BJA

British Journal of Anaesthesia, 117 (6): 767–74 (2016)

doi: 10.1093/bja/aew342
Clinical Practice

Linear and non-linear heart rate metrics for the assessment of anaesthetists' workload during general anaesthesia

J. Martin [1], F. Schneider[1], A. Kowalewskij[1], D. Jordan [1], A. Hapfelmeier [2], E. F. Kochs [1], K. J. Wagner [1], and C. M. Schulz [1,*]

[1]Department of Anaesthesiology, Klinikum rechts der Isar, Technische Universität München, Ismaninger Str. 22, München, 81675, Germany and [2]Institute of Medical Statistics und Epidemiology, Klinikum rechts der Isar, Technische Universität München, Ismaninger Str. 22, München, 81675, Germany

*Corresponding author. E-mail: c.schulz@tum.de

Abstract

Background. Excessive workload may impact the anaesthetists' ability to adequately process information during clinical practice in the operation room and may result in inaccurate situational awareness and performance. This exploratory study investigated heart rate (HR), linear and non-linear heart rate variability (HRV) metrics and subjective ratings scales for the assessment of workload associated with the anaesthesia stages induction, maintenance and emergence.

Methods. HR and HRV metrics were calculated based on five min segments from each of the three anaesthesia stages. The area under the receiver operating characteristics curve (AUC) of the investigated metrics was calculated to assess their ability to discriminate between the stages of anaesthesia. Additionally, a multiparametric approach based on logistic regression models was performed to further evaluate whether linear or non-linear heart rate metrics are suitable for the assessment of workload.

Results. Mean HR and several linear and non-linear HRV metrics including subjective workload ratings differed significantly between stages of anaesthesia. Permutation Entropy (PeEn, AUC=0.828) and mean HR (AUC=0.826) discriminated best between the anaesthesia stages induction and maintenance. In the multiparametric approach using logistic regression models, the model based on non-linear heart rate metrics provided a higher AUC compared with the models based on linear metrics.

Conclusions. In this exploratory study based on short ECG segment analysis, PeEn and HR seem to be promising to separate workload levels between different stages of anaesthesia. The multiparametric analysis of the regression models favours non-linear heart rate metrics over linear metrics.

Key words: anaesthesia; heart rate variability; heart rate; patient safety; workload

Excessive workload may impact the anaesthetists' ability to adequately process all the information available during clinical practice in the operation room and may result in inaccurate situational awareness, impaired decision-making and performance.[1] Therefore, the influence of increased workload during clinical practice on the anaesthetists' performance and patient safety are the subject of on-going research.[2–4] As workload is not an inherent property but rather emerges from the

Editorial decision August 18, 2016; **Accepted:** September 15, 2016

Editors key points

- Workload is the dynamic balance between the challenge of a task and the individual's response to it.
- Excessive workload can impact on anaesthetists' performance, but is difficult to quantify.
- The authors compared rating scales, heart rate and heart rate variability indices during different stages of anaesthesia.

interaction between the requirements of a task, the circumstances under which it is performed and the skills, behaviours and perceptions of the operator, workload may be described as a dynamic balance between the challenge of a task and the individual's response to that task.[5] Thus, workload assessment tools should detect unfavourable changes of this dynamic balance, to identify situations at risk and prevent patients from harm.

Several methods have been used to measure workload in the anaesthetic environment, among them procedural methods, subjective rating scales, and physiological measurements.[4] Physiological measurements, in contrast to subjective rating scales, may provide an objective assessment of workload. In several studies heart rate (HR) measurements have been used to gauge the workload of anaesthetists.[6–8] It has not yet been investigated whether parameters of heart rate variability (HRV) could be more useful than simple HR, to classify the level of workload for anaesthetists.[4] HRV metrics have been used to quantify mental workload in both experimental settings and field studies.[3 9–11] HRV metrics describe the oscillation in the interval between consecutive heart beats and the oscillations between consecutive instantaneous heart rates.[12] In a study by Henelius and colleagues[3] on mental workload classification, the mean HR reached a higher classification performance than the other HRV metrics.[3] However, in this regard, the authors note that HRV metrics might be useful for the classification of mental workload, in situations with less pronounced differences in task difficulty.[3] In the workload assessment of anaesthetists administering anaesthesia, linear and non-linear heart rate metrics have not yet been investigated concomitantly.

