Physiological Measurement Applied in Maritime Situations: A Newly Developed Method to Measure Workload on Board of Ships

Wendie Uitterhoeve[1], Marcella Croes-Schalken[2], and Dick Ten Hove[1]

[1] Maritime Research Institute Netherlands, P.O. Box 28,
6700 AA Wageningen, The Netherlands
[2] Maritiem Instituut De Ruyter, P.O. Box 364, 4380 AJ Vlissingen, The Netherlands
{w.m.uitterhoeve,d.t.hove}@marin.nl

Abstract. This article describes a method to measure the effects of workload and human performance on board of ships in navigation tasks. Physiological measurements and both objective and subjective observations were executed simultaneously. The added value in this design is the interpretation of physiological results together with the subjective and objective evaluation of experienced workload and performance. As all of the parameters separately are not indicated as absolute values to rule on workload, combining physiological information with subjective and objective observations leads to a more pronounced insight in workload. With this developed method entering a new terrain is possible, where scientific research of human performance is applied in nautical navigation.

Keywords: Workload measurements, human performance, navigation, manoeuvring simulator, physiological measurements.

1 Introduction

During all kinds of activities, there is a relation between task demand, the amount of effort someone has to put in and the performance. Most optimal is a combination of mediate task demand, minimum effort and maximum performance. By increasing effort an increase in demand can be balanced while performance stays optimal. But a too high demand leads to a decrease of performance. Avoiding such situations starts with measuring the actual workload and performance. Although such methods exist for aviation and automotive, they are not common in nautical settings [2], [3], [4].

2 Methodology

2.1 Basic Principles

The innovative aspect in the developed method to measure workload, effort and performance is the combination of several measurements. The physiological results are interpreted together with the subjective and objective evaluation of experienced

C. Stephanidis (Ed.): Posters, Part I, HCII 2011, CCIS 173, pp. 327–331, 2011.

workload and performance. As all of the parameters separately are not indicated as absolute values to rule on workload, combining physiological information with subjective and objective observations leads to a more pronounced insight in the relation between performance and workload.

2.2 Experiment Set-Up

In cooperation with Dutch pilots and Eagle Science, the developed method is tested during simulations on a full-mission manoeuvring bridge simulator and in real life on board of sea-going vessels. In this initial experiment the main task was to safely guide a car carrier underneath a bridge immediately after a quarter bend. Difficult in this scenario was the strong side wind, which made turning and lining-up just before the bridge a complex manoeuvre. During the so-called decision point the candidate had to decide whether to pass the bridge or not: if not lined-up correctly, the manoeuvre should be aborted and started again.

2.3 Detailed Description of Used Components

Reference Level. Indicating stressfull situations is difficult without recording a reference situation during relaxation. No exact number represents workload, only changes in several phenomenon give an indication of the level of workload. For that reason a zero load physiological measurement (in rest) expanded with an interview and anamnesis is essential.

Physiological Measurements. The human body responds in several ways to increasing effort. In this experiment three physiological aspects were measured using a portable multi-channel system carried by the candidates, namely the electrical activity of the heart muscle by an electrocardiogram (ECG), the respiration by measuring the expansion of the chest and abdomen and finally the electrical activity of facial muscles using electromyography (EMG). With these measurements information is collected about heart rate and heart rate variability, respiration rate and tidal volume, and the amount of muscle tension in the face.

Task Analysis. In order to get a feeling of the workload during the experiment, the amount of orders and/or operations was listed. This can be done by an observer or by analysing time traces of for example the steering actions or changes in the propulsion settings.

Performance Rating. In this experiment the main task, which was to safely guide a car carrier underneath a bridge, was rated in total by an expert using an assessment form. Hereby five key skills, specific for a piloting task, were defined and rated.

Effort Rating. Immediately after the simulation, the candidate has to fill in a Rating Scale of Mental Effort [1]. The candidate rates how much effort he had invested during the piloting task. This RSME ranges from 0 to 150, and is labeled from ‘absolutely no effort’ (score 3) to ‘extreme effort’ (score 114). Additionally the candidate is interviewed to get information about experienced effort during specific incidents, to be used as input for subsequent analysis.

Observations and Event Description. As stated before, no individual result is absolute in capturing the amount of experienced workload and human performance. Only a combination of several phenomenon, registered in one or more of the previous ratings and measurements, pointing in the same direction confirm a total view of the situation. In contrast with automotive and aviation, sailors have more freedom to move. A video registration of the operational pilot is not always sufficient. For that reason, additional observations by the researcher during the sailing are essential to get a total impression of the situation and to correctly interpret the outcome of the above mentioned variables.

3 Results

3.1 Applicability of Method

The experiment showed that it is possible to measure workload, experienced effort and performance. The interpretation of physiological results together with the subjective and objective evaluation of experienced workload and performance results in an overall picture of the situation. The answers from the interviews combined with the heart rate variability are a good estimate of the moment that the candidate experiences increased effort. In all the simulations the candidates identified the decision point as most strenuous, which was also visible in the HRV analysis. The performance during stressfull moments adds information about the ability to maintain the task. To find the cause of increased effort and/or decreased performance, information from the task analysis together with the findings of the observer can be used. Task analysis and subjective results were used to focus on the details of the physiological measurements.

