Available online at www.sciencedirect.com

ScienceDirect

IFAC PapersOnLine 52-19 (2019) 91–96

Heart-Computer Synchronization Interface to control human-machine symbiosis: a new human availability support for cooperative systems

F. Vanderhaegen[1], **M. Wolff**[2,3], **S Ibarboure**[3], **R. Mollard**[2,3]

[1] *Université Polytechnique Hauts-de-France, LAMIH CNRS UMR 8201*
59313 Valenciennes, France (e-mail: frederic.vanderhaegen@uphf.fr)

[2] *Univ. Paris Descartes, UMR 8257 COGNAC-G, 45, rue des Saints-Pères - 75006 Paris, France (email: marion.wolff@parisdescartes.fr, regis.mollard@parisdescartes.fr)*

[3]*ESTIA-PEPSS, Technopole Izarbel, 64210 Bidart, France (email: m.wolff@estia.fr, r.mollard@estia.fr, s.ibarboure@estia.fr)*

Abstract: The paper proposes an original architecture to control human-machine symbiosis by using Heart-Computer Synchronization Interfaces (HCSI). This symbiosis depends on the limits of three autonomy prerequisites: the knowledge required to treat a situation, the availability of the human and technical resources when achieving tasks, and the possibilities to act by using dedicated interfaces. As inattention is one the causes of a lack or a loss of the symbiosis related to human availability, the new system consists in controlling it by studying the impact of the synchronization of dynamic event occurrence with heart rate. The results of an exploratory study are relevant and promising: subjects for who the activation of visual and sound alarms were synchronized with heartbeats made significantly more perception errors than subjects for who this activation was not synchronized. They demonstrate that the design of human-machine systems has to be aware of such synchronization that may affect human perception abilities and degrade the efficiency of the cooperative activity achievement. This is then a new challenge for defining future cooperative systems based on human availability supports to perceive data from automated tools.

Keywords: heart-computer synchronization interface, human error, human perception, cooperation, synchronizarion

---

1. INTRODUCTION

News concepts of interfaces such a Brain-Computer Interfaces has been developed recently. Heart based interfaces are usually used for the sports coaching, the medical monitoring or the analysis of human factors such as workload, stress or emotion. The concept of Heart-Computer Interface does not yet exist. However, regarding the study of cooperation between humans and machines for instance, it can be useful for monitoring the human cognitive state and sharing task regarding heart based indicators.

This paper proposes then an original new concept named Heart-Computer Synchronization Interface (HCSI) to study such human abilities. More precisely, it details interface architecture to control human-machine symbiosis based on the impact of the synchronization of event occurrence with heart rate. Results of an exploratory experimental protocol show that human perception abilities are significantly degraded when events occurs synchronously with the heart rate. As such synchronization can generate hazardous breakdown of human-machine symbiosis, it is worth developing such Heart-Computer Interface in order to control it and reduce human detection errors.

Section 2 introduces the concepts of human-machine symbiosis and cooperative systems. Section 3 presents usual human factors related to human availability that can justify the cooperation activities between humans and machines. Section 4 details the HCSI architecture and section 5 presents an experimental protocol to study the impact of the synchronization of event activation with heart rate.

2. HUMAN-MACHINE SYMBIOSIS AND COOPERATIVE SYSTEMS

Human-machine symbiosis relates to the dependencies that exist between human and machine activities. For instance, when humans take manual notes, they need a piece of paper and a pen. If there is no pen or no paper, taking note is impossible. Manual notes highly depend on the presence of these supports. Another example is an electrical or a computer failure on an air traffic control room that makes the use of the radar screen or of the electronic flight plan display impossible (Odell et al., 2014; Calder, 2018; Noëth 2018; Shanahan, 2018). The activities of the air traffic controllers depend on the availability of these control devices. Unusual procedures have to be applied in order to recover possible

10.1016/j.ifacol.2019.12.116

safety failures of these devices: reduction of the number of aircraft on the controlled geographical sectors, reduction of the taking off and the landing, limitation of the communications with pilots by using the radio, etc. In this case, the human-machine symbiosis relates to the use of interactive supports. Indeed, the regular use of a technical system by a human operator increases the level of symbiosis between them and makes difficult the use of another new support. This possible modification of interactive support can lead to an increasing of human workload or stress.

