Enhanced Cognition via Augmented Interoception

Alwin de Rooij
Department of Communication and Cognition
Tilburg University, Tilburg, Netherlands
alwinderooij@tilburguniversity.edu

ABSTRACT

Interoception, the ability to perceive signals that originate from within one's own body, plays an important role in regulating the hormonal and neuro-endocrine processes that underlie cognitive performance. In this position paper, it is proposed that interoception can be augmented by mapping physiological data measured with artificial sensors, and that is under normal circumstances not available to the senses, to the biological senses in real-time. When changes perceived in such a mapping coincide with changes in cognitive processes, new relationships between the augmented interoceptions and cognition can be learned. Speculatively, these relationships can be exploited to enhance cognition. Two studies have shown that using a mapping from the eye's pupil size, which rapidly traces changes levels in the stress hormone and neurotransmitter noradrenaline, to sound, can indeed lead people to learn relationships between such a mapping and their cognitive processes. However, there are also several design challenges that need to be addressed before the augmentation of interoception can be developed into a technology that truly enhances cognition. These challenges include the need to design for supporting attention, learning, and managing reciprocal effects between the designed mappings and cognition.

CHI'19 Extended Abstracts, May 4-9, 2019, Glasgow, Scotland, UK.

ACM ISBN 978-1-4503-5971-9/19/05.
DOI: https://doi.org/10.1145/3290607

KEYWORDS

Augmented interoception; Enhanced cognition.

INTRODUCTION

Interoception, the ability to perceive signals that originate from within one's own body, plays an important role in regulating the hormonal and neuro-endocrine processes that underlie cognitive performance [1]. Interestingly though, not all such signals can be perceived [2]. There is currently no conclusive evidence, for example, on whether people can perceive the dilations and constrictions of their eye's pupils, cf. [3]. Yet, pupil size rapidly traces changes in noradrenaline in the central nervous system, a neurotransmitter and stress hormone, which regulates amongst other things attentional focus, flexibility, and arousal. Given that technologies exist to measure bodily processes that people themselves cannot perceive (in detail) [2], there is an opportunity for designers to develop new ways in which technology can enhance the ability of people to perceive the hormonal and neuro-endocrine processes they normally have no access to [4]. Possibly, with the potential to enhance cognition and cognitive performance.

This ambition may be achievable by using design principles applied in sensory substitution and augmentation studies [2]. Recent studies show, for example, that wearing a belt that always vibrates where the magnetic north is, enables people to develop a novel "sense" for the north, and use the belt to support navigation tasks in novel ways [5]. In the same way, interoception could be augmented [2]. That is, by mapping physiological data that is measured with artificial sensors, and which is typically not available to the senses, to the biological senses in real-time. When changes perceived in such a mapping coincide with changes in cognitive processes, e.g. an increase in noradrenaline due to perceived difficulty during a thinking task, new relationships between the augmented interoceptions and cognition can be learned, e.g. that changes in the perceived mapping indicate difficulty, and that the task is difficult. Speculatively, perceiving one's own hormonal and neuro-endocrine systems at work in real-time may thus lead people to discover themselves if and how such signals can be exploited to support cognitive performance.

AUGMENTING INTEROCEPTION TO ENHANCE COGNITION

It is, however, an open scientific question whether people are able to learn relationships between a mapping of physiological data measured with artificial sensors, which is otherwise not accessible, to the biological senses; and let alone whether what is learned can be exploited to enhance cognition.

To address the former, de Rooij et al. [2] conducted two studies that used a mapping from pupil size measured with an eye-tracker, to audible sound (changes in volume and frequency of a sine wave) (Figure 1). Participants engaged in a mathematics task, an insight problem solving task, and a reading task, which items varied in difficulty. These variations in difficulty were assumed to cause changes in noradrenaline levels, as was predicted in previous studies, cf. [3], and with that cause changes in pupil size [3]. One half of the participants used the mapping from pupil size to sound during the tasks;

Figure 1. Augmented interoception by mapping pupil size that is recorded with an eye-tracker in real-time, to changes in the volume and frequency of an audible sound (sine wave). This setup was used in study 2 that was discussed.

