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5-7-2019

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Daviaux, Y., Bey, C., Arsac, L., Morellec, O., & Lini, S. (2019). Feedback on the Use of Matb-li Task for Modeling of Cognitive Control Levels Through Psycho-Physiological Biosignals. *20th International Symposium on Aviation Psychology*, 205-210.

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FEEDBACK ON THE USE OF MATB-II TASK FOR MODELING OF COGNITIVE CONTROL LEVELS THROUGH PSYCHO-PHYSIOLOGICAL BIOSIGNALS

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Modeling individuals' cognitive control levels in operational situations is a major challenge for safety in aeronautical industry. Standardized experimental tasks - as the Multi-Attribute Task Battery II (MATB-II) - are dedicated to such a challenge that can be faced using psycho-physiological biosignals. These biosignals are known to be sensitive to cognitive workload, performance, and expertise that are intricate features of MATB-II subtasks. Thus, it remained necessary to investigate whether these features could be set to ensure controlled experimental conditions. Two groups (15 experts in time-pressured decision making and 13 novices) completed 3 MATB-II sub-tasks (tracking, monitoring, and resource management tasks). Biosignals accounting for autonomic nervous system activity were measured continuously, as objective markers of cognition. Confrontation between performance data and (objective and subjective) cognitive markers reported contrasting perspectives regarding the exploitation of MATB-II as a pertinent tool to insure controlled experimental conditions in the context of cognitive control characterization.

Designing adaptive human-machine interface is a major challenge in aeronautics, where the stakes relate to security. To this aim, we were looking to characterize experts' cognitive states in operational context, using psycho-physiological objectification tools. This paper will set out the details of the approach chosen to take up this challenge using the Multi-Attribute Task Battery (MATB-II, Santiago-Espada et al. 2011) computer-based task.

Theoretical framework of this study: Hollnagel's Extended Control Model

This study is based on Hollnagel's cognitive control theory (Hollnagel 1998) to address cognitive resource management. Although cognitive resources are usually seen as a form of "fuel" for cognitive processes – a fuel that could be assessed to determine the operators' margins and limits (Yerkes & Dodson 1908) – the specificity of this model is that it considers a principle of cognitive resource saving, which is more of a mean of optimization, than a simple cognitive resource consumption reduction process. Its main advantage is therefore to approach cognitive processes at an integrative level: there would be cognitive shortcuts to face familiar situations, and means to protect oneself against the unknown. Mental representation, abstraction ability, sufficiency principle and anticipation could be some of these means. The suggested ECOM model (Extended Control Model, Hollnagel 1998) mentions 4 identifiable levels of cognitive

control, from long term planning with the highest level of abstraction to short adaptative loops with short available time. It was thus required to propose a human-machine interaction environment in which these levels of cognitive control could be simulated, granting access to the operator's performance as well.

Experimental simulation: MATB-II

To this end, the Multi-Attribute Task Battery computer-based task developed by the NASA team (MATB-II in revised version, Santiago-Espada et al. 2011) was identified as a favorable simulation environment. Although MATB-II is originally a multi-task environment, it offers isolated subtasks that are resembled levels from the ECOM model. Among the 5 proposed tasks, 3 stood out: a "tracking" task (Track), which consists in holding a sight in the center of a target using a joystick (short adaptative loop with short available time) ; a "monitoring" task (Monit), which consists check for abnormal gauge oscillations on 4 gauges and correct it as quickly as possible, pressing the corresponding key on the keyboard (short-term planning); and a "resource management" task (Manag), which consists in maintaining the level of 2 tanks consuming resources, by activating/deactivating pumps that enable the transfer of resources from different tanks (highest planning level). To satisfy the stakes of this project, the cognitive states needed to be characterized during the realization of these tasks.

Objectification of the cognitive states in operational situation and interpretations

Heart rate variability (HRV), electrodermal activity (EDA), and pupillary dilatation are known for cognitive state objectification means in operational situations (e.g., Wilson 2002). As indirect markers of autonomic nervous system's activity, these physiological indicators are also considered representatives of workload, involvement in the task, emotional states, and waking indicators. Given their ubiquitous nature, we needed to ensure the nature only was a dependent variable (Track vs. Monit vs. Manag). Confounding variables which are workload, operator's involvement and emotional states, therefore needed to be controlled. Since confounding variables and the nature of the task are closely intertwined, the only way to guarantee control of the experimental conditions would be to check the confounding variables' stability between tasks. Since the MATB-II enables to 1) program difficulty levels, 2) measure the operators' operational performance, and 3) subjectively assess the workload, it was the perfect tool to obtain feedback on the participants' involvement through their performance in each task, and on the workload perceived, thanks to subjective assessment scales (NASA-TLX, Hart 2006).

Experimental conditions programming

The MATB-II computer-based task offers an environment allowing event programming for each task, independently from each other. To our knowledge, no gold standard already exist to ensure standardized difficulty. Pre-testing experimental conditions being a common approach in human sciences, pre-experimentation on 5 participants allowed to adjust the difficulty of the tasks, according to subjective feedback on the perceived difficulty.

