Psychophysiology and high-performance cognition - a brief review of the literature

The psychophysiological method can be used to detect some simple cognitive states such as arousal, attentiveness, or mental workload. This approach can be especially interesting when cognition has some productive purpose, as in knowledge work, and tends to be related to human-computer interaction (HCI). However more interesting for applied purposes are acts of coordinated high-level cognition. High- level (or higher-order) cognition (HLC) is typically associated with decision making, problem solving, and executive control of cognition and action. Further, an intuitive approach for assessing whether someone is engaged in HLC is to measure their performance of a known task. Given this, it is reasonable to define high-performance cognition (HPC) as HLC under some performance restriction, such as real-time pressure or expert skill level. Such states are also interesting for HCI in work, and their detection represents an ambitious aim for using the psychophysiological method. We report a brief review of the literature on the topic.

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Psychophysiology and high-performance cognition - a brief review of the literature

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ABSTRACT

The psychophysiological method can be used to detect some simple cognitive states such as arousal, attentiveness, or mental workload. This approach can be especially interesting when cognition has some productive purpose, as in knowledge work, and tends to be related to human-computer interaction (HCI). However more interesting for applied purposes are acts of coordinated high-level cognition. High- level (or higher-order) cognition (HLC) is typically associated with decision making, problem solving, and executive control of cognition and action. Further, an intuitive approach for assessing whether someone is engaged in HLC is to measure their performance of a known task. Given this, it is reasonable to define high-performance cognition (HPC) as HLC under some performance restriction, such as real-time pressure or expert skill level. Such states are also interesting for HCI in work, and their detection represents an ambitious aim for using the psychophysiological method. We report a brief review of the literature on the topic.

Keywords: cognition, flow, high-performance cognition, psychophysiology

1 INTRODUCTION

Knowledge work can be thought of as acts of coordinated high-level cognition (with some productive purpose). High-level (or higher-order) cognition (HLC) is typically associated with decision making, problem solving, and "executive" control of cognition and action [20]. Such states are already interesting with respect to human-computer interaction (HCI) in work. Further, an intuitive approach for assessing whether someone is engaged in HLC is to measure their performance of a known task. Given this, it is reasonable to define high-performance cognition (HPC) as HLC under some performance restriction, such as real-time pressure or expert skill level. Such states are also interesting for HCI in work.

2 DISCUSSION

The difficulty in using such definitions is that there does not exist a fixed approach to operationalise them - indeed a reductionist approach to cognitive localisation has been criticised [25].

Some work [14, 18, 21] has been done with the theory of Flow [10, 8], but this approach remains problematic because the theory is descriptive of subjective states, and not predictive of physiological states. A stronger link can be found in simpler cognitive mechanisms, which may in combination provide an index to HLC/HPC under the right measurement protocol.

For example, if a task and task strategy is held constant, Prat and Just [22] have proposed that at least three cortical network–level attributes underlie individual differences in cognitive performance, namely:

1. efficient use of neural resources
2. high synchronization (coordination) between cortical centres
3. adaptation of cortical networks in the face of changing demands

Similarly, the 'channel model' of Flow provides some pointers as to the type of cognitive states which should be observed, varying by channel, e.g. aspects of attention, mental workload, decision making, engagement or error detection.

2.1 Contributing Mechanisms

Cognitive Efficiency. Several reports present evidence of neural efficiency [3, 4, 17], where expert judgement or improved skill results in comparatively less cortical activation, as measured by EEG.

Synchronisation. The degree of synchronization between cortical regions relates to individual differences in performance, with strong evidence in word encoding and language functions [23, 26, 27].

Adaptation. Brouwer *et al* posited that learning to master a task is accompanied by decreased effort during task execution [6]. They present evidence that physiological variables indicate decreasing effort due to time but not learning, on an n-back task with 0, 1, and 2 back coniditions. This paper also presents a useful table of the relative contribution to variance of each signal feature from EEG, ECG, EOG and respiration.

Attention 'blink'. The 'attentional blink' (AB) deficit occurs when individuals must rapidly process an overwhelming amount of information, in the process 'losing' awareness of forward-masked stimuli. The temporal scale of the deficit varies by individual and time. In [24], Slagter *et al* hypothesised that striatal dopamine level determines AB size in a U-shaped relationship, with high levels causing distractibility and low levels causing impaired updating. The same group proposed a psychophysiological method for detection of AB size by eye blink rate, based on the link between blink rate and dopamine [13, 7].

Perceptual Decision. Describing any physiological signal as relating precisely to a stimulus or task is extremely difficult. Event Related methods use many averaged trials to describe a waveform or spectral perturbation. Single-trial approaches would be required for knowledge work but such efforts are not very mature [1].
O'Connell *et al* [19] describe evidence for a perceptual decision variable; that is, the cognitive process of the momentary encoding of sensory information necessary for the decision (evidence) and the sequential integration of evidence into a decision variable suitable for driving action. An EEG signal was identified for this process in supramodal settings, using only straightforward preprocessing, and relying on novel characteristics of the task such as continuous stimulus presentation.

Breadth of Attention. Various studies have found that breadth of attention can be indexed from the frontal alpha asymmetry of EEG [11].

Mental Workload. EEG band powers have been reported to correlate with performance [15, 16]. A more common method for detecting mental workload using ECG has been covered in numerous literature, e.g. [12].

Error Detection. Critchley [9] describes 'a functional system centred around the dorsal ACC for rapid detection and signalling of cognitive and behavioural errors'. He indicates that this system is detected (under relevant task conditions) within the signal of midline EEG and in EDA, and in pupil size.

2.2 Feedback Approaches

The field of biofeedback raises interesting options, as the injection of a well-defined manipulation of the physiology permits a 'ground-truth' type of analysis. In other words, by deliberately altering the system in the domain of interest, causal inference is possible [5].

For example, Allen *et al* [2] describe alteration in subjective emotional states after neurofeedback training of alpha asymmetry. In general the literature on biofeedback or neuromodulation for induction of cognitive or emotional states is rich, and the experimental paradigm suggested helps remove significant obstacles, although new issues are raised, e.g. ethics.

3 CONCLUSION

In summary, the options to capture indices of HLC/HPC from physiology are limited. However enough evidence exists to give an indication that multi-factorial approaches may be profitable, at least where task and behavioural activity can be sufficiently well-described.

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