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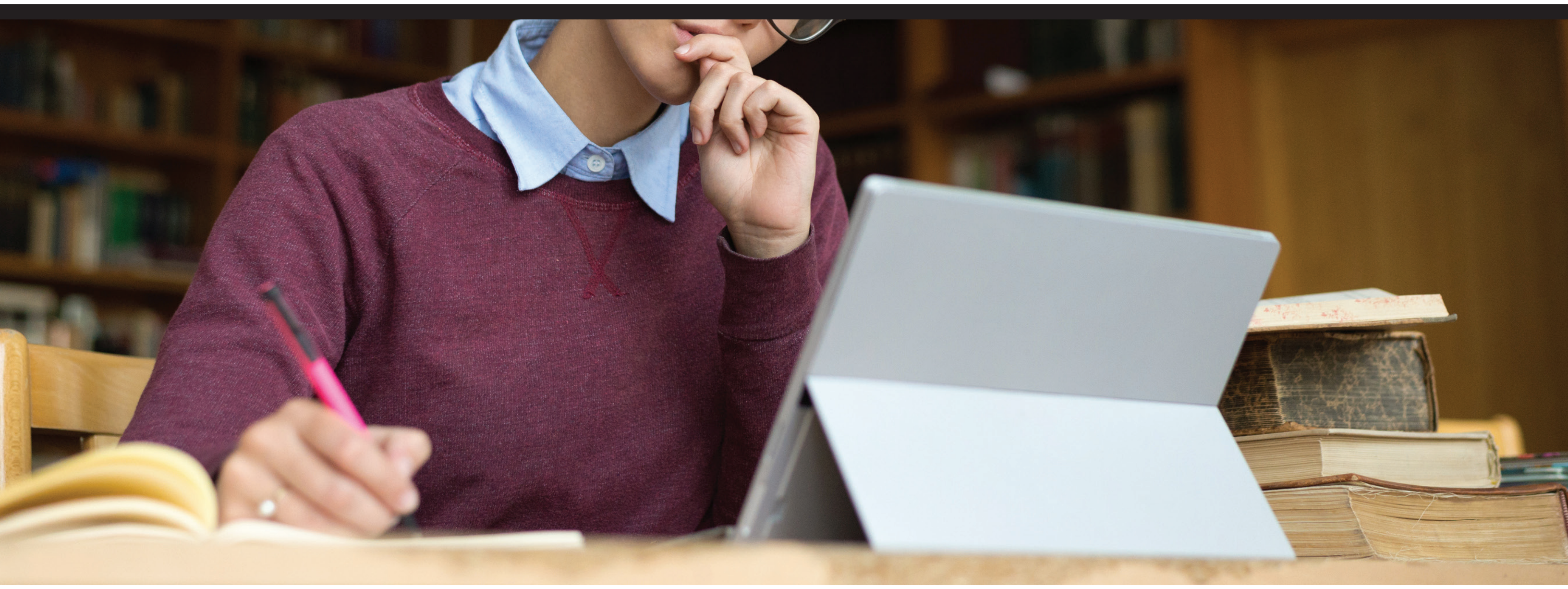

EXPERIMENTAL SUPPLEMENTS

From Mobile Tools for Cognitive Introspection Towards Cognitive Augmentation

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In an increasingly interconnected world with more and more technology surrounding us, more and more people end up with psychological and mental health issues. Mobile Computing technologies is often introduced into society without knowing about impact and consequences. We need new mobile tools for everyday life to better manage our attention and give us introspection into our cognitive self. There are patterns in human physiological signals (facial expressions, heart rate, nasal temperature, eye movements, blinking, etc.) that can reveal information about cognitive functions of individuals and groups.

In our research, we work on recognizing cognitive behavior with unobtrusive, affordable mobile sensing. Our first research effort focused on reading tasks, yet we are moving towards more general cognitive sensing (for example, assessing confidence and fatigue). In this article, we motivate the potential of unobtrusive, mobile sensing for personal introspection into our cognitive activities. These introspection tools are the basis for what we call *Experimental Supplements*, a way to augment our cognition by reproducing experiences from one person to the other. For us, this is a first step towards "coding our cognition" (affecting human behavior in an unconscious way).

FROM MOBILE PHYSICAL TO COGNITIVE SENSING

We now have mobile computers that track our health and fitness from counting steps to counting calories. We also see a move to record physiological signals, such as heart rate. Nowadays, smart watches, like the Apple Watch, are equipped with sensors that were used in medical appliances just a couple of years before. As a continuation of this work, we apply mobile sensing to cognitive tasks as well. Technologies like fMRI, EEG, or Functional Near-Infrared Spectroscopy (fNIRS) seem to be most promising for this task. Yet applying them to a mobile setting is still difficult as they are bulky and their recordings are often noisy due to motion artifacts. In this line, we found head-worn "smart eyewear," a promising novel research platform, as the head seems to be a perfect position for those sensing devices (most of our senses are located there). The challenge is still how to reliably monitor cognition in a mobile setting and where to start for such an endeavor. We decided to explore reading, as it's a ubiquitous knowledge acquisition task, usually recognizable as well from people surrounding the reader (based on focus and eye movements).

