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Electrocardiographic features for the measurement of drivers' mental workload

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ABSTRACT

This study examines the effect of mental workload on the electrocardiogram (ECG) of participants driving the Lane Change Task (LCT). Different levels of mental workload were induced by a secondary task (n-back task) with three levels of difficulty. Subjective data showed a significant increase of the experienced workload over all three levels. An exploratory approach was chosen to extract a large number of rhythmical and morphological features from the ECG signal thereby identifying those which differentiated best between the levels of mental workload. No single rhythmical or morphological feature was able to differentiate between all three levels. A group of parameters were extracted which were at least able to discriminate between two levels. For future research, a combination of features is recommended to achieve best diagnosticity for different levels of mental workload.

1. Introduction

The measurement of mental workload is of particular importance within ergonomic research. Therefore, it is all the more necessary that the applied measurement methods are valid. There are three principal approaches for the measurement of mental workload: (1) subjective measures (2) performance-based measures and (3) physiological measures (O'Donnell and Eggemeier, 1986). The advantage of physiological methods is that they allow a direct and continuous measurement of the current workload level. The most frequently used physiological method for the assessment of mental workload is the electrocardiogram (ECG) (Paxion et al., 2014; Miller, 2001). In principle, an indefinite number of features can be extracted from an ECG signal. The crucial question is, which of them differentiate best between different levels of mental workload. We decided to conduct an experiment in order to examine the suitability of different ECG features for the measurement of driver's mental workload. We chose an exploratory approach and extracted a large number of different rhythmical and morphological features from the ECG signal thereby identifying those which differentiated best between different levels of mental workload.

1.1. Mental workload and ECG

So far there is no overall accepted definition of mental workload (Young et al., 2015). In general, human information processing capacities are regarded as limited (Broadbent, 1958; Kahneman, 1973). Mental workload refers to the amount of resources needed for the processing of a certain task (Eggemeier et al., 1991). It depends on characteristics of the task, the situation and the person.

Mental workload is known to have a direct influence on the autonomic nervous system (ANS) (Cohen et al., 2007). Since the ANS is also responsible for the control of the cardiovascular system, mental workload compromises the normal regulation of the heart rate (HR) and electrophysiology of the cardiac cells (Bilchick and Berger, 2006; Lown and DeSilva, 1978). Thus, the electrocardiogram is believed to be an adequate physiological signal that can be used to quantify the influence of mental workload on the human body (Dishman et al., 2000; Salahuddin et al., 2007).

A typical ECG signal can be seen in Fig. 4a. In principle, two different categories of features can be extracted from an ECG signal:

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rhythmical and *morphological* features. Rhythmical features are obtained from the instantaneous HR which can be calculated by finding the QRS complexes and the time distances between them. The time lapse between two subsequent beats is called RR interval. The variation of the RR interval over time is referred to as HRV (Acharya et al., 2006). On the other hand, morphological features can be obtained by detecting the P, QRS and T waves in the ECG and defining mathematical formulations to quantify the properties of those waves (Karpagachelvi et al., 1005).

A lot of experiments have been carried out in the past with the aim of quantifying the influence of mental workload on the ECG with quite mixed results. It is reported that the HR increases with an increase of mental workload (Lenneman and Backs, 2007; Mulder et al., 2004), but this was sometimes only observed in lower levels of workload, while HR stayed constant at higher levels (Richter et al., 1998). In other studies, the sensitivity of HR depended on the type of effort (auditory or visual) and the test mode (simulator or field study) (Engström et al., 2005; Stuiver et al., 2014). The HRV was found to react faster to changes in momentary workload than HR (Mulder et al., 2004). An increase in workload corresponded with a decrease of HRV (Mulder et al., 2004) although it is also reported that HRV turned out to be sensitive only in lower levels of workload (Richter et al., 1998; Stuiver et al., 2014) or that no effect of different levels of workload on HRV was found at all (Engström et al., 2005). One important thing to note is the fact that HRV is not reflected by *one* single feature but comprises various parameters. Therefore, the sensitivity of HRV is also dependent on the specific calculation of the applied parameters (Manzey, 1998). Unfortunately, many studies dealing with HRV as a measure of mental workload do not provide information about the calculation procedures. This fact has to be considered when different HRV studies are compared.