Human-machine symbiosis can then be an obstacle to the system autonomy when at least one of the components is out of order or missing. A lack or a loss of symbiosis can be due to human factors such as overload, stress, attention or distraction. On the other hand, an excess of symbiosis can also be a cause of human hazardous behaviors. As example, the regular use of an automated car speed controller can lead to vigilance decreasing, inter-distance reduction or reaction time increasing (Dufour, 2014).

The human-machine symbiosis depends on the limit of three autonomy prerequisites that avoid a decision maker to act alone and without any supports (Vanderhaegen, 2017):
- The existence of sufficient knowledge to control a given foreseen or unforeseen situation.
- A minimum availability of the physical and cognitive resources to be ready to act.
- The possibilities to interact by using dedicated human-machine interfaces.

These limits can lead human operators to cooperate with others or with automated tools. Human-machine cooperation activities generate then another kind of symbiosis based on the complementarities of the decision makers in terms of knowledge, availability or possible interactions. Knowledge discovery, knowledge exchange, knowledge sharing or knowledge reinforcement are examples of possible processes to recover human knowledge limits by automated systems (Vanderhaegen, 2016). Human availability assessed with factors such as workload, attention, vigilance or stress can also justify the activation of these technical supports. The dynamic task allocation principle uses such human availability indicators in order to share tasks between humans and machines (Vanderhaegen, 1999). Regarding cooperative activities, complementarities on knowledge or availability are assumed if interactions between human and machine make them possible. They are better optimized if cooperation, learning or resilience abilities are involved (Vanderhaegen, 2012; Vanderhaegen, Zieba, 2014, Enjalbert, Vanderhaegen, 2017), or if specific interaction supports such as common, shared or joint workspace exist (Pacaux-Lemoine, Debernard, 2002; Jouglet et al., 2003).

Complementary about human availability depends on factors such as attention, vigilance or workload. The next section presents some of them.

3. HUMAN FACTORS FOR HUMAN-MACHINE SYMBIOSIS CONTROL

Measurements of workload, attention or vigilance lead to identify situations that may affect or improve human availability. Different supports are used to realize such assessments:
- Eye-trackers to analyze physical characteristics of the eyes or gaze.
- Facial recognition systems to identify emotional characteristics.
- EEG systems to recognize the solicited brain areas during an activity.
- Heartbeats based systems to capture the evolution of heart rates.
- Verbalization recording systems to study verbal activities.
- Subjective assessment methods to record self-feelings about different cognitive or behavioral parameters.

Human availability study can also be useful to assess specific human behaviors such as attentional blindness, the tunnel effect, blindness to change, attentional dissonance or the illusion of attention (Simons, Chabris, 1999, Chabris, Simons, 2010; et al., 2011; Jones et al., 2014; Liao, Chiang, 2016; Vanderhaegen, Carsten, 2017; Vanderhaegen et al., 2019). These behaviors are linked to a temporary blindness of attention abilities that prevents humans from detecting obvious changes or unexpected events. This occurs mainly when humans have to share their attention between multiple tasks (ie, shared attention) or when a task requiring all the resources of attention is an obstacle to taking into account other tasks (i.e, selective attention). Eye-trackers can be used to study visual attention or workload by analyzing indicators such as eyelid closure percentage, blink rate, fixation time, saccades, pupil diameter, number jerks, sweeping speed, or gaze direction (Galluscio & Fjelde, 1993, Rosch, & Vogel-Walcutt, 2013). These are useful supports for analyzing foveal vision rather than peripheral vision. When a subject looks at a given point of a working scene, the analysis of the corresponding eye movement assumes that attention is focused on that point. However, attention may also focus on other points without any eye movement. These behaviours are called overt attention and covert attention respectively (Findley, 2003). Changes in heart rate are usually related to changes in workload, stress, or emotions (Tealman et al., 2009, Geisler et al., 2010, Pizziol et al., 2011, Hidalgo-Muñoz et al., 2018). Since humans do not hear their heartbeat at rest, except after physical exercise, high stress, or strong emotion, a new hypothesis consists in considering that attention may be affected by the synchronization of dynamic events with heart rate.. A recent study has shown that when human subjects are confronted with flashing alarms in correlation with their heart rate, the solicitation of their insula decreases and their ability to correctly detect alarms degrades, the insula being the part of the brain dedicated to perception and awareness (Salomon et al., 2016).

