Improve Your Behavioral Study with a Complementary Neurophysiological Study and Vice Versa

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Abstract
Neurophysiological methods offer insights into human cognition. However, these neurophysiological methods are often limited by the artificiality of an experimental setting or the intrusiveness of the method. It is often advisable to complement an HCI experiment using neurophysiological methods with a behavioral experiment, either in a laboratory or field setting.

In this paper we discuss four guidelines for why and how to effectively design complementary behavioral and neurophysiological experiments in an HCI context. We use examples from our research to demonstrate these points. These guidelines can help researchers design effective studies using both neurophysiological and behavioral experiments.

CHI 2018, April 21-26, 2018, Montreal, Canada

Author Keywords
Behavioral research; neuroscience; functional magnetic resonance imaging (fMRI); eye tracking; electroencephalography (EEG); mouse cursor tracking

ACM Classification Keywords
H.5.2. Information interfaces and presentation: User Interfaces; J.4. Social and Behavioral Sciences.

Introduction
When studying human-computer interaction (HCI), neurophysiological methods offer insights into human

cognition that cannot be obtained using traditional methods. However, these methods are often limited by the artificiality of an experimental setting or the intrusiveness of the method. For these reasons, it is often advisable to complement an HCI experiment using neurophysiological methods with a behavioral experiment, either in a laboratory or field setting.

The purpose of this paper is to discuss four guidelines for why and how to effectively design complementary behavioral and neurophysiological experiments in an HCI context. These guidelines include: (1) use theory to extend, rather than replicate the neurophysiological experiments with behavioral experiments; (2) enhance ecological and external validity by carefully designing a behavioral study; (3) use the results of each methodology to inform the other; and (4) use neurophysiological and behavioral studies in tandem to inform HCI artifact design. By applying these points, researchers can more effectively design complementary neurophysiological and behavioral experiments that together provide insights into phenomena under study.

Reasons for a Complementary Neurophysiological Study

Through traditional behavioral studies, we can observe users' interactions with computers. Using surveys, we can ask them to explain why they behave (or plan to behave) in certain ways. Unfortunately, often times users do not know why they behave a certain way, or they may have reasons (e.g. social desirability) to not disclose their true thoughts or motivations. Neurophysiological studies can use tools such as functional magnetic resonance imaging (fMRI), eye tracking, electroencephalography (EEG), and mouse cursor tracking to better understand the cognitive processes behind the user behaviors. Research shows that using multiple methods provide a more holistic view of constructs under investigation [7]. For example, fMRI can capture automatic or unconscious mental processes that are difficult or impossible to measure with traditional tools [2]

Reasons for a Complementary Behavioral Study

Provide Ecological and External Validity

Often neurophysiological studies face challenges with ecological validity. Riedl et al. [5] identify three dimensions of intrusiveness: degree of invasiveness, degree of natural position, and degree of movement. For example, the fMRI methodology requires users to lie still in a supine position while being scanned. Realistic interaction with a computer is limited. Other neurophysiological tools may involve intrusive head gear or attachments to the face or limbs.

Evaluate the Design of HCI Artifacts

Using neurophysiological methods can help objectively explain *how* the design of an artifact influences the user's neurology and thereby *why* an artifact may influence decisions and behaviors [8].

How to Design a Complementary Study

Guideline 1: use theory to extend, rather than replicate, the neurophysiological experiments with behavioral experiments. We recommend designing a behavioral experiment that extends a neurophysiological experiment in terms of method, context, or both. This can result in a behavioral experiment that is substantially different from its neurophysiological counterpart. In these cases, it is especially important that both experiments be linked by theory, such as the same theoretical explanation and related hypotheses. In this way, neurophysiological experiments can be augmented by testing their findings in realistic contexts and with larger sample sizes.

In Anderson et al. [1] we conducted a fMRI experiment that examined how users habituate to security warnings. We also tested whether users habituate to polymorphic warnings—that is, warnings that change their appearance. Although the fMRI hypotheses were strongly supported, ecological validity was limited. To enhance the ecological validity of the study overall, we designed a behavioral laboratory experiment in which participants conducted a realistic task on their own laptops. However, the underlying theory was the same, and we tested a subset of the fMRI hypotheses via mouse cursor tracking, which unobtrusively measured attention.

Guideline 2: enhance ecological and external validity by carefully designing a behavioral study. The constraints of neurophysiological methods often require participants to hold still through the course of a study. Behavioral studies, particularly those that occur outside the lab, can be more true to life and thus increase ecological validity. While surveys are helpful in gathering participant perceptions and intentions, a behavioral study allows researchers to pair how people behave with the insights of *why* they behave that way as measured in the neurophysiological study.

In one project [6], we conducted a series of experiments: one was a task completed while we recorded EEG data. During the next stage, in a new room and without the EEG net, participants completed an image classification computer task on their own laptops. We tracked their behavior in response to security messages that were displayed during the course of the primary task. We were able to pair the data collected during the EEG part of the experiment with the data from the image classification task. In this way, we were able to improve the ecological validity of the study overall and demonstrate why people did not behave the way they said they would. Rather, they behaved consistent with the pattern established in the EEG study.

Guideline 3: use the results of each methodology to inform the other. Krakauer and colleagues [4] note that behavioral experiments are often needed either before or after conducting the neural experiments in order to close a mutually-beneficial “knowledge loop.” In that way, the behavior under investigation can be better defined through pilot or preliminary testing. Similarly, behavioral testing can be informed by the results of the neural data.

For example, in a study on users’ risk perception [6], we measured an implicit reaction to risk using EEG which predicted subsequent responses to risk in a computing setting. We also collected behavioral measures of participants’ perceptions of risk in a way that participants did not obviously associate with the main experiment. In this way, we were able to compare both behavioral and neural measures of risk perception and use each to inform the other.

Guideline 4: use neurophysiological and behavioral studies in tandem to inform HCI artifact design.

Measuring neural data can provide insight into the precursors to behavior, which help explain why a behavior occurs. In contrast, behavioral studies can be used to evaluate the influence of HCI artifact design on relevant real-world outcomes. When evaluating an HCI artifact design across neurophysiological and behavioral studies, one should strive to ensure the design manipulation is similar across studies.

In Jenkins et al. [3], we manipulated the timing of warnings: whether a warning was shown between vs. in the middle of a task. We found strong fMRI evidence of dual-task interference (DTI) when a security message interrupted another task and DTI was reduced when a security message followed immediately after another task. This finding was used to inform the design of security message in Google Chrome. We designed the message to display at low- and high-DTI times, and found displaying the message at low-DTI times substantially improved behavior. By conducting fMRI and behavioral experiments together, we were able to incorporate the neural insights from an fMRI experiment into an IT artifact design that we tested in the field, leading to greater support for the IT artifact design.

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