Thus, the present study investigates HR, linear and non-linear HRV metrics and subjective ratings scales for the assessment of anaesthetists' workload, during routine cases of general anaesthesia in an exploratory approach. We studied which metrics are promising to reflect changes of workload associated with the differing anaesthesia stages *induction*, *maintenance* and *emergence*.

Methods

Study design

This prospective observational study was performed at a primary care university hospital between November 2013 and October 2014 and was approved by the ethics committee of the medical faculty of the Technische Universität München (N° 5771/13, April 29th 2013). ECG raw data and subjective rating scales of 40 anaesthetists providing general anaesthesia were obtained. All anaesthetists provided informed and written consent. General anaesthesia was administered to ASA I patients undergoing elective minor orthopaedic limb surgery. All patients underwent tracheal intubation. The rooms used for induction of anaesthesia and the operating rooms were equally equipped and staffed. The anaesthetists were instructed that no alteration of their daily routine activities (e.g. sleep, eating and drinking habits) was required. All participants were not on any medication. Thus, all cases of anaesthesia took place under similar conditions.

Data collection

Physiological data were captured with a chest belt (BioHarnessTM 3, Zephyr, Maryland, USA) worn under the anaesthetists' scrubs. ECG and activity level were registered continuously. The ECG raw signals were recorded with a sampling rate of 250 Hz. The activity level integrates data from the built-in 3-axis accelerometer, reflecting movements of the participants. The system is described in detail elsewhere.[13] A trained researcher was present to record times and events and asked the anaesthetists to rate their workload on subjective scales after *induction* of anaesthesia, during *maintenance* and after dismissal of the extubated patient from the operation theatre. For this assessment of subjective workload, the one-dimensional Borg scale[14] and the six-dimensional National Aeronautics and Space Administration Task Load Index (NASA-TLX) were used.[15] As a subjective rating scale, the NASA-TLX has been widely used in different settings and is considered to be highly reliable and sensitive to changes in workload levels.[2 16] Each dimension of the NASA-TLX was analysed separately. The Borg Scale of Perceived Exertion (Borg Scale) has been applied several times in anaesthetic settings including simulated critical incidents.[4 6 17]

Data processing

HRV metrics were calculated based on five min segments from each of the three anaesthesia stages *induction*, *maintenance* and *emergence*. The five-min-period representing the anaesthesia stage of *induction* started with the beginning of pre-oxygenation. The starting point of the segment representing *maintenance* was 2.5 min before the midst of surgery that was calculated *post hoc* based on the recorded time stamps of incision and suture, respectively. The segment related to *emergence* had its starting point one min before extubation. Each period had the same duration to ensure reliability and accuracy.[18]

ECG raw data were processed using the ARTiiFACT software, an open access tool designed for ECG pre-processing and HRV analysis.[19] First, the R peaks were determined in the ECG recordings by application of a high-pass filter (10 Hz) to eliminate movement artifacts and by use of a 50μV global threshold to account for signal noise. Then, the data were visually screened with respect to the correct detection of the R peaks. Obviously missing or additional R peaks were corrected manually. In the next step, the inter-beat intervals (IBIs) were calculated from the R peaks. Incorrect IBIs were deleted based on the artifact detection algorithm by Berntson and colleagues 1990. In order to perform analysis on a complete series of numbers these IBIs were corrected using cubic spline interpolation allowing for small interpolation errors.[19] In a last step, time domain and frequency domain methods and non-linear methods were used to calculate the participants' HRV metrics.

Selection of heart rate metrics

Beyond mean heart rate, several linear and non-linear HRV metrics were studied. For the calculation of the metrics the software