3.2 Physiological Results

Two different ways of analysing the signals from the ECG give interesting results. The first is a spectral analysis, using three band-pass filters indicating not only the activity of the coherence between respiration and heart beat (MF 0.06-0.14 Hz), but also the activity of the autonomic nerve system, containing a sympatic part (active during stress, LF 0.02-0.06 Hz) and a parasympatic part (active during recovering, HF 0.14-0.45 Hz). Healthy people in rest show a larger value for the coherence parameter compared to people experiencing more stress, because their heart beat is more correlated to the respiration frequency. See also figure 1, shown below. Although in this figure the value for the amount of energy in the sympatic region seems the same, the absolute value during stress is much higher than during the relaxation moment. The amount of parasympatic energy is higher during the stress moment than in rest, which seems paradoxical. During the relaxation measurement there was no need to recover, while after the period with increased effort the parasympatic counterpart starts to recover the body. This leads to a larger absolute and relative contribution of the parasympaticus.

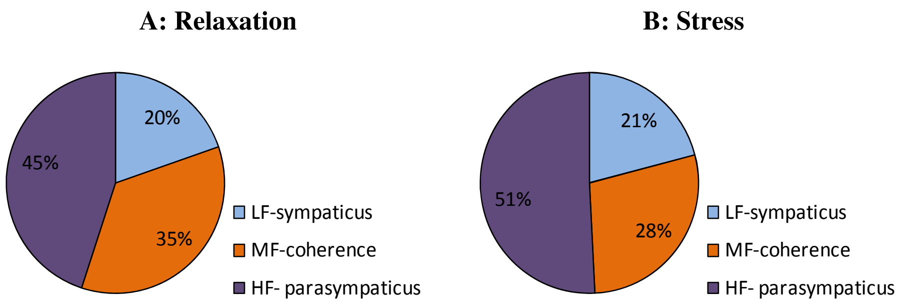

Fig. 1. Results from spectral analysis of heart beat. Presented is the amount of energy in three specific frequency areas. A: shows the values for a healthy person in rest, B: shows the values for the same person in a stress situation.

The second type of analysis is about heart rate variability (HRV). During relaxation large variation between two heart beats occurs, i.e. great HRV. The inter beat interval (IBI) becomes smaller and more constant in time if someone experiences increased effort. This is presented in figure 2 which shows the inter beat interval during a moment of relaxation and stress. Both the mean value and deviation of the inter beat intervals are larger in rest than during a moment of stress. In the stress situation, the cloud with inter beat intervals shifts to the lower left corner.

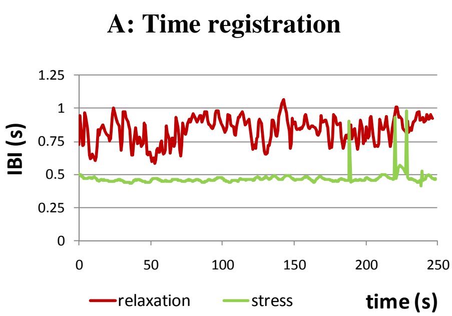

Fig. 2a. Time registration of inter beat intervals

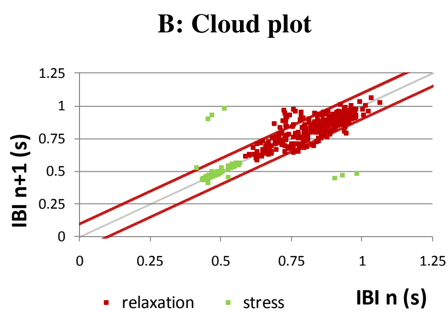

Fig. 2b. Cloud plot of inter beat intervals

Both for the same person during relaxation and during the decision point (stress).

Although the usefulness of the heart beat measurement is very valuable, the results of the respiration and facial muscle measurement were insufficient to show any relation with performance and mental effort. A combination of technical problems during the measurement and results which were not clearly interpretable, made the respiration and facial muscle measurement subordinately.

3 Conclusions

The interpretation of physiological results together with subjective and objective observations gives a good evaluation of experienced workload and performance. The contribution of the physiological measurements, and especially the results from the heart, are an added value.

4 Future Applications

During a future experiment a more specific primary task, which time traces can be analysed afterwards, will be indicated. As an example deviation from a predefined track, speed or drift angle can be used as performance standard. The performance measurements can be expanded with rating a secondary tasks, using a so called peripheral detection task. The candidates reaction time by pressing a button when a light flashes, gives additional information about the relation between effort and performance. Also possible relations between task analysis, performance, RMSE score and physiological results will be examined.

With this developed method entering a new terrain is possible. A terrain where scientific research of human performance is applied in nautical navigation. Physiological measurements can substantiate employability of sailors, assessments and selections, but also contribute in developing new waterways or harbours.

Acknowledgments. Special thanks to the volunteers from the Dutch Pilot Association for their contribution in the experiment.

References

1. Zijlstra, F.R.H.: Efficiency in work behavior. A design approach for modern tools. PhD thesis, Delft University of Technology. Delft, The Netherlands (1993)
2. De Waard, D.: The Measurement of Drivers Mental Workload. PhD thesis, University of Groningen, Traffic Research Centre. Haren, The Netherlands (1996)
3. Veltman, J.A., Gaillard, A.W.K.: Pilot workload evaluated with subjective and physiological measures. In: Brookhuis, K.A., Welkert, J., De Waard, D. (eds.) Proceedings of the Europe Chapter of the Human Factors ans Ergonomics Society Annual Meeting in Soasterberg, Aging and Human Factor, November 1993, pp. 107–128. University of Groningen, Traffic Research Centre, Haren, The Netherlands (1996)
4. Grootjen, M., Neerincx, M.A., van Weert, J.C.M., Truong, K.P.: Measuring cognitive task load on a naval ship: Implications of a real world environment. In: Schmorrow, D.D., Reeves, L.M. (eds.) HCII 2007 and FAC 2007. LNCS (LNAI), vol. 4565, pp. 147–156. Springer, Heidelberg (2007)