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Automatic classification of eye activity for cognitive load measurement with emotion interference

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ABSTRACT

Measuring cognitive load changes can contribute to better treatment of patients, can help design effective strategies to reduce medical errors among clinicians and can facilitate user evaluation of health care information systems. This paper proposes an eye-based automatic cognitive load measurement (CLM) system toward realizing these prospects. Three types of eye activity are investigated: pupillary response, blink and eye movement (fixation and saccade). Eye activity features are investigated in the presence of emotion interference, which is a source of undesirable variability, to determine the susceptibility of CLM systems to other factors. Results from an experiment combining arithmetic-based tasks and affective image stimuli demonstrate that arousal effects are dominated by cognitive load during task execution. To minimize the arousal effect on CLM, the choice of segments for eye-based features is examined. We then propose a feature set and classify three levels of cognitive load. The performance of cognitive load level prediction was found to be close to that of a reaction time measure, showing the feasibility of eye activity features for near-real time CLM.

1. Introduction

Interest in including cognitive technology in clinical practice has seen an increase in recent years. Common applications are the use of cognitive tests to assess the deficit when impairments occur in central nervous system neuropathology [40], for example, head injury [1], Schizophrenia [2], long-term alcohol abuse [3], Alzheimer disease and related disorders [4], to name a few. Moreover, cognitive assessment can also be of benefit in screening discharge patients [5] and in construction of individualized rehabilitation strategies [2], since cognitive skills are associated with daily living and social activities. As Spaulding et al. [2] have suggested, "a cognitive technology can be perfected that would contribute significantly to diagnosis, treatment and rehabilitation planning, evaluation of patients' response to treatment, and the design of future treatment modalities". Although the specification of function to be measured is different, evidence shows those aforementioned diseases or disorders are associated with memory capability [2–4]. Since cognitive load occurs as a result of the limited working memory available during a task [35], measuring cognitive load on patients in the cognitive tests can offer insights for patient treatments. For example, high cognitive load and short stimulus duration were found to create a critical performance distinction for schizophrenic patients [36].

Other applications include reducing medical errors due to high memory load on clinicians in the context of emergency

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department. Studies have showed that the interruptions (cause information loss) and multitasking induce high cognitive load that contributes to medical errors [37]. Solutions proposed include using electronic tools to support adaptive process [37] on site and providing effective training [38] beforehand to reduce the cognitive load in work place.

Another focus is on evaluation of clinical information systems. Approaches are based on usability engineering and cognitive task analysis to ensure low cognitive load involved in use of such systems while users are carrying out tasks [39].

The development of an automatic cognitive load measurement (CLM) system is thus motivated by assessing user (patient) dynamic cognitive load, using psychophysiological and behavioral signals. Conventional methods for CLM, in particular subjective assessment, reaction time and performance (accuracy) cannot provide satisfactory results in all situations as they rely on overt responses without adequate temporal sensitivity, which they assume that users (patients) are willing to provide [6].

One fundamental problem that has limited the use of psychophysiological and behavioral signals for CLM to date is the presence of artifacts due to other mental resource demands [28]. Task-focused mental activity is not the only possible source of variation manifested in psychophysiological and behavior signals. For example, speech, heart rate variability, GSR and respiration are reported as effective features not only in CLM but also in emotion recognition and stress detection (e.g. [14,15]). For affective data, emotion is often elicited by stimuli with the task performance as a function of emotional state or as appraisals of a situation [16]. When collecting cognitive load data, task difficulty is carefully controlled with neutral (i.e. non-emotive) stimuli and emotional stimuli are avoided. An interesting question is what would happen to the psychophysiological and behavioral signals when users (patients) are performing a cognitive task and are subject to concurrent emotional stimuli. Such a question has important considerations in practice, where emotions and cognitive load cannot be expected to occur in isolation as they often do in the research laboratory – how should cognitive load classification systems be built that are robust to such types of variability?

The work in this paper is novel in (i) assessing eye pattern changes during tasks with emotional stimuli, with a view to validating eye activity-based CLM; (ii) recognizing the eye activity patterns for five levels of induced cognitive load, there by going beyond simply distinguishing low and high cognitive load levels; (iii) determining the eye feature dependence on arousal factors and the appropriate measurement timing for reliable load level estimation during task execution with interference from other sources.

2. Eye activity background and related work

2.1. *Advantage of using eye activity for CLM*

Four arguments are forwarded in favor of using eye activity patterns for CLM: (i) eye activity contains three classes of eye information, but still uses one sensor for data collection. Pupil dilation is a physiological signal whose changes are due to autonomic nervous system activity in the peripheral nervous system. Eye blink is a behavioral signal [17] (some papers also call it a psychophysiological response [19]) controlled by the central nervous system (CNS). Fixation and saccade are encoded by neural signals from cortical and subcortical systems. The different mechanisms could measure various underlying processes responsible for different aspects of cognitive activity. (ii) Eye activity is more ubiquitous than other modalities: we are free to use our eyes everywhere and anytime. (iii) Pupillary response and eye blink have been shown to correlate with both visual and aural cognitive tasks [9,17], thus can be applied in broad scenarios. (iv) Eye activity data collection is less intrusive than other physiological signal data collection. For example, eye tracking technology has been demonstrated to follow eye activity remotely [9].

2.2. *Pupillary response*

The basic function of pupil diameter change is to protect the retina (the light reflex) and also to respond to a shift in fixation from far to near objects (the near reflex). Changes that reflect variations in cognitive activities are relatively small compared with the changes due to light reflex and near reflex. In addition, the light reflex results in a relatively rapid pupillary response [20]. Therefore, if objects have nearly constant depth in the user's (patient's) visual field, we can consider the task-evoked pupillary response to comprise the low frequency components in the pupillary response spectrum.

Over a few decades of research on pupillary response, researchers still do not agree whether the pupil is a measure of emotional arousal or mental effort. Empirical studies found that pupil size increases as participants are exposed to more arousing images and sounds, regardless of valence [21,22]. Early research [23] on arousal and cognition attempted to manipulate some arousal factors while controlling the cognitive demands of tasks. They concluded that cognitive factors have a higher priority than the arousal factors in affecting pupil dilation. The arousal effect in pupillary response was not observed in sentence listening and addition tasks but only in the low cognitive load task, listening to countdown numbers [23]. However, in that experiment, tasks were controlled in auditory presentation and arousal levels were manipulated by the proximity of the stimulus (a word) to the subject of the sentences, reward or threat of electrical shock. The effect of auditory-induced emotion might be transient and not be as strong as in visual presentation, and the auditory based cognitive load might be higher compared with visual tasks, therefore we used affective images to induce controlled emotional effects.

2.3. *Eye blink*

Eye blinks occur only two to four times per minute for functional purposes [17]. There are other, non-functional types: reflexive blink (a protective response, e.g. to a puff of air), voluntary blink (a purposeful response depends on one's will) and endogenous blink (unconsciously occurs). The majority of eye blink behaviors are endogenous blinks, which are centrally controlled and have a link to cognition [17,20], therefore this type of blink is used for CLM. During a task-centered scenario, voluntary blinks can be avoided by