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Non-conscious errors in the control of dynamic events synchronized with heartbeats: a new challenge for human reliability study

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

1. Univ. Polytechnique Hauts-de-France, CNRS UMR 8201, LAMIH, Le Mont Houy, 59313 Valenciennes Cedex 9, France
2. Univ. Paris Descartes, CNRS UMR 8257, COGNAC-G, 45 rue des Saints-Pères - 75006 Paris, France
3. ESTIA/PEPSS, Technopole Izarbel, 64210 Bidart, France

Email : frederic.vanderhaegen@uphf.fr, marion.wolff@parisdescartes.fr, m.wolff@estia.fr, regis.mollard@parisdescartes.fr, r.mollard@estia.fr

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Keywords: non-conscious error, control of dynamic events, human reliability, heartbeat, cognitive blindness, human attention

Abstract: This paper studies the synchronization between dynamic events with heartbeats and its impact on non-conscious errors in the control of dynamic events. It proposes a methodology to compare two groups of subjects: a group for which alarms are synchronized with the heartbeats of the subjects and a group for which they are not. Quantitative and subjective data were recorded during four experimental phases from a low level to a high level of workload. Results showed that there was a significant impact of such a synchronization of events with heartbeat: people produced more errors when this synchronization was present and they were not really conscious about the disruption of their abilities. This study is very promising and shows the interest of developing future on-line or off-line human reliability assessment methods based on unsafe behaviors associated with this synchronization.

1. Introduction

Situation awareness is a well-known concept for human reliability study. It depends on human factors such as attention, workload, stress or emotion, and its modeling usually includes three levels of conscious activities: the perception, the understanding and the anticipation of dynamic events (Jones & Endsley, 1996; Stanton et al., 2001; Dekker, 2017). Any disruption at one level may lead to the occurrence of unsafe events. This paper focuses on the first level, when a degradation of human perception abilities occurs. The lack of perception abilities can have different causes such as high stress or workload, lack of attention, panic, failed training, or bad working conditions (Hollnagel, 1998, 2000; Vanderhaegen, 1999; Kubota et al., 2001; Samina et al., 2019). The paper proposes an exploratory study to build a theoretical model of unconscious mistaken control when the degradation of availability of cognitive resources affects the application of competences or the possibilities to act. The unconscious mistaken control is based on the so-called Competence-Availability-Action possibility (CAP) model dedicated to the human capabilities to control dynamic events (Vanderhaegen, 2017; Vanderhaegen & Jimenez, 2018). Competences are the procedures or rules to identify the tasks to be achieved, to self-regulate human availability and to act on the controlled process. The availability relates to the cognitive and technical resources that are available for achieving the required tasks, and the possibilities to act depend on the human-machine interaction supports and on the task allocation between human and machine. The paper studies the impact of the degradation of attention abilities on the availability of human resource. Its conceptual framework is built regarding results from previous studies:

- In Simons and Chabris (1999), an experiment was organized using a video where players exchange a basketball and an unexpected subject (e.g., a young woman with an umbrella or a gorilla) moves between the players during the game. If people are asked to count the number of passes made by a given team, 46% of them do not perceive the presence of the unexpected subject. According to these authors, the probability of perceiving an unexpected object may be related to its similarity with the objects on which attention is focused and also to the complexity of controlling the task to be performed.
- In Salomon et al. (2016), since the brain does not hear the heartbeat in a normal situation, the authors ask whether events whose frequency of occurrence mimics these heartbeats have the same effect on human perception. They have shown that when an image flashes in a way that is synchronized with the heart rate, the activity of the insular cortex decreases significantly, causing difficulty or even inability of the subjects to perceive the flashing shapes. Relationships exist between insula with visual awareness and perception by making a connection between interoceptive and exteroceptive stimuli (Salomon et al., 2018) and between insula stimulation and heartbeats (Chouchou et al., 2019).