Whereas the other half heard a control sound that had the same sonic characteristics as the real mapping from pupil size to sound. That is, they used a fake mapping. After each task they were asked to rate Likert scales about the degree to which they learned something about their thinking process because of the sounds, and whether they were able to hear the sounds at all while engaging in the thinking tasks. Moreover, they reported what, if anything, they learned.

Prior to the first study (*n* = 57), participants were informed that the sounds they would be hearing would correlate with changes in their thinking processes, such as difficulty and cognitive load. People learned more about their own thinking processes when hearing the mapping from pupil size to sound, than when hearing the fake mapping, but that this was conditional upon them hearing the sounds at all. Participants learned about their own task performance (e.g., *"Memorizing numbers is difficult for me"*) and control strategies (e.g., *"I'm often not paying attention while reading"*). However, the sound itself also enabled learning in an unforeseen way. In particular, for participants that heard the fake mapping during the tasks (*"I'm easily distracted by sound"*).

Prior to the second study (*n* = 40), participants were not informed about the correlations between the sounds they were hearing and some of their cognitive processes. Here, the results showed a negative main effect of using the mapping from pupil size to sound compared to the fake mapping. However, participants reported they learned more about their own thinking processes when using the mapping from pupil size to sound compared to using the fake mapping, in a manner that was again conditional upon them hearing the sounds at all. Participants learned about task performance (e.g., *"[Later in the task] I became slower at performing calculations"*) and control strategies (*n* = 20, e.g., *"… I had to concentrate on this task"*).

Interestingly though, there were also some reports in study 2 about potential reciprocal effects between the mapping from pupil size to sound and cognition. That is, some participants reported that when the sound changed accordingly with a particular cognitive process, the characteristics of the changing sound could also cause – or at least amplify that same cognitive process – suggesting a form of interaction that could take place (e.g., *"The more I became nervous, the more it [the sound] became annoying [influencing my nervousness]"*).

DESIGN CHALLENGES

The discussed studies suggest that people can learn relationships between a mapping of physiological data (pupil size) measured with artificial sensors (an eye-tracker), which is otherwise not accessible, to the biological senses (to audible sound). Perceiving one's own hormonal and neuro-endocrine processes at work led people to learn (novel) relationships between these processes and cognition. Speculatively, these relationships can be exploited to enhance cognition.

However, the discussed studies also suggested several design challenges that need to be addressed to start developing a form of augmented interoception that truly enhances cognition. Three challenges are proposed as a way forward: (I) *Supporting attention*: Positive effects of using a mapping from pupil size to sound on learning were conditional upon the ability to perceive the sound during a task. A design challenge is therefore to develop a mapping to the biological senses that is attention grabbing. But one needs to be mindful about potential intrusiveness of such a mapping into the thinking processes of the user. (II) *Supporting learning*: The negative main effect in study 2, where no instruction about the meaning of the sound was provided, suggested that learning needs to be explicitly supported. Previous studies on sensory augmentation suggest that longitudinal use is required to enable learning [5]. A design challenge is therefore to support effective learning. (III) *Utilizing reciprocity*: Reciprocal effects between the mapping from pupil size to sound and cognition suggests that interactions can be designed. This could be done by designing the look and feel of the mappings in such a way that they amplify or perhaps diminish the hormonal and neuro-endocrine processes they represent. Taking the existence of reciprocity into account should prevent unintended effects. But perhaps more excitingly, it can also be used to enable regulation of cognition, opening up new ways to achieve enhancement of cognitive performance, beyond those initially proposed in this position paper.

REFERENCES

[1] Hugo D. Critchley & Sarah N. Garfinkel. 2018. The influence of physiological signals on cognition. *Current Opinion in Behavioral Sciences,* 19, 13-18.

[2] Alwin de Rooij. Emergence of metacognitive knowledge via audible pupil size, unpublished manuscript.

[3] Maria K. Eckstein, et al. 2017. Beyond eye gaze: What else can eye tracking reveal about cognition and cognitive development?. *Developmental cognitive neuroscience,* 25, 69-91.

[4] Alwin de Rooij, Hanna Schraffenberger, & Mathijs Bontje. 2018. Augmented metacognition: Exploring pupil dilation sonification to elicit metacognitive awareness. *Proceedings of TEI '19.* ACM.

[5] Sabine König, et al. 2016. Learning new sensorimotor contingencies. *PloS One*, 11.12, e0166647.