Psychophysiology as a Tool for HCI Research: Promises and Pitfalls

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Abstract. Psychophysiology, an area of psychology that measures individual's physiological responses to refer to one's psychological state, can provide a set of useful measures HCI researchers can take advantage of. However, there are limitations to the method itself and room for misinterpretation. This paper introduces psychophysiology, and also shows how research methods psychophysiology offer can be used for HCI research, advantages and disadvantages of using research tools from psychophysiology.

1 Introduction

A student essay written and posted online by MIT in 1998 [14] reads "...from studying how human physiology and psychology, we can design better interfaces for people to interact with computers. Work in this domain is only beginning (indeed the number of papers written on this topic has increased in the past few years), and there is much that we don't yet know about the way the human mind works that would allow more perfect user interfaces to be built. (p.4)"

Yes, ten years has passed. Though it may have not been as magnificent as this (presumably) young student predicted, there were small yet solid advances made here and there in the area of psychology research. There were also technological advances made for physiology research. Today, as Kim et al. [7] put, HCI researchers are calling for study of human interaction, cognition and physiology to apply such knowledge in system development and implementations. However, it seems that measuring and analyzing physiology data is still not commonly found in HCI research today. Part of the reason may be entrance barrier (understanding of the relationship between human psychology AND physiology, learning to collect physiological data, high cost of physiology equipment, etc.). Another reason may be lack of effort to introduce and share knowledge on using physiology for HCI research.

This paper is an attempt to introduce the advantages (and also warn about the possible mistakes made) of applying psychophysiology for HCI research.

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2 Psychophysiology and HCI

2.1 Psychophysiology as an Academic Discipline

Psychophysiology as an academic discipline that studies the interrelationships between the physiological and psychological aspects of human behavior [15]. A typical study in this area observes human's physiological responses to understand human's psychological status and/or changes.

Due to its interdisciplinary nature, research from various disciplines including, but not limited to, psychology, cognitive science, medicine, anatomy and neuroscience are incorporated.

The type of physiological responses used for psychophysiology studies include blood flow pattern in the brain (functional magnetic resonance imaging; fMRI), heart rate variability, sweat production (skin conductance; SC), respiration, Electroencephalography (EEG; commonly known as 'brain wave'), muscle contraction (Electromyography; EMG), eye movement, and much more.

2.2 Psychophysiology Providing Tools for HCI Research

A wide variety of techniques ranging from qualitative to quantitative are used in HCI studies. The qualitative ones such as in-depth interviews and focus group interviews can provide great depth of insight. However, they are open to misinterpretation and requires a great deal of experience to avoid this.

The quantitative ones can be further divided to self-reports and observational ones. Former includes questionnaire and survey, and latter includes response time, counting number of errors (or attempts), and so on. The advantage of using quantitative methods is that the data produced can be used for inferential statistical analysis, providing insight beyond descriptive statistics. However, many quantitative techniques, especially the self-report types, are also open to serious errors. The data may be less-than-accurate because the subject cannot remember certain things clearly, or even motivated to lie (e.g., "have you voted during the last election?").

The research tools psychophysiology offers are quantitative and observational. What makes these tools interesting is that they provide a way to tap into human mind. A large body of literature in psychophysiology provides a fairly solid ground for interpreting the data. In other words, it can provide an alternative way to find how much attention is being paid to the task or how difficult the interface is to use – both which subjects might provide inaccurate answers to when asked using a self-report questionnaire, depending on circumstances.

3 Useful Psychophysiological Research Techniques

As mentioned above, a large variety of physiological responses are subject for study in psychophysiology. This section will introduce a few of them that HCI researchers are more familiar with, or may find more useful than others.

3.1 Sweat Production (SC) and Stress

It is known that people sweat under stress. This is also true when computer users are stressed out from the difficulty of the task given. In order to find how easy or difficult an interface is to use, HCI researchers may measure the amount of sweat production, or skin conductance (SC) of the subject [11, 16].

Deep down, skin conductance is directly related to the activation of sympathetic system of the central nervous system. This is good because it means skin conductance is independent from the activation of the parasympathetic system, which can cause misinterpretation of the activity of many human organs or systems which are under influence of both central nervous systems (for example, human heart may beat faster because the sympathetic system is activated, or because the parasympathetic system is deactivated, or both).

However, there are downsides for using skin conductance. One of them is the sensor (electrode) placement. Sweat glands in humans are concentrated in palms and soles. Many computer-related tasks and their interfaces require users' hands. Collecting skin conductance data from the palm may restrict subjects from using both hands freely. Furthermore, in certain tasks that require both hands (such as typing text with a keyboard), using palm is out of question. Alternatively, sole of the foot may be used, but this is inconvenient since subjects are required to remove their socks and have their foot kept lifted through the whole session to prevent electrodes touching the floor.

Using skin conductance as an index of task (or interface) difficulty is it's slow response speed. Rather than constantly producing sweat, human sweat glands 'spout out' sweat. It takes about six seconds for sweat glands to respond to an arousing event, though exact timing varies by individual. This makes it hard for researchers to pinpoint the exact timing of a particular event that causes stress in the human subject. For this reason, comparing the total amount sweat or average skin conductance level over time within a subject during different tasks (which takes longer than 10 seconds to complete) is recommended rather than attempting to identify the exact moment that causes stress [15].