The next section proposes then an original system architecture to study such an indicator based on heart rates and their synchronization with dynamic event occurrences.

4. HEART-COMPUTER SYNCHRONIZATION INTERFACE

The proposed system aims at controlling human-machine symbiosis by studying the impact of the activation of dynamic events synchronized or desynchronized with the heart rate. The architecture is based on a Heart-Computer Synchronization Interface (HCSI), Figure 1. On the work environment, different supports are required to measure on-line the heart rate, to control the intermittent events the subject has to recover, to display the dynamic event evolution and to record the results about the impact of the synchronization of events with heartbeats.

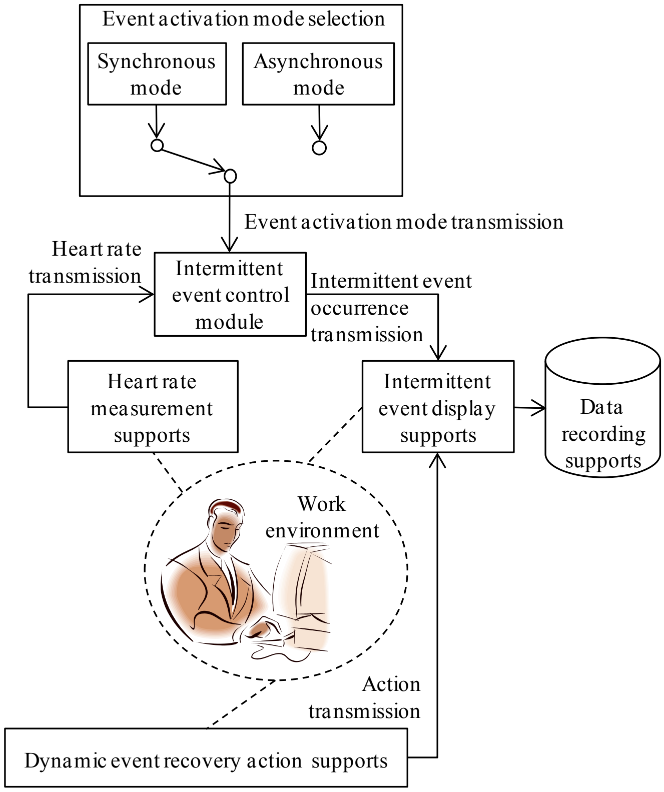

Fig. 1. The proposed HCSI architecture.

The intermittent event control module aims at managing the event activation regarding the synchronization or desynchronization mode and the current heart rate. The synchronization mode consists in transmitting the intermittent event activation synchronously with the heart rate. The desynchronization mode activates events asynchronously with the heart rate, Figure 2. It takes into account the real-time heart rate measurement *HR(t)* and the event activation mode *AM(t)* in order to control the event occurrence by applying a dedicated algorithm, Figure 2. The time of an intermittent event occurrence is based on the duration *Te* assessed in millisecond. The constant named α with $\alpha \in]0, 1[$ aims at activating the event occurrence in the asynchronous mode. The processing of the blinking event occurrence takes t2+*Δt* time when a beat *b(t2)* is detected at *t2* time.

