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Pilot performance in automated cockpits: event related heart rate responses to datalink applications

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Pilot performance in automated cockpits: demonstration of event-related heart rate responses to data link applications

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ABSTRACT

This study explored the feasibility of applying a particular "heart rate analysis" method to the assessment of human machine interface effectiveness in cockpits. The methodology proposed is: "Event-related Heart Rate"(EHR) as an indicator of dynamic characteristics of human information processing during instrument and display scanning and the execution of discrete tasks. Both the methodology and technical requirements for simulator event control are described. The implementation of EHR is illustrated by a case study performed during a simulation experiment on cockpit data link Human Factors issues.

Abstract

This study explored the feasibility of applying a particular 'heart rate analysis' method to the assessment of human machine interface effectiveness in cockpits. The methodology proposed is: 'Event- related Heart Rate'(EHR) as an indicator of dynamic characteristics of human information processing during instrument and display scanning and the execution of discrete tasks. Both the methodology and technical requirements for simulator event control are described. The implementation of EHR is illustrated by a case study performed during a simulation experiment on cockpit data link Human Factors issues.

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1. Introduction

Heart rate, which is relatively easy to measure, has a long history as a source of information for indexing many psychological concepts like ‘arousal’, ‘task involvement’, ‘anxiety’ and more recently, ‘mental load’ and ‘effort’. Heart rate is a.o. influenced by the para-sympathetic nervous branch, that is quick enough in its response, to react to momentary changes in tasks. The sympathetic branch is, however, much slower in response and will therefore influence the more overall level of heart rate. As an example, if a student pilot feels intimidated by an instructor, heart rate will be raised consistently by the sympathetic branch and will not fluctuate clearly with on-going tasks. Multiple psychological and physical factors affect heart rate, and such factors must be controlled or measured independently if their separate effects are to be examined.

The scope of analysis of heart rate can be *‘time based’* or *‘event based’*. The observation that heart-rate variability (HRV), which is the beat-to-beat fluctuation of the heart rhythm, typically decreases under conditions that could be classified as ‘mentally loading’, initiated several research efforts in both laboratory and field studies (for a review see Jorna 92). Spectral analysis of inter-beat intervals provided a quantification option for heart rate variability with respect to power in different frequency bands. Consistent time periods are used to allow comparisons across periods with a stable task loading and/or consistent levels of psychological stress. The disadvantage is the possible impact on task realism, as ‘flying turns for 5 minutes’ to investigate workload of manual control, can be very relevant from a scientific point of view, but is not realistic for most operational circumstances. Pilots have many tasks of relative short duration that have to be handled in a dynamic, changing environment. An alternative technique is to record both heart rate and the actual mission ‘event’ timelines including pilot inputs and the occurrence of external problems and to study the heart rate *changes* in relation to particular mission ‘events’.

2. Methodology

Event- related Heart Rate (EHR): in the scenario, certain stimulus events are presented to which a pilot response is anticipated. After the experiment, segments of heart rate recorded around the event are 'cut', inspected and *averaged* together. The reasoning is that all fluctuations that are not related to the specific event, will average out. The result is a net response of that subject linked to the event. Comparisons can now be made between type of events, for example different types of alerting systems to study the effectiveness for attracting the 'pilots attention'. Such comparisons need to be based on the same number of events, or on a sufficient sample size per event. The exact number required has to be determined by practical experience, or standard samples.

Heart rate should be recorded together with respiration to control for sighing, deep breaths etc. Especially breath holding will initiate a reflex that reduces heart rate. An accurate linking with respect to real time accuracy of heart rate with the stimulus or mission events is mandatory. Software should be able to locate the selected events and cut a specified section of the recording. This section includes some time before the event (reference) and some time after the event in order to study the change in response as a function of the event. Heart rate is an a-synchronous signal that has to be interpolated in order to enable the cut and paste function accurately over a certain time segment. Averaging software for segments is required to obtain a global heart rate profile that can typify a pilots response to the event.

3. Case study: ATC cockpit datalink

The study investigated the crew interactions with an improved cockpit data link interface with several means for exchanging the message to the crew (Van Gent 96). Data link messages were displayed either at a multi-function display, so the pilots(s) could read the message, or the message was presented by means of synthetic speech. Heart rate and respiration were recorded for the 'Pilot Not Flying' (PNF) by means of VITAPORT I equipment that allows digital inputs from event codes to be stored together with the data. The scenario control principles applied for controlling the occurrences of events in simulators, has been denoted as 'context simulation' (see Jorna 1997 for more details).