Photo, istockphoto.com

FIGURE 1. Different kinds of eye trackers (left to right): two stationary video-oculography systems, two mobile video-oculography systems and one electro-oculography system.

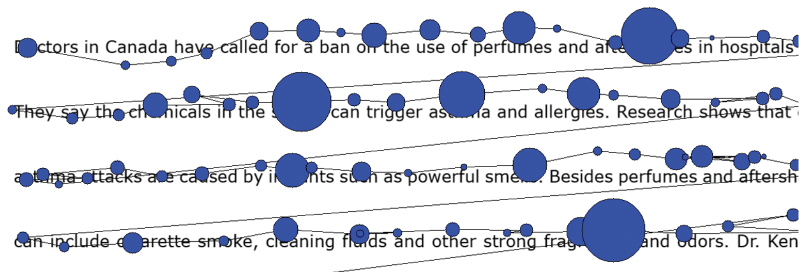

FIGURE 2. Sequence of fixations and saccades recorded by a stationary eye-tracker. The size of the circles represents the time spent on the corresponding location. The segments correspond to the saccade between the fixations.

Tools for Cognitive Introspection: From Tracking Specific to More General Cognitive Activities

To explore cognitive states, we first looked into reading tracking. Reading is a complex cognitive process related to knowledge intake. Yet compared to other cognitive processes, it is still easy to define and to evaluate. An observer can readily detect whether or not a person is reading based on their eye movements. In the following, we describe our efforts to track reading activities and creating a "step counter" (counting how many words a person is reading). Afterwards, we describe our efforts to make this tracking more general, including other cognitive states (e.g., fatigue).

How much do you read every day?

The pedometer was one of the key devices that enabled people to track their physical activity. Tracking the cognitive activity is a new challenge that eye tracking and wearable sensors can help to address, especially for analyzing the reading activity. We are developing methods that can be used for estimating the number of words read.

We used two different kinds of technologies to record the eye movement: video-oculography (VoG) and electro-oculography (EoG). VoG is based on cameras and infrared light. It can be either head mounted (MVoG) or fixed beneath a computer screen (SVoG). For EoG, electrodes measuring current around the eyeball are in contact with the skin. This allows detection of horizontal and vertical movement of the eyeball but it is not possible to know precisely where someone is looking. As seen on Figure 1, the movement of the eyes while reading is saccadic: the eyes stop at some positions (fixations) and jump from one position to another one (saccades).

Text is usually organized as sequences of aligned words. So a typical reading behavior will be a sequence of forward saccades followed by a long backward saccade to return back to the beginning of next text line. This pattern is the key information used to analyze the reading behavior and estimate the number of words read. For the SVoG and MVoG, the detailed process to estimate the number of words read is done in three steps. (1) We set a threshold α for detecting which long backward saccade is corresponding to a line break. (2) We extract five features related to the eye movement: the total reading time, the sum of line break saccade distances, the sum of all saccade distances (without the line breaks), the number of line breaks, and the number of fixations. (3) We build a regression model based on SVR (Support Vector Regression), which is used to predict the number of words read based on the extracted features. For the EoG, different features are extracted as the EoG signal contains only information about the horizontal and vertical movement of the eyes (and not the absolute position of the gaze). As EoG signal is noisy, we focused on the analysis of the horizontal movement, and more precisely on the backward movement. We extracted two features: the number of minima and average value of the minima. Then an SVR model is used to predict the number of words read.

We recorded 14 participants reading different texts (English news), which amounted to 109,097 words read. Depending on the learning approach, we obtained a weighted average error among all devices between 9.4% and 11.5%. Like a pedometer, the more you read, the better is the estimation, as overestimation and underestimation tend to compensate each other.

Even if this error is relatively low, there are still some problems to consider when using eye trackers. One of the major problems is the need to calibrate before using the system. This can be annoying for the user, especially if it is necessary to do it every time that one stops using the system for some time. We also noticed that the pupil detection sometimes fails for the VoG, especially with some users whose eyelids are less open than others. For the EoG, head movements will induce noise in the electrodes and affect the ceation of the system.

Tracking Fatigue and Cognitive Load

We recently extended our research beyond reading, looking at other cognitive functions and focusing on fatigue, cognitive load and alertness. First studies from our groups indicate that mobile sensing can also be used to quantify these processes. The reader might wonder why it is important to track one's fatigue, since they know how tired they are at any given time. Actually, that might not be the case. As we showed in a long-term fatigue study, users are quite inaccurate in assessing their own fatigue level using a questionnaire. Comparing the questionnaire results to a ground truth using a psychology fatigue test (Pschomotor Vigilance Task), the questionnaire answers seem randomly distributed and not indicative of the fatigue level. However, we could detect the fatigue level based on blink data from unobtrusive Electrooculography smart glasses (J!NS MEME). Given that we can record and analyze more complex cognitive states using these unobtrusive sensing devices, how can we use this type of information? How can we use this data to help users with their problems? We believe that general cognitive activity recognition will be the enabling technology for the concept of experiential supplements, which we explain in the following section.