For Track, level 2 on 3 (pre-programmed medium level) was chosen as default level. For Monit, adjustments during the pre-tests have led us to consider faulty gauge scheduled every 10 seconds, randomly made the difficulty similar to that of the Track task. For Manag, pre-tests led us to program one faulty pump event every 10 to 20 seconds for a duration of 15 seconds, to match Track's and Monit's perceived difficulty.

Hypothesis

Considering the pre-experimentation efforts, we expected no observation of inter-condition effects on the confounding variables, be it on the subjectively declared workload or the

performance. Considering the ubiquitous nature of the psycho-physiological variables, we were expecting to observe significant correlations with the cognitive load and performance levels, indicating the necessity for data correction.

Method

Participants

A group of experts in high time-pressured context task management (high-level handball players, $N = 15$; 16.6 ± 1.1 years old ; 8.2 ± 2.9 years of practice) was compared with novices ($N = 13$; age 20.6 ± 2.0 ; years of practice < 2 years), for a total of 28 participants. After they had been informed of the experimentation conditions, adult participants and legal representatives of underage participants signed a written consent to participate in accordance with the Helsinki Accords (General Assembly of the World Medical Association, 2014).

Experimental design

Experimental visit

Participants were checked for enough sleep the night before and no energy drinks in the last 6 hours. The experimental session was held in a temperate (20°C), constantly lit, soundproof room. Participants then trained for each condition for 1 minute as a habituation session. We made sure performance instructions were understood for each condition, if not, a second attempt was realized. Participants then performed each experimental condition randomly. Each condition lasted 5 minutes, with at least 3-minute rest between conditions.

Experimental conditions

As presented in the introduction, 3 out of the 5 MATB-II subtasks led to 3 distinct experimental conditions. These mono-task conditions create a human-machine interaction relevant with the ECOM model's definition of control levels.

Measurements

Physiological measurements

The participants' electrodermal activity (EDA) and cardiac activity (ECG) were measured continuously at 1000-Hz and amplified with a dedicated acquisition chain and an A/D 24-bit converter (MP150 and BioNomadix system, Biopac, California, USA). For EDA, 2 Ag/AgCl electrodes were placed respectively on the index's and the middle finger's first phalanx, on the non-dominant hand [1]. For the ECG, 3 Ag/AgCl electrodes were placed in conformity with the representation of Einthoven's triangle. Pupillary dilatation data were collected continuously in 60-Hz by a dedicated system (T60 XL Eyetracker, Tobii, Sweden), after individual calibration. All physiological data were recorded on a shared computer for synchronization.

Subjective measurements (cognitive load)

At the end of each experimental task, the level of cognitive load perceived by the subjects was assessed using NASA-TLX. Participants assign a score of 0 to 100 (one score every 5 points) to 6 sub-scales including mental demand, physical demand, time demand, global effort, frustration level, and estimated performance.

Performance measurements

For Track, the performance indicator chosen was Root-Mean-Square Deviation (sampled at 1-Hz). For Monit, reaction times sampled at 100-Hz (maximum allowed by MATB-II software) were collected as dependent variable. For Manag, the difference between both of the tanks' target filling and actual filling was collected at 0.1-Hz.

Data processing

Data were processed in Matlab programming environment (Matlab 2017a, The MathWorks, Natick, MA, USA).

Electrodermal activity

Time-frequency analysis for 0.08 to 0.24-Hz bands was applied to the EDA signal using complex demodulation, according with Posada-Quintero et al. (2016). Spectral power was averaged over time to provide an indication on the sympathetic autonomous activity (EDAsymp, no unit).

Heart rate variability

The ECG raw signal's was preproced according with Pan and Tompkins (1985, QRS complex detection) and Dos Santos et al. (2013, correction of abnormal values in R-R values tachogram). Spectral analysis was performed for each condition on the entire time window (5-min) for low frequencies ($0.04 \text{ Hz} < \text{LF} < 0.15 \text{ Hz}$) and high frequencies ($0.15 < \text{HF} < 0.4\text{-Hz}$)(Task force paper, 1996). Spectral powers LF_{pow} and HF_{pow} are expressed in s^2/Hz . The $\text{LF}_{\text{pow}}/\text{HF}_{\text{pow}}$ ratio reports on the sympatho-vagal system (ratio, no unit).

Pupil dilation

Time series of left and right pupillary diameters were linearly interpolated, merged, then averaged over time and normalized by the time series' standard deviation to provide the EyeT index (no unit).

Cognitive load (subjective)

Scores from the 6 NASA-TLX subscales were averaged to obtain a global score out of 100 (Hart, 2006).

Performance measurements

For Track and Monit, the data have been averaged over time to provide performance indexes, respectively $\text{Track}_{\text{perf}}$ (in millimeters, mm) and $\text{Monit}_{\text{perf}}$ (in milliseconds, ms). For Manag, data from both managed tanks have been averaged between themselves, then averaged over time to provide the $\text{Manag}_{\text{perf}}$ index (no unit).

Subsequently, each data series has been transformed into z-scores to be compared and merged as needed.