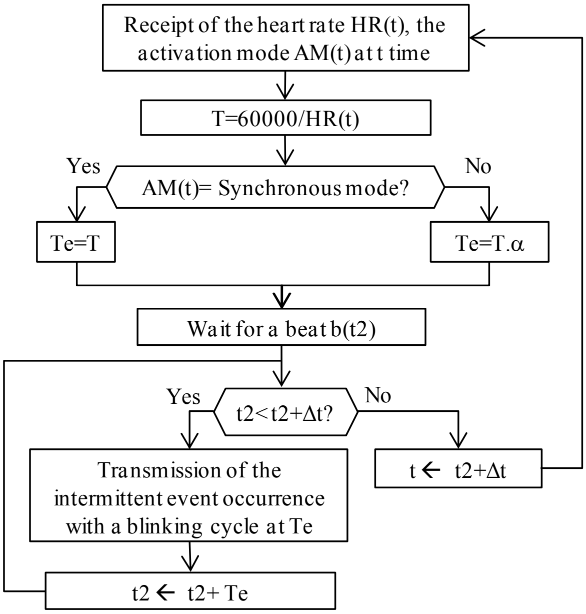

Fig. 2. The intermittent event activation module.

This architecture was adapted for an experimental protocol to study the impact of the synchronization of alarms activation with heartbeats.

5. EXPERIMENTAL STUDY AND RESULTS

The proposed experimental protocol is detailed on (Wolff et al., 2019). It is based on the MultiAttribute Task Battery (Comstock, Arnegard, 1992) and consists in detecting alarms during four experiments with increased complexity, Figure 3.

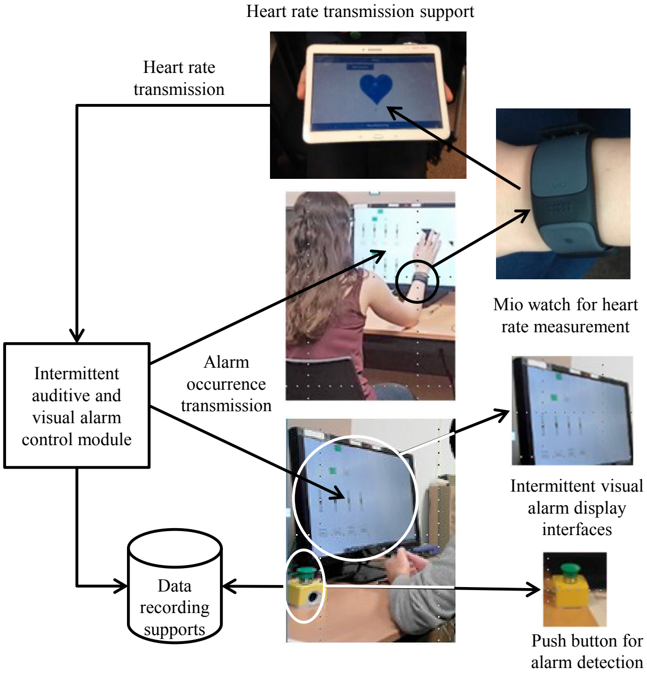

Fig 3. The experimental protocol to stud the HCSI.

During the level 1 of the experiments, the subject controls four cursors and two indicator lights. For the three other levels, eight cursors and four indicators appear. The cursors move vertically. When one of the them moves the end of its track, either upper or lower, the subject has to press the corresponding function button of the touchscreen (i.e., F1, F2, F3, F4) to bring the process back to its initial state. One light indicator is initially lit and the other is turned off. When one of them changes state (i.e., the unlit indicator turns on or the lit indicator turns off), the subject has to press the corresponding function button (i.e., F5 or F6) to bring the process back to its initial state. If the subjects take more than five seconds to react, the process returns to its initial state and they are warned by an auditory alarm. The levels 2, 3 and 4 are similar to the level 1 characteristics but include eight cursors and four indicator lights, Figure 4. The order of occurrence of cursor or indicator changes is programmed, and is reproduced eleven times for the level 1 during three minutes, and thirty-four times for the three following levels during six minutes. For the last two levels, a secondary task occurs. It is the resolution of a tangram puzzle with seven pieces, which breaks down more and more quickly between level 3 and level 4. The subjects have to rebuild it by pressing the touchscreen and they also have to control the cursors and display buttons.