3.2 Heart Rate (HR) Variability and Attention

Human heart is affected by both sympathetic and parasympathetic systems of the central nervous system. This means that its activity is affected by both arousal and paying attention to external stimuli.

Research shows that the speed of heart beat slows down when one is paying attention to a stimulus presented [17]. This can be explained from an evolutionary psychology perspective: when an unknown change is noticed in the environment, the body automatically responds to it by calming down (or slowing down) the activities of the internal organs until proper assessment of the situation is made. If the change turns out to be life-threatening, then the famous 'fight or flight' reaction, which includes intensive activity in sweat glands and quick acceleration of heart rate follows. If the change does not pose any harm to human, then the heart rate gets faster, but no faster than the normal speed.

It is important to acknowledge that deceleration of heart rate is an index of external attention. Measurement of external attention is useful for HCI research since it serves as an index of whether the subject is paying attention to the menu of the computer screen, or whether that gentle chime has actually got the subject's attention.

The other type of attention is called internal attention, which happens when one puts mental effort to solve math questions [9]. When this happens, heart rate acceleration is observed. Hence, it is important to see the context of the settings heart rate data has been collected and determine whether the heart rate getting fast is a heart rate acceleration which is a byproduct of internal attention, or simply a heart rate deceleration from not paying attention. Also to put into consideration is the subject's arousal level – excitation leads to arousal in the sympathetic system, which triggers heart to beat faster. When analyzing heart rate data, context matters a lot.

There are two ways to measure heart rate. One is to measure the electrical pulse produced by the human heart every time it contracts and pumps blood out to the whole body. This measurement is called electrocardiogram, or ECG. The other way is to measure the blood flowing in and out to the tip of the finger and/or toe, which is called photoplethysmography (PPG). Photoplethysmography is typically measured by emitting infrared light into the skin. The level of light absorption changes by the amount of blood flowing underneath the skin, and this is used to measure heart rate.

ECG monitors the electrical activity of heart, while PPG monitors the mechanical activity of heart. In a perfect world, both has to be able to serve as equally perfect indices of heart activity. But neither is perfect.

ECG requires three electrodes, attached on both arms, both legs, or above the chest. Chest placement is rarely used outside of a hospital setting, though it provides the clearest ECG. Attaching electrodes on arms or legs is more practical for HCI research, but the distance from the heart tends to make it more vulnerable to noise (caused by subject's body movement and internal organ activities) and weak pulse. From my personal experience, arms tend to provide cleaner ECG than legs.

PPG needs to have one sensor attached to a finger or a toe. Generally, fingers are better than toes for collecting PPG data because they are closer to the heart. Nevertheless, if the subject's heart is relatively weak and the hand or foot is in a position that makes it hard for blood to flow in, there may not be enough blood flowing in and out for the infrared light sensor to notice and record the PPG.

For these reasons, both are somewhat vulnerable to errors, especially by missing individual heart beats. However, many of these issues can be prevented by preparing the best possible settings for the subject. As long as the study condition is fine, ECG is as reliable as PPG [13].

Sensor placement again can be a problem: ECG requires three locations on the arm or the leg. PPG may require only one but it has to be either a finger or a toe. And it is best to avoid the sensors touching hard surface. As a result, type of data to be collected for heart rate and location for sensor placement depends on the type of task for the subjects.

3.3 Eye Tracking and Attention

As the maxim "eye is the window to mind" suggests, it has been long thought that human gaze reflects the top priority of cognitive processes [6]. This is one of the reasons HCI researchers find eye tracking to have great potential to be an important research tool.

In the past, electrooculography (EOG) that measures resting potential of the retina was used to track the eye movements. However, EOG can only show to which general direction the eye has moved to; not exactly where the eye gaze if fixed to [6, 15].

With advances in real-time optical data processing, monitoring of the retina by using infra-red light became more sophisticated.

Data produced by eye tracking is useful not only since it provides quantitative data that can be subjected for statistical analysis, but also because it can be visualized in ways that are intuitive for audience when presented. One is heat map, which color-codes each area of the computer screen where usually red is colored to the area that the eye fixation happened longest and dark blue (or no color) represents little or no eye gaze in the area. The other is an animation of which part of the screen the gaze has been moved to (which, some companies call “gaze replay”) in accordance to time. When used properly, both visualization techniques are powerful enough to convince audience with little or no knowledge in statistics [3, 4, 6].

In the past, eye tracking equipments required a head-mounted camera that monitors the retina movement and alto a head-mount that fixes the subject’s head since the equipment was not capable of making adjustments according to head movements. Today, there are equipments in the market that does not require head-mounted cameras. Some of them are capable to make adjustments to minor (and gentle) head movements.