However, not only the rhythmical features but also the morphological features may be affected by mental workload. Particular studies carried out investigating morphological changes of the ECG signal have reported that when patients with ischemic heart disease undergo mental workload, a depression or an elevation of the ST segment and an increased variation of the QT intervals (also called QT dispersion) can be observed (Ginopoulos et al., 2003; Gottdiener et al., 1994; Specchia et al., 1984). In another study dealing with patients suffering from ventricular arrhythmias it was demonstrated that mental workload has a significant impact on the repolarization of the ventricles. Changes in the T wave were lower in healthy subjects than in arrhythmia patients (Abisse et al., 2011).

The aim of this work is to gain information from the ECG using its rhythmical and morphological features and to evaluate if and how those features change in the presence of mental workload while driving.

2. Methods

2.1. Participants

We examined a total of thirty-three voluntary students. Due to a technical problem, the ECG data of the first five participants were not available. Another participant had to be removed because of serious problems with the driving task. Our final sample consisted of $N = 27$ participants (1 female, 26 male). The sample aged from 18 to 30 years ($M = 22.9$ years). All participants had the chance to win one of three shopping vouchers (worth 25 EUR each).

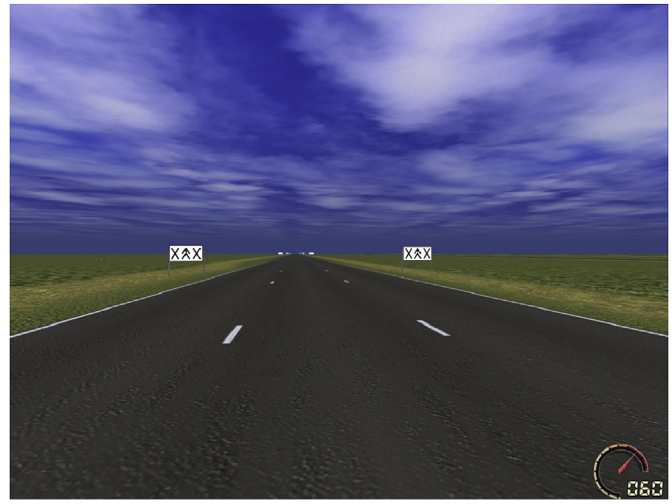

Fig. 1. Lane Change Task. Participants drive at a limited speed of 60 km/h and perform regular lane changes which are indicated by signs next to the road.

2.2. Materials & procedures

2.2.1. Primary Task: The Lane Change Task (LCT)

The Lane Change Task (LCT) is a simulated driving task which was originally developed to measure driver distraction (Mattes, 2003). The simulation consists of a road with three lanes (see Fig. 1). The task is to drive at a limited speed of 60 km/h and to perform regular lane changes which are indicated by signs next to the road. The mean distance between two signs is 150 m which results in a lane change every 9 s. The LCT is designed as a circuit which offers the possibility to drive several laps without a break. One lap takes about 3 min. As a measure of performance the mean deviation of a normative driving path is derived for each participant (I. O. for Standardization and Road vehicles, 2010).

Participants operated the LCT via a force feedback wheel (Logitech G27) which was mounted to a table and foot pedals which were placed on the floor under the table. A standard PC together with a beamer were used to project the LCT on a screen.

2.2.2. Secondary task: N-Back task

In order to induce different levels of mental workload, we applied the *n-back task* as secondary task[2]. In addition to the driving task, participants listened to computer generated sequences of digits. Every sequence consisted of the digits 0–9 in different order. Participants were asked to repeat aloud the n-th digit of the present sequence (see Fig. 2. There were three different levels of difficulty [L1 (0-back), L2 (1-back) and L3 (2-back)]. Every series lasted 25 s. Two sequences were separated by a five seconds break. Mistakes were recorded for every level of difficulty.

2.2.3. Subjective measurement: NASA-TLX

As a subjective measure of mental workload, participants completed the NASA-Task Load Index (NASA-TLX, (Hart and Staveland, 1988)). The questionnaire consists of six items measuring mental demands, physical demands, temporal demands, performance, effort and frustration level. It showed to be very reliable for the measurement of different levels of workload (Borghini et al., 2014; Hart, 2006). Every item could be answered on

[2] Note: We constantly refer to our secondary task as n-back task. However, this type of task is also known as digital recall task (Mehler) and is not to be confused with the n-back task of Kirchner (1958).