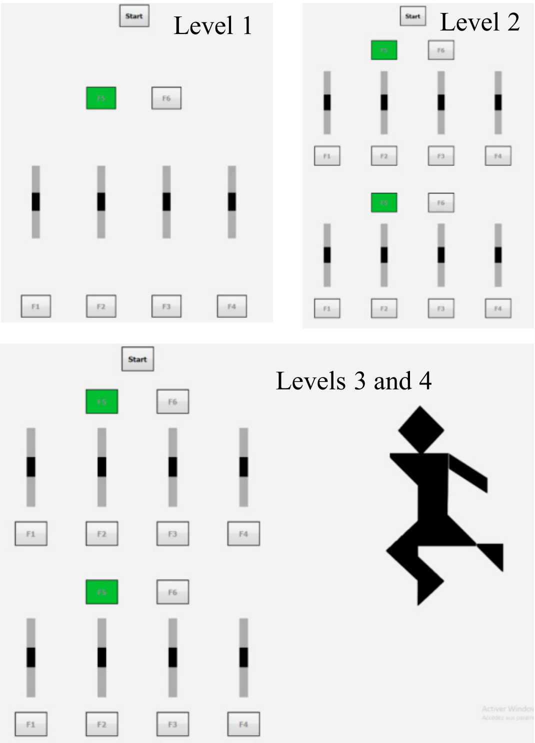

Fig. 4. Four experimental levels with increased complexity.

Two intermittent alarms appear simultaneously at the same location on the screen during the experiments. They are two amber and red flashing squares with a surface of 3 cm by 3 cm. They are displayed randomly and distributed over the four experimental levels of difficulty. When both alarms occur, there is a specific sound that is similar to the beep used in aeronautics to indicate an abnormality. When the subjects see these visual alarms accompanied by an auditory signal, they have to press the push button to valid the alarm detection. If they do not press it within ten seconds, then there is an error of omission. For 15 subjects (i.e., Group 1), these alarms are activated in a synchronous mode, and for 12 subjects (i.e., Group 2), it is in the asynchronous one. They occur at the same place, 6 times on level 1 and 8 times on the other levels. The value of α is fixed at 0.2. The current beat $b(t2)$ is detected manually in order to activate a series of blinking alarms for a period of 10 seconds (i.e., Δt=10s, flashing on for 100 ms and off for Te-100ms).

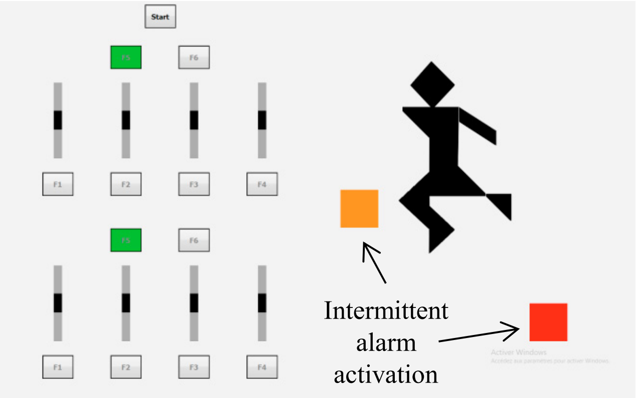

Fig 5. The intermittent alarm activation.

Several data have been recorded and analyzed. The participants are wearing a Mio™ watch to capture the on-line heartbeats and to activate the intermittent alarms for the Group 1 and Group 2 consequently. The data from the Tobii™ eye-tracker was used to assess the scan rate of the alarm areas. The next steps of the proposed methodology concerns other recorded data. They are quantitative performance assessment related to omissions or false detection of alarms, the heartbeat recording and subjective data from methods such as Task Load index (Hart & Staveland, 1988). Two kinds of analysis, an ANOVA analysis and a Fisher-Snedecor test (i.e., F test) are proposed to study the impact of the experimental conditions for each group and each experimental level. Figures 6 and 7 give results on TLX, the heart rates, the scan rates, and the errors of intermittent alarm detection. They display the T test result and the average values with confidence intervals around mean points for a p-value of 0.05. A difference of 2,50 points on the global mental workload occurs between the Group 2 (Average: 51.10, Standard Deviation: 3.60) and the Group 1 (Average: 48.56, Standard Deviation: 3.19). For all the subjects, the increasing of the workload evaluation between the different experimental levels (i.e. from Level 1 to Level 4) is significant (F (3, 78) = 54.5791, p = 0.0000). Related to such global workload, results on heartbeats confirm that the experimental protocol was valid from the point of view of the increasing of the mental workload. Even if the Group 1 (Average = 84.77 beats per minute, Standard Deviation = 18.83) has an average heartbeats slightly higher than the Group 2 (Average = 82.93 beats per minute, Standard Deviation = 10.46), the difference is not significant. There is a greater dispersion for the synchronous condition. Nevertheless, the effect of the difficulty of the task is relevant and there is a progressive variation according to the experimental level, whatever the group of subjects (F (3, 75) = 7.47; p = 0.0002).