The analysis used the event 'Aural alert from ATC up link' as the event for selecting, cutting and averaging of heart rate segments. Normally, that event will first attract the attention of the pilot, to be followed by the task elements: process the presented information; decide on the action required in co-ordination with the fellow crew member and finish with the initiation and execution of the response by means of a down link message to ATC. In the case of data link standard replies like 'WILCO' can be selected from a display menu.

3.1. Manual flight and synthetic speech for ATC

The results as obtained for a pilot in the simulation condition: Manual flight and synthetic speech for ATC message content are depicted in figure 1.

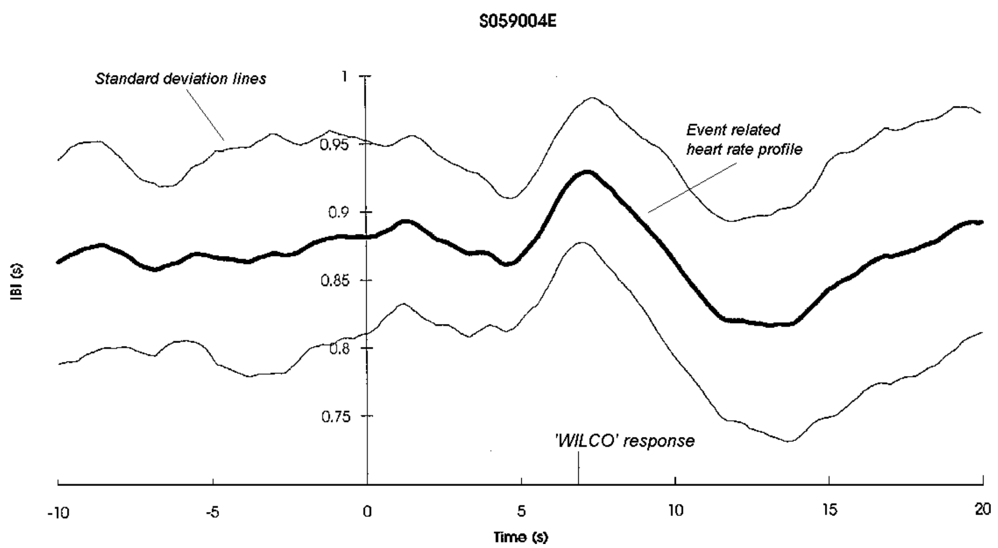

Fig. 1 Event related heart rate response, averaged over multiple events (n=26) for a pilot not flying while handling communications tasks with Air Traffic Control through data link. The centred event was an ATC up link (time zero) displayed by synthetic speech, which required a 'WILCO' response later on. The occurrence of that response, as determined by independent measures of the time of selecting the 'WILCO' button, is indicated. (figure from Jorna 1997)

The results show a distinct pattern of a linked response to this event as reflected in the averaged heart rate profile. Before the event, variations in heart rate were indeed averaged out, confirming uneventful conditions just prior to the triggering event. After the occurrence of the up link, heart rate slows down shortly , a response well known from laboratory study experience (for a review see Koers 1997) and often associated with information uptake, followed by a subsequent increase when the pilot is absorbing the information (note the plotting convention in inter beat intervals, meaning heart rate goes down when the intervals increase!).
The sequence is completed with a distinct decrease in heart rate as the 'WILCO' response is selected and executed. This decrease in the profile can be associated with the required concentration of the pilot but can also be linked to possible breath holding, which is presently under investigation.

3.2. Manual flight and displayed text for ATC

The same pilot performed identical tasks under a different regime of experimental conditions. In this case reading is required as opposed to listening to the message. The results for this case are depicted in figure 2.