The paper is a complementary and exploratory contribution about the study of human factors that affect perception ability by a lack of attention, and provoke non-conscious errors in the control of dynamic events, in terms of competence application or possibility for action. More precisely, it proposes a study of the impact of the synchronization of dynamic events with heart rate in terms of quantitative human performances and subjective evaluations of human factors. Regarding the conceptual framework, an experimental study is proposed by generating events or recording human activities with non-intrusive elements such as a connected watch for measuring heartbeats and an eye-tracker for measuring eye activities. It focuses on two main goals. The first one consists in analyzing the perception of unexpected auditory and visual alarms. The second aspect aims to generate these alarms in two ways during four experimental levels of difficulty: one way where the occurrence of alarms is synchronized with heartbeats and one way where it is not. The results of the exploratory study will support the development of an unconscious mistaken control model.

Section 2 presents different concepts of causes or consequences related to non-conscious errors in the control of dynamic events. It aims to identify relations between physiological factors such as heart rate with human error occurrence. Section 3 proposes a methodology and an experimental protocol for studying such unconscious behaviors. Section 4 gives results of experiments done with 27 persons.

2. Non-conscious errors in the control of dynamic events

Non-conscious errors in the control of dynamic events can be studied with prospective, retrospective or cognitive human error assessment methods. These methods usually assess, either qualitatively or quantitatively, erroneous human behaviors that can impact system safety (Reason, 1990; Gertman, 1993; Kirwan, 1997; Vanderhaegen, 2001; Cacciabue, 2004; Hickling et al., 2013; Baraldi et al., 2015; Qiu et al., 2017; Rangra et al., 2017; Petrini et al., 2017; Bevilacqua & Ciarapica, 2018; Burans & Bonaceto, 2018). Most of them study human errors related to what the users are supposed to do. Moreover, they usually focus on the impact of human error on system safety or on erroneous behaviors when controlling emergency or safety critical situations. On-line approaches to the analysis of errors of control are based on the measurement of human factors. They relate for instance to quantitative measurements or to results obtained with subjective evaluation methods (Vanderhaegen, 1997, 1999, 2010; DiDomenico & Nussbaum, 2005; Yang et al., 2010; Naderpour et al., 2016; De Winter et al., 2018; Li et al., 2018). Cooperation or learning support systems can also protect the human-machine system from mistaken control by sharing tasks between human and machine or by learning from human errors (Rognin & Blanquart, 2001; Jouglet et al., 2003; Zhang et al., 2004; Vanderhaegen et al., 2011; Vanderhaegen, 2012; Ouedraogo et al., 2013; Aguirre et al., 2013; Polet et al., 2013; Vanderhaegen & Zieba, 2014; Corrigan et al., 2015; Weyer et al., 2015; Torretta et al., 2017; Enjalbert, Vanderhaegen, 2017).

Non-conscious errors in the control of dynamic events can be likened to a cognitive conflict that is a temporary inconsistency in which at least one limited resource is required several times or at least two sources of information are contradictory (Dehais et al., 2012). Such conflicts are also called dissonances. A cognitive dissonance is a conflict between cognitions, i.e. between knowledge or between parameters of knowledge such as intention, attitude, belief, behavior, memory or attention (Festinger, 1957). Its detection or control can produce negative impacts such as discomfort, overload, embarrassment or positive ones such as self-satisfaction, enjoyment, well-being or pride (Vanderhaegen & Carsten, 2017). The concept of dissonance was extended by Vanderhaegen (2014) who proposed the concept of collective or organizational dissonances, i.e. conflicts of cognitions between persons, systems, groups or societies, adapted from the concept of cindynics dissonance proposed by Kervern (1995). Strategies of dissonance reduction exist when the dissonance is detected (Festinger, 1957): the rejection of the dissonance when it is not accepted, or the reinforcement of the current knowledge in order to modify it or to create new knowledge. The rejection can be applied to turn a deaf ear to conflicting knowledge or elements of knowledge. Then, humans do not take dissonances into account consciously. However, if they do not detect them, they cannot process them, and they may not be aware of their possible hazardous consequences. These hidden individual or collective dissonances can then provoke stressful or shameful situations when humans will discover they failed to detect crucial information for instance. A *tunneling* effect is a kind of hidden dissonance related to unconscious mistaken control of dynamic events (Vanderhaegen, 2016a). It is also named inattentional blindness, change blindness or cognitive tunneling (Simons & Chabris, 1999; Jensen et al., 2011; Liao & Chiang, 2016). It is linked with a temporary blindness of attentional resources that avoid humans to detect obvious changes or unexpected events. It occurs mainly when humans have to share their attention between several tasks or when a task that requires all attentional resources is an obstacle to take other tasks into account. This provokes illusions of the perception of the real work environment. For instance, the illusion of control occurs when humans self-overestimate their real abilities to control dynamic events (Kottemann et al., 1994; Kahai et al., 1998). The illusion of attention relates to a mistaken belief of humans who wrongly think that they are awake and aware of the current situation (Chabris & Simons, 2010). In such cases of unconscious mistaken controls, humans do not behave as they think they do, and what they are supposed to see cannot be what they get in mind. Such behaviors can be studied through several human factors such as attention or workload.