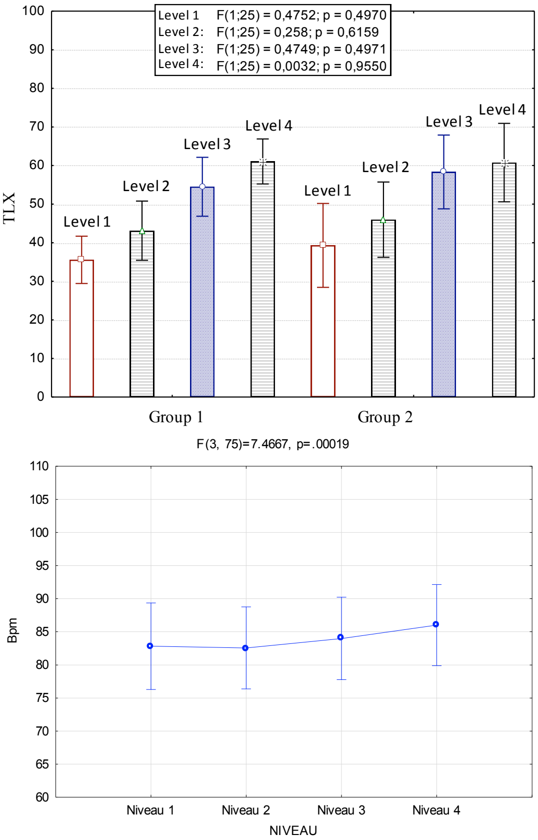

Fig. 6. TLX and heart rate results.

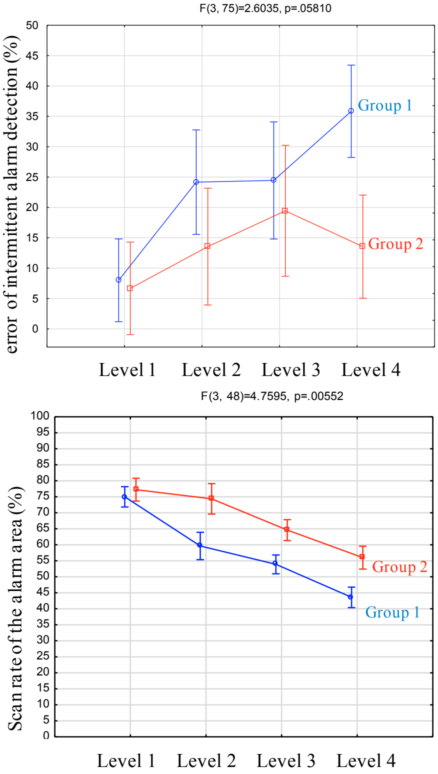

Fig 7. Scan rate and detection errors.

Whatever the experimental condition, the scan rate of the alarm zone decreases gradually according to the experimental level. The higher the mental workload is, the less the subjects tend to look towards the zone where the alarms are displayed: the difference between the Level 1 and the Level 4 is about 27% and the result regarding the F test is significant. Subjects from the synchronous condition tend significantly to look less at the alarm areas than subjects from the asynchronous condition. This observation increases regarding the workload level of the experimental condition. The statistical analysis of the intermittent alarm detection error indicates that subjects of the Group 2 make about 13.30% of errors (Standard Deviation = 8.53) whereas subjects of the Group 1 realize about 23.11% of errors (Standard Deviation = 9.14). The Fisher-Snedecor test shows that this difference between Group 1 and Group 2 is significant (F (1, 25) = 8.15, p = 0.008). The impact of the experimental levels on human error occurrence is also significant (F (3, 75) = 7.23, p = 0.0002).