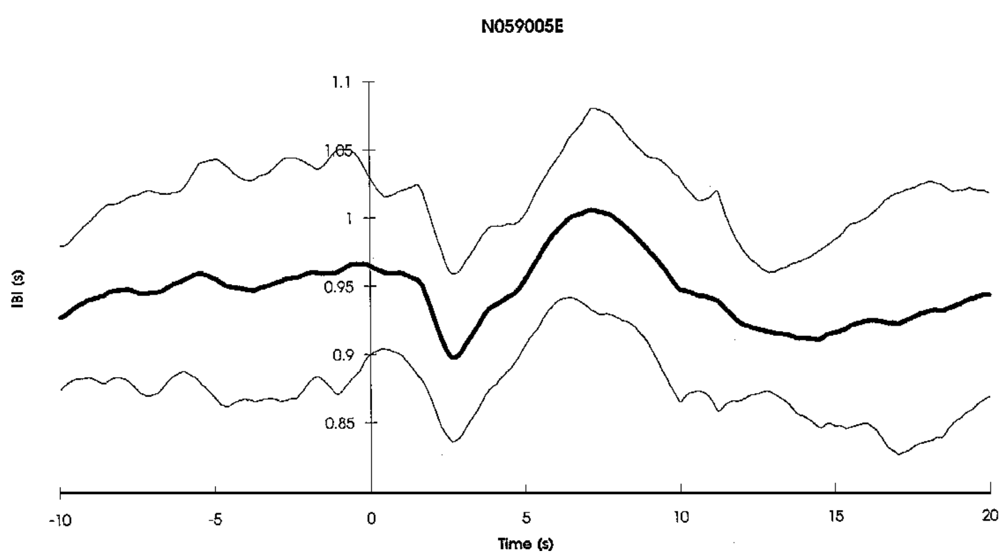

Fig. 2 Event related heart rate response, averaged over multiple events (n=26) for a pilot not flying for handling communications tasks with Air Traffic Control through data link. The centred event was an ATC up link (time zero) displayed as text on the navigation display, which required a 'WILCO' response later on. (figure from Jorna 1997)

In the case of reading from the display, a marked difference in response can be observed. After the alert, a short period of heart rate acceleration was observed, followed by a quite more distinct increase in heart rate as compared with the synthetic speech condition, apparently associated with 'working though the text'. After absorbing the information again, heart rate decelerates markedly during the selection and execution of the ‘‘WILCO’’ response.

Similar analysis were performed for another subject pilot to explore the between subject consistency of this pattern. The results are depicted in figure 3.

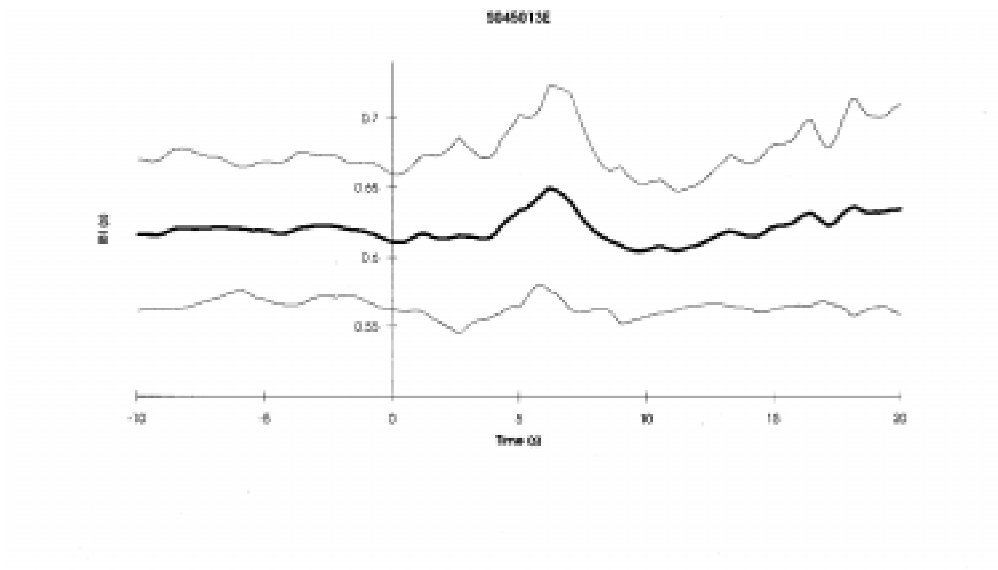

Fig. 3 Event related heart rate response, averaged over multiple events (n=34) for another pilot not flying while handling communications tasks with Air Traffic Control through data link. The centred event was an ATC up link (time zero) displayed by synthetic speech, which required a ‘WILCO’.