FROM INTROSPECTION TO EXPERIENTIAL SUPPLEMENTS

We can now record a more holistic view on a person (mental and physical activities and contexts), and most of the problems we face in life have already been experienced and solved by others. Thus, we propose to build a system for recording experiences as digital data, and transforming the digital record of experiences into a user-adapted form called "experiential supplement" by taking into account the user's internal states and cognitive biases. This makes the experience transfer easier. On a basic level, we clone an environment and try to induce physiological signals and responses from a "successful" experience in the past on the current situation of the user. The process of generating experiential supplements can easily be understood with the analogy of medicine/supplements production, as shown in Figure 3. As a concrete application, we consider applying it to create learning supplements for education.

The traditional approach to sensing the learning experience is to analyze the usage log and performances of the students. However, the performances reflect only the outcome of the learning experience. The thinking process, the cognitive experience, the emotions felt by the students, etc., are almost all ignored, although they are an essential part of the learning experience. More sensors are necessary to estimate the mental states of the students while they are learning. We are building a deep sensing platform combining physical and physiological sensors measuring the BVP (Blood Volume Pulse), EDA (electrodermal activity), skin temperature, eye movement, pupil diameter, EEG (electroencephalogram), head and body movement, and even the communication with other people, as shown in Figure 4.

Several mental states, such as understanding, concentration or interest are reflected in our physiological or physical activity, such as typing more quickly, sweating, frowning, moving on one's seat, etc., which can be measured with sensors. We can already track our reading progress, detect how tiresome a specific activity is and where our attention level is during the day. The next step is to help users to manage our mental health better by helping us to code our cognition. The open question we want to grasp with our research is "Is it possible to augment or 'code' our cognition using tools like experimental supplements?" Users should be able to make conscious decisions just once and mobile systems should help them to stay on track unconsciously. ■

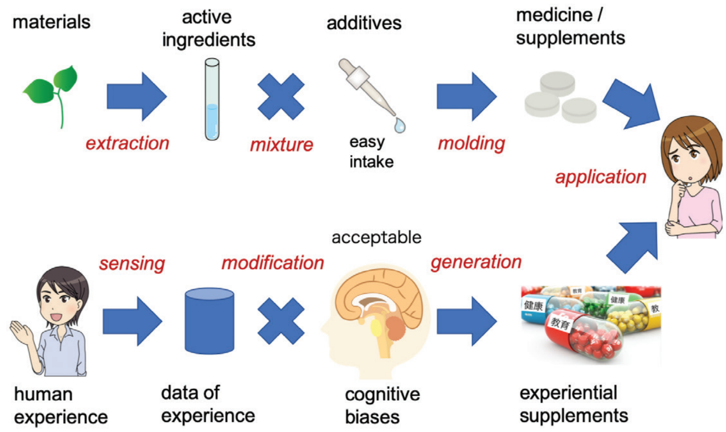

FIGURE 3. In the case of actual supplements, active ingredients are extracted from materials and mixed with additives for easy intake. After molding, supplements are ready to be taken by a person. The same holds for human experience. Data of experience are extracted from human experience and modified into a more acceptable form by taking into account the nature of human cognition, such as cognitive biases and nudges. A piece of information generated after the above modification is called "experiential supplements," which can be applied to help change the behavior of a person.

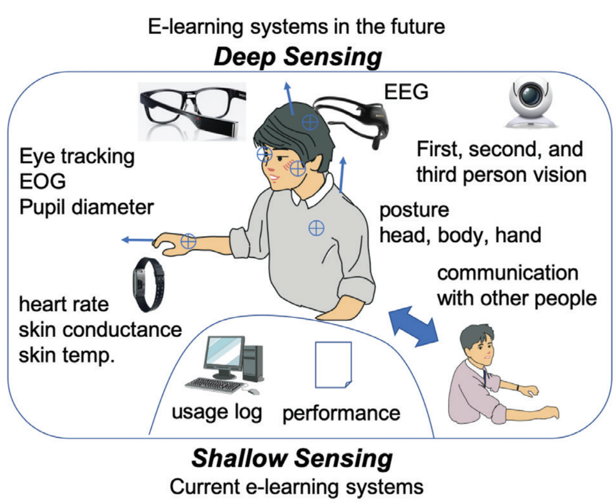

FIGURE 4. Most of the current e-learning systems sense learners by only using the usage log of the system, as well as the results of performance tests. As compared with such "shallow sensing," we employ "deep sensing" by using various sensors shown in this here.

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