6. CONLUSION

This paper has presented a new concept of interface based on the use of the heart rate. The Heart-Computer Synchronization Interface consists in applying the heart rate measurement as an indicator of human availability during joint activities achievement involving humans and machines. An experimental protocol demonstrated that a breakdown of such human-machine symbiosis can be due to the synchronization of dynamic event occurrence with heart beat. This synchronization increases significantly the number of errors of alarm detection. Therefore, this paper opens new opportunities for designing future cooperative system based on HCSI to detect human availability. Future researches will test the effects of different values of the parameters of the intermittent event activation module. They will also apply the HCSI to control human-machine symbiosis and improve cooperation by avoiding a breakdown of the symbiosis due to the synchronization between dynamic events with heart rate.

ACKNOWLEDGEMENT

The present research work has been supported by the Scientific Research Network on Integrated Automation and Human-Machine Systems (GRAISyHM), and by the Regional Council of “Hauts-de-France” (Regional Council of Nord – Pas de Calais – Picardie from France). The authors gratefully acknowledge the support of these institutions.

REFERENCES

Calder, S. (2018). Thousands stranded by flight cancellations after systems failure at Europe’s air-traffic coordinator. Independent, April3, 2018.

Chabris, C. F., Simons, D. J. (2010). The invisible gorilla: and other ways our intuitions deceive us. Crown, New York.

Comstock, J.L., Arnegard, R.J. (1992). The MultiAttribute Task Battery for human operator workload and strategic behavior research. Technical Report 104174, Hampton, VA, NASA Langley Research Center.

Enjalbert, S., Vanderhaegen, F. (2017). A hybrid reinforced learning system to estimate resilience indicators. Engineering Applications of Artificial Intelligence, 64, pp. 295-301.

Dufour, A. (2014). Driving Assistance Technologies and Vigilance: Impact of Speed Limiters and Cruise Control on Drivers' Vigilance. Seminar on the Impact of Distracted Driving and Sleepiness on Road Safety, April. Paris La Défense.

Findley, J. M. (2003). Visual selection, covert attention and eye movements? In Active Vision: The Psychology of Looking and Seeing. J. M Findlay and I. D Gilchrist (Eds), Oxford Psychology Series, UK, pp. 35-54.

Galluscio, E. H., Fjelde, K. (1993). Eye movement and reaction time measures of the effectiveness of caution signs. Safety Science, 16(5–6), 627-635.

Geisler, F. C. M., Vennewald, N., Kubiak, T., Weber, H. (2010). The impact of heart rate variability on subjective well-being is mediated by emotion regulation. Personality and Individual Differences, 49, 723–728.

Hart, S. G., Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. Advances in psychology, 52, 139-183.

Hidalgo-Muñoz, A. R., Mouratille, D., Matton, N., Caussec, M., Rouillard, Y., El-Yagoubi, R. (2018).Cardiovascular correlates of emotional state, cognitive workload and timeon-task effect during a realistic flight simulation. International Journal of Psychophysiology, 128, 62–69

Jensen, M. S., Yao, R., Street, W. N., Simons, D. J. (2011). Change blindness and inattentional blindness. WIREs Cognitive Science, 2, 529-546.

Jones, M.P., Chapman, P., Bailey, K. (2014). The influence of image valence on visual attention and perception of risk in drivers. Accident Analysis and Prevention, 73, 296–304.

Jouglet, D., Piechowiak, S., Vanderhaegen, F. (2003). A shared workspace to support man–machine reasoning: application to cooperative distant diagnosis. Cognition, Technology & Work 5 (2), 127-139.