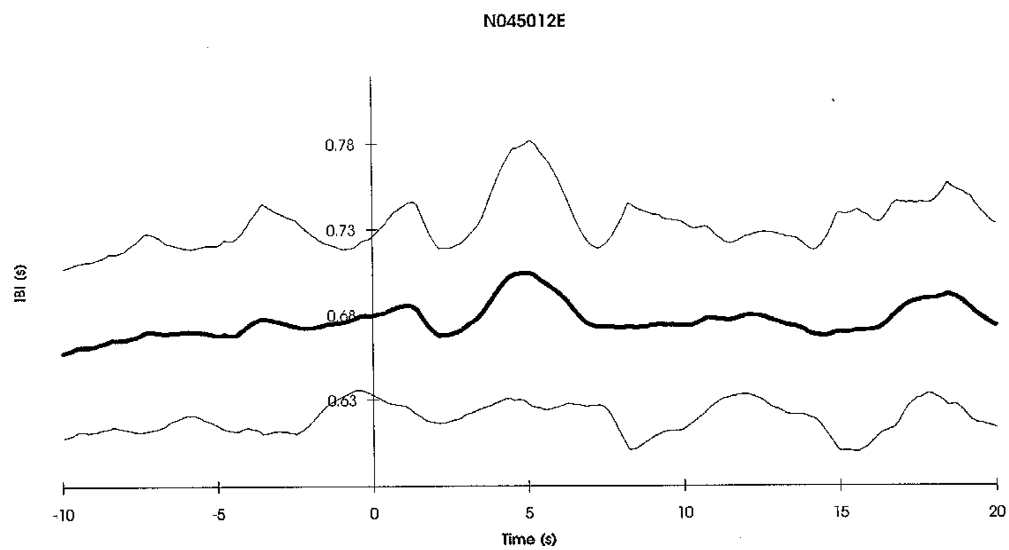

Fig. 4 Event related heart rate response, averaged over multiple events (n=41) for another pilot not flying for handling communications tasks with Air Traffic Control through data link. The centred event was an ATC up link (time zero) displayed as text on the navigation display and requiring a consent form the crew later on.

The responses described earlier were replicated by the data of another pilot tested. The same comparison as earlier was made with the presentation of displayed text as an alternative to synthetic speech. The result for this condition is depicted in figure 4.

3.3. Response to Automation failures

To illustrate the response of a pilot to an automation failure in the case of FMS gating through advanced Data link, an 'Auto pilot disconnect' event was selected for this analysis. Such events have a low frequency of occurrence so the pilots are not prepared. The auto pilot disconnect was scheduled to occur immediately after handling an up link from ATC.

The results obtained are depicted in figure 5.