Statistics

Statistic tests were carried out with XLSTAT (XLSTAT 2018.1, Addinsoft, France). A non-parametric variance analysis to compare 2 expertise modalities [Intra-subject comparison: Exp vs. Nov] by 3 experimental conditions [Inter-condition comparison: Track vs. Monit vs. Manag] was applied to compare the different variables.

Results

Each variable's averages and standard deviations are presented in table 1a.

Table 1 : Results of data processing.

	Track		Monit		Manag		Effect
	Experts	Novices	Experts	Novices	Experts	Novices	
Performances' scores (mm / ms / no unit)	25,1 ± 7,3	21,9 ± 3	1279 ± 194	1166 ± 243	-745 ± 455	-444 ± 238	Expertise
Scores for Workload NASA-TLX (sur 100)	48,3 ± 11,9	51,8 ± 15	50,2 ± 10,5	59,9 ± 12,3	47,9 ± 12,5	47,3 ± 11,2	Condition
EDAsymp (index, no unit)	0,52 ± 0,05	0,54 ± 0,1	0,54 ± 0,08	0,61 ± 0,21	0,56 ± 0,07	0,56 ± 0,1	Condition
HRV LFpow (s ² /Hz)	103,9 ± 26,9	92,8 ± 33,7	105,8 ± 22,5	101,1 ± 31,8	107,5 ± 36	95,3 ± 30,2	
HRV HFpow (s ² /Hz)	13,1 ± 7,5	10,4 ± 4,3	12,9 ± 6,3	12,8 ± 6,4	13,9 ± 8,1	11,3 ± 4,7	
HRV LFpow/HFpow (ratio, no unit)	9,1 ± 2,6	9,3 ± 1,8	9,2 ± 2,3	8,8 ± 2,6	8,9 ± 2,5	8,9 ± 2,1	
Pupil dilation (index, no unit)	13 ± 4,9	12,7 ± 2,7	14,8 ± 4	13,9 ± 2,1	18,6 ± 3,3	17,4 ± 4,6	Condition

Discussion

This work relates to a project whose global goal is to model the cognitive states of operators in operational situation, using psycho-physiological tools. To this end, MATB-II was suggested as the appropriate experimental environment, because it offers a range of standardized experimental tasks addressing situations that mobilize distinct cognitive states as defined in Hollnagel's cognitive control levels theory. Psycho-physiological variables measured during these tasks being indirect witnesses of the autonomic nervous system's activity, interpretation of the experimental effects can therefore be tricky, considering their ubiquitous nature. This work's aim was thus to make sure that only the nature of the tasks differed between experimental conditions (i.e., that cognitive load and/or involvement in the task (via performance) should not be confounding factors). Precautions were taken in the form of pre-tests to adjust the experimental tasks' difficulty. Consequently, we made the hypothesis that the experimental condition would have no detectable effects neither on the subjectively declared workload, nor on the performance.

Interpretation of effects

Contrary to our first hypothesis, a major effect of experimental conditions was detected on subjectively scores of cognitive load. Although adjustments were carefully made prior to the experimentation – in accordance with common experimental approaches – it is however not possible to confirm that cognitive load has been standardized, and thus that only the nature of the task differed between experimental conditions. This is particularly problematic as far as psycho-physiological data interpretation is concerned, since we observe a similar effect. The difficulty of cognitive load standardization resides in the fact that, to our knowledge, there is no existing gold standard to normalize difficulty between cognitive tasks of different nature. The multiple setting parameters used to adjust the difficulty of a given task makes it particularly difficult to implement similar experimental conditions. As an example, the Track condition offered only 3 spatial difficulty levels (i.e. the more difficult the level, the wider the sight's random movements). Comparatively, the Manag condition offered dynamic (flow management), spatial (which pumps?) and time (when? for how long?) setting parameters. It was therefore difficult to imagine establishing configuration rules to come close to difficulty level standardization. Regarding performance measurements, variance analysis has allowed to detect an interaction effect between the expertise level and experimental conditions. Performance being one of the behavioral witnesses of the involvement in a task, it is once again tricky to confirm that participants' involvement is similar from one task to the next, and that only the nature of the task differed between experimental conditions. We should also note that task performance and cognitive load are closely linked. Poor performance can indeed reflect both an overload and an underload, according to Yerkes and Dodson's law (Yerkes and Dodson 1908). Difficulty level configuration therefore also plays a crucial role, to make sure that poor performances are not linked to a form of boredom in case of too simple a task, or to a total disengagement from a task which is too complex.

About the MATB-II task

Despite the difficulties mentioned in this paper, we should note that MATB-II was used in an unusual way during this study. This experimental environment has indeed originally been developed to simulate a given level of cognitive load in multi-task experimental conditions (e.g., Fairclough et Venables 2006). To our knowledge, no experimentation had tried comparing MATB-II experimental sub-tasks between themselves, attempting to control / normalize confounding factors such as cognitive load and involvement in the task via performance. Even though the solution put forward to address demands like this project's still seems relevant to us today, it is good practice to use this feedback to take precautions when treating and interpreting

data, systematically measuring the levels of subjectively assessed cognitive load and the task performances. This would allow to adjust dependent variables (psycho-physiological) to model the operators' cognitive states as accurately as possible.

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