Liao, C.-W., Chiang, T.-L. (2016). Reducing occupational injuries attributed to inattentional blindness in the construction industry. Safety Science, 89,129–137.

Noëth, B. (2018). Radar failure in the Lisbon area control center is disrupting air traffic. Aviation23.be, October 29, 2018.

Odell, M., Hollinger, P., Aglionby, J., (2014). UK air traffic control failure identified, Financial Times, December 13, 2014.

Pacaux-Lemoine, M.-P., Debernard, S. (2002). Common work space for human–machine cooperation in air traffic control. Control Engineering Practice, 10(5), 571-576.

Pizziol, S., Dehais, F., Tessier, C. (2011). Towards human operator state assessment. Proceedings of the 1st International Conference on Application and Theory of Automation in Command and Control Systems, pp. 99-106, IRIT Press.

Rosch, J. L., Vogel-Walcutt, J. J. (2013). A review of eye-tracking applications as tools for training. Cognition Technology & Work, 15, 313–327.

Salomon, R., Ronchi, R., Dönz, J,. Bello-Ruiz, J., Herbelin, B., Martet, R., Faivre, N., Schaller, K., Blanke, O. (2016). The insula mediates access to awareness of visual stimuli presented synchronously to the heartbeat. Journal of Neuroscience, 36(18), 5115-5127.

Shanahan, C. (2018). Chaos in the air as radar fails. Irish Examiner, October 3, 2018.

Simons, D. J., Chabris, C. F. (1999). Gorillas in our midst: sustained inattentional blindness for dynamic events. Perception, 28, 1059-1074.

Taelman, J., Vandeput, S., Spaepen, A., Van Huffel, S. (2009). Influence of mental stress on heart rate and heart rate variability. In: Vander Sloten J., Verdonck P., Nyssen M., Haueisen J. (eds), 4th European Conference of the International Federation for Medical and Biological Engineering. IFMBE Proceedings, vol 22. Springer, Berlin, Heidelberg, pp. 1366-1369.

Vanderhaegen, F (1999). Toward a model of unreliability to study error prevention supports. Interacting With Computers, 11, 575-595.

Vanderhaegen, F. & Jimenez, V. (2018). The amazing human factors and their dissonances for autonomous Cyber-Physical&Human Systems. First IEEE Conference on Industrial Cyber-Physical Systems, Saint-Petersbourg, Russia, May 14-18, 2018.

Vanderhaegen, F. (2012). Cooperation and learning to increase the autonomy of ADAS. Cognition, Technology & Work, 14 (1), pp. 61-69.

Vanderhaegen, F. (2014). Dissonance engineering: a new challenge to analyse risky knowledge when using a system. International Journal of Computers Communications & Control, 9(6), 750-759.

Vanderhaegen, F. (2016). A rule-based support system for dissonance discovery and control applied to car driving. Expert Systems With Applications 65, 361-371.

Vanderhaegen, F. (2017). Towards increased systems resilience: new challenges based on dissonance control for human reliability in Cyber-Physical&Human Systems. Annual Reviews in Control, 44, 316-322.

Vanderhaegen, F., Carsten, O. (2017). Can dissonance engineering improve risk analysis of human–machine systems? Cognition, Technology & Work, 19(1), 1-12.

Vanderhaegen, F., Wolff, M., Mollard, R. (2019). Synchronisation de stimuli avec la fréquence cardiaque : nouveau défi pour le contrôle de dissonances attentionnelles. In « Défis de l'automatisation des systèmes sociotechniques », Vanderhaegen, F., Maaoui C., Sallak M., Berdjag D. (Eds), ISTE Edition, sous presse.

Vanderhaegen, F., Zieba, S. (2014). Reinforced learning systems based on merged and cumulative knowledge to predict human actions. Information Sciences, 276(20), 146-159.

Wolff, M., Vanderhaegen, F., Brethault, M., Brisson, H., Mollard, R. (2018). Vers une possible contribution à la compréhension de "l'effet tunnel" : une étude exploratoire. Proceedings of the Ergo'IA 2018 conference. Bidart-Biarritz, 3-5 oct. 2018. NY : ACM