However, eye tracking technology available today still has its own limitations. The largest challenge is that it is hard to use on subjects with seriously bad vision. This is not because of the vision itself, but because of the lenses (both glasses or contact lenses). In theory, the equipment should be able to be adjusted for such lenses, but in practice, virtually no machine in the market provides such calibration. However, there are indeed quite a few equipments that automatically adjust to subjects who wear glasses for relatively light myopia. Incapability to track vision to sudden and/or fast head movement is another limitation for contemporary eye tracking technology.

3.4 Facial Muscle Activity (EMG) and Emotion

Muscle fibers of human (as well as other animals) contract when they are triggered by electrical current. Electromyography (EMG) is a measure of the electrical activity of muscles, which directly index muscle activities.

Facial EMG refers to indexing of facial muscle activities. Psychophysiology researchers have been using facial EMG to monitor emotional changes in human [5, 12]. There are three muscle groups monitored for this purpose: Currugator supercilii, Zygomatic major, and Orbicularis oculi [15].

The Corrugator supercilii muscle group is the “frowning” muscle. It is located between the nose and the forehead and when activated, it draws the eyebrow slightly downward and creates vertical wrinkles between the eyebrows. Corrugator activity is typically used as an index of negative emotion.

The Zygomatic major is a muscle group that is located at both ends of the lips. When activated, it pulls the lips from both sides and mostly used when one is smiling. For this reason, it is used as an index of positive emotion. However, it is also activated when one is experiencing other types of non-positive emotion (e.g., One screaming “Eeeek!” out of disgust), so the data has to be analyzed with caution.

The Orbicularis oculi is another muscle group that is getting attention as an alternative for the Zygomatic major muscle group as an index for positive emotion. The Orbicularis oculi muscle group is located right below the lower eye lids, and it is primarily responsible for eye blinks. It is also responsible for gathering of skin around the eyes when one is smiling, which is called the *Duchenne smile*. A Duchenne smile involves contraction of both the zygomatic major muscle group and the orbicularis oculi muscle group, and it is seen as an indicator of one experiencing true happiness (a Non-Duchenne smile only involves the zygomatic major muscle group and interpreted as an indicator of social smiling which does not involve happiness; for review, see Ekman, Davidson, and Friesen [2]).

One of the challenges using facial EMG is that the muscle groups are small and the electrical activity is very weak. Especially, orbicularis oculi muscle group is so small that researchers are forced to place two mini electrodes (diameter of 4-millimeters) very close (about 5-millimeters), which makes it vulnerable to errors during data collection.

4 Conclusion: No One Measure Is Perfect

This paper has reviewed skin conductance, heart rate, eye tracking, and facial EMG as tools for HCI research. There are, of course, other tools such as Electroencephalography (EEG; also known as ‘brain wave’), functional Magnetic Resonance Imaging (fMRI; also known as ‘brain imaging’), and many more. Each has its own unique advantages and disadvantages as a tool for research.

Though psychophysiology promises to provide useful research tools for HCI, there are limitations that generally apply to them [8]. The largest one is external validity. As mentioned above, skin conductance, heart rate, facial EMG all requires some kind of sensor to be attached on parts of the subject’s body. And this adds to the awkward feeling to already unnatural setting (e.g., being put into a usability lab with a one-way window and, possibly, video camera rolling) the subject may experience during a session.

Eye tracking is no less artificial than other measurements. The least intrusive technology still requires participants keep their head movement minimal and if needed, move gently. The subject has to be reminded of this, and this inevitably causes unnatural tension in the subject which, depending on the type of study, may have fairly large negative impact on the data collected.

Another limitation is that the data collected is open to interpretation. Though many people tend to believe psychophysiology provides an absolutely objective data and interpretation. For example, Hornbaek (2005) argues that physiological measures are objective, using "physiological measures of fun in playing computer games (p.92)" as an example. Unfortunately, this view can be wrong – especially in the context of HCI research.

Studies in psychology tend to use simple stimuli, which helps avoid unexpected factors to interfere. But in many cases, HCI research has to use real-life equipments and/or interfaces as stimuli that are much more complex than those stimuli used in a typical psychology experiment. So the data collected always have to be interpreted with the context in mind. Could the heart rate have picked up speed because the subject was not paying attention, or because the subject was puzzled by the menu system and had to think about it? Was the subject sweating more because the interface was hard to use or because there was an image of a huge spider shown on the screen? When designing the session, it would be the best to eliminate all factors that may result unwanted interference during data collection, but even after data has been collected, it would be the best to go back and think if there is any room for alternative explanation for certain physiological responses.

And researchers should keep in mind that though research tools provided by psychophysiology may offer new insights, none of them is perfect by itself and it is best to be used in combination with other research methods.

Through his online column, Jacob Nielsen, a well-known HCI guru and consultant, advices design agencies who are seeking ways to convince clients to pay for usability testing, "using sound methodology is the true sign of professionalism" and they have to "point out usability's astounding return on investment."[10] Including psychophysiology to the set of tools available may also be a good idea for design agencies for improving usability of the final product. Psychophysiology should be able to make good friends with both HCI researchers and HCI practitioners. It’s just the matter of choosing the right tool and applying it the right way to get the right answer to the right question.

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