology in HCI. Although this field is very broad, taking an essentially practical approach enables us to present a relatively comprehensive overview of the relevant topics.

Our focus constrains the psychophysiological technology that we consider here, as we are concerned with only those devices that are lightweight, wearable or remotely operable, and application-ready. This rules out room-sized sensors, such as the ones utilised in functional magnetic resonance imaging.

Overview Section 1.1 briefly describes prior reviews of psychophysiology in HCI, after which the following organisation is used:

- 2: Definitions: the terminology necessary for understanding signals and associated metrics with which one may index psychological states

- 3: The state of the art: description of each of the most commonly used signals or methods, in turn, in sections 3.1 to 3.10, then sections 3.11 and 3.12, which focus on signal fusion, from both a theoretical and a practical perspective

- 4: An overview and reference to guide users of psychophysiology, including a reference table summarising prior work, along with sections on generic application areas for psychophysiology in HCI (4.1) and general guidelines for use, which also serve as a practical reference for putting the information in this primer to use (4.2)

- 5: Concluding remarks on the complexities and limitations of psychophysiology, with an introduction to the subtle challenges posed by more complicated issues of theory and epistemology, such as choice of interpretive model

1.1 Related reviews

The foundational text for the field of psychophysiology is arguably the *Handbook of Psychophysiology* (Cacioppo et al., 2000), a comprehensive reference covering the underlying scientific disciplines. With more than 1,000 pages, this comprehensive handbook cements many principles and covers a wide range of subjects, such as developmental, clinical, and environmental psychophysiology. The range of topics extends well beyond HCI, in fact, hence falling beyond the scope of our interest.

A reference book with a more applied orientation is *Engineering Psychophysiology* (Backs and Boucsein, 2000), which proceeds from engineering psychology and ergonomics. Research in these fields can be considered to be closer to our scope. The first part of the book reviews issues such as methodological considerations, theoretical issues, signal processing, and recording methods, whilst the application part reports on a mixture of laboratory and realistic studies, thereby demonstrating a relevant gap to the application of psychophysiology in the real world.

In HCI, psychophysiology has been gaining ground as both a method for studying user experience and a technique to be incorporated into interactive systems. Particularly instrumental for the latter has been the introduction of physiological computing as a field in which human physiological data act as system input in real time (Allanson and Fairclough, 2004). Early reviews of physiological computing highlighted the complexity of psychophysiological inference and its validation (Park, 2009), alongside challenges in representing the psychophysiological state of the user (Dirican and Göktürk, 2011), designing explicit and implicit interventions in the bio-cybernetic loop, and ethics implications (Fairclough, 2009b). Recently, several books (Fairclough and Gilleade, 2014) and special issues of journals (Silva et al., 2015; Jacucci et al., 2015) have reported on advances in physiological computing for HCI.

Several reviews have covered some portion of the research corpus on the application of psychophysiology in HCI. Psychophysiology, along with multimodal techniques, has been gaining attention in the field of *Affective Computing*, as evidenced in recent reviews (D'mello and Kory, 2015; Lopatovska and Arapakis, 2011; D'Mello and Kory, 2012; Zeng

et al., 2009). Usually these are high-level reviews considering how fusing and combining modalities is possible in detection of emotions, and they seldom go into the details of each signal or metric (Calvo and D'Mello, 2010). Ravaja (2004) described the literature on the application of psychophysiology in *Media Psychology* research, while Kivikangas et al. (2011) created a review for computer-game research.

Furthermore, specific topics have inspired recent reviews. Cowley (2015), for instance, undertook a preliminary review of the use of psychophysiology to assess states of high-level cognition, a new and promising area of study, which is typically associated with decision-making, problem-solving, and executive control of cognition and action. Novak et al. (2012) compiled a detailed review of data-fusion applications (the source for Tables 2.1, 2.2, and 4.1). Other, partially overlapping reviews include those by Lisetti and Nasoz (2004) and by Jerritta et al. (2011), which briefly summarise previous applications in emotion recognition and affective computing. Another high-level review, by Brouwer et al. (2015), focuses on the most successful applications, warning about some pitfalls and providing recommendations.

In light of the above, there is a clear absence of a reference article geared for HCI that could serve as a compact guide for researchers of various backgrounds.

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