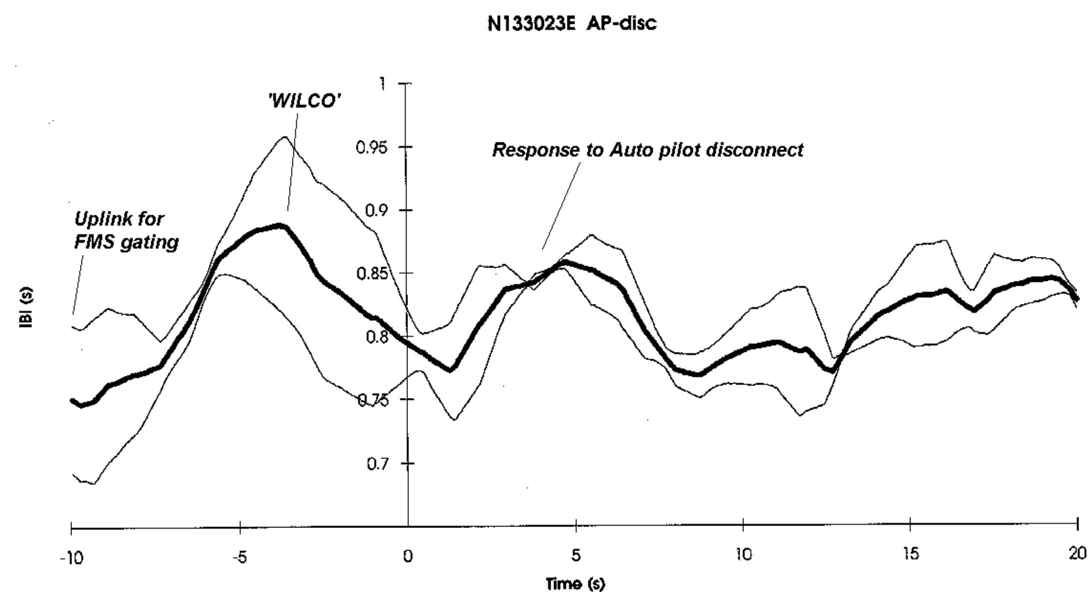

Fig. 5 Event related heart rate response, averaged over multiple events (n=3) for a pilot confronted with a auto pilot disconnect after accepting the FMS gating of an ATC up link. The disconnect was initiated automatically 10 seconds after the up links.

The results demonstrate the occurrence of the apparently, typical, 'WILCO' response in heart rate also for this pilot, just before the surprising event of an auto pilot disconnect. The profile illustrates that even subsequent events with short intervals between them, can still cause distinct responses to be observed. Also, only three events in the average were sufficient to replicate the earlier results for the 'WILCO' obtained with 26 events in the earlier average (also different subject pilot).

The intuitive expectation of a pilots response to an auto pilot disconnect event would be a distinct rise in heart rate. The data however, show a different, more particular response. The heart acceleration following the completion of the communication task is followed by a decrease in heart rate, again apparently associated with the intake of information to determine the problem. No ‘panic’ related response is observed. Note the effect of the event on the standard deviation of the averages obtained. It is almost reduced to zero at the precise moment the pilot takes corrective actions. After the event, heart rate seems to stabilise to more normal levels.

4. Discussion

The aim of this study was to demonstrate the feasibility of using Event related Heart Rate measures to complement and assist studies into human-machine interaction in automated cockpits. These cockpits are particularly suited for this application as the cockpit devices require many discrete tasks to be completed by the crew. The technical requirements for this technique are formidable with respect to the integration of both experimental control over simulation events and the associated data recordings with accurate synchronising provisions over multiple data sources. The application of the techniques could be demonstrated and resulted in the detection of distinctive heart rate responses to particular events scheduled in the scenario. In this respect, this laboratory technique could be transferred successfully to the complex environment of dynamic full mission simulation.

The results seem to justify the following preliminary observations:

- EHR patterns seemed characteristic for the event types in this study and occurred consistently over different flights and subject pilots.
- Response patterns can vary quickly over time, allowing detailed study of pilot responses in a dynamic environment.
- EHR responses indicate pilot responses that are counter intuitive at first sight, where an increase would seem likely to indicate a startle response, a decrease was observed probably indicating a controlled information sampling strategy by the pilot to resolve the problem that occurred.
- EHR seems a useful tool to gain more insight in dynamic aspects of pilot behavior
- Depending on the event, also low frequencies of event presentation can produce relevant EHR.

With the EHR technique, a wealth of additional information seems to be accessible from complex simulations, improving the cost effectiveness of such studies. Not all events registered in the data link experiment could be analysed within the scope of this study. Questions, of a mere scientific nature still remain, like what is the mediating role of respiration in determining the observed information uptake decelerating response in EHR. All in all, the technique seems to present a welcome addition to ‘period based’ measurement techniques that produce objective results over a certain period of time, like ‘traditional’ spectra calculated over 300 seconds periods of consistent task performance. Most important however, seems the opportunity to take more advantage of the possibility to exploit the results of complex simulations more cost effective, and allow for the build up of a data base of simulation results that can be used for post hoc analysis with potential satisfactory outcomes.

5. References

Gent, van R.N.H.W., (1996) Cockpit data link phase II: towards increased user acceptance by operationally defined design human interface concepts. NLR technical publication, in press.

Jorna, P.G.A.M. (1992). Spectral analysis of heart rate and psychological state: A review of its validity as a workload index. Biological psychology, 34, 237-257.

Jorna, P.G.A.M. (1997). Context simulation: an interactive methodology for user centred system design and future operator behavior validation. In: Cognitive engineering in the aviation domain (Sarter & Amelberti eds.). Lawrence Erlbaum inc. Publishers. In press.

Koers, G. (1997) Brain control of heart regulation. Phd thesis. University of Groningen, Netherlands.