When tasks are performed concurrently, the attentional resources may be saturated because of their limited capacity due to their control by short-term memory (Kahneman, 1973). Humans can then choose to concentrate their effort on one of the tasks, leaving aside the secondary task: this is the paradigm of selective attention (Cherry, 1953). Attention is the focus of the mental activity on a subset of the perceptual area by selecting the appropriate information. Therefore, it has a role in controlling and guiding this activity. It implies a minimum degree of vigilance related to the state of awakening of human operators. The vigilance depends on ultradian and circadian fluctuations, and two situations can be distinguished: the evaluation of this state at a given time and its evolution over time (Mackworth, 1961). Three levels of attention exist: the selective or focused level, the sustained level and the distributed or divided level (Ballard, 1996; Oken et al., 2006;

Srinivasan et al., 2009; Chen et al., 2018). Selective or focused attention aims at focusing cognitive resources on priority tasks whereas sustainable attention consists in maintaining selective attention continuously by taking into account possible modifications or evolutions of the tasks to be realized. Distributed attention relates to the human ability to treat different types of relevant information simultaneously. These distinctions sometimes lead to confusions around the definition of these concepts and attention can then be related to an instantaneous state of awakening, and vigilance to a sustainable state of attention. Relationships between attention and emotion can also be identified. For instance, negative emotions or positive emotions can be linked to focused attention or distributed attention respectively (Srinivasan et al., 2009). Mental workload can impact the state of vigilance and therefore the attention. It is the difficulty to realize tasks perceived by human operators depending on their cognitive, physical and physiological state. High and low levels of workload can lead to a decrement of human performances due to an increasing frequency of human errors (Weiner et al., 1984; de Waard, 1996; Vanderhaegen, 1999). However, the decrease of human performance can also be linked with the stability of workload evolution over the time, instead with an instantaneous workload calculation (Vanderhaegen, 2016b). Selective or sustained attention can be maintained by using several means. However, controversies exist on some of these means (Vanderhaegen & Jimenez, 2018). For instance, dieting or fasting can improve vigilance (Fond et al., 2013), chewing a stick of gum can increase attention, vigilance and performance (Smith, 2010; Onyper et al., 2011), listening to music can improve concentration and performance (Mori et al., 2014; Chtouroua et al., 2015), and using a dedicated decision support system can lead to improving performance and to decreasing workload (Stanton & Young, 2005). An auditory alarm generated by a beep seems to be more efficient in terms of safety than an alarm activated by a sound with positive or negative emotional connotations (Stasi et al., 2010). Human performance can differ when operators use means of interaction that can involve different senses such as hearing or sight (Sanderson et al., 2004). Other studies demonstrated that there is no significant impact of noise or of music on human performance (Dalton & Behm, 2007) or that silence through mindfulness can increase attention in particular during human disorder recovery conditions (Prince-Paul & Kelley, 2017). Moreover, the use of a decision support system can lead to dissonances such as affordances, contradictions or interferences that can affect system safety (Vanderhaegen, 2017) and to an increasing of hypovigilance, human response time or safety risk (Dufour, 2014). Neuropsychological studies generally require sensitive technical sensors, physically connected to the brain, in order to assess the neural activities related to cognitive processes such as perception or problem-solving. From an engineering viewpoint, these cognitive processes are usually assessed by using technical support systems such as eye trackers or facial recognition systems. Eye trackers can be used to study visual attention or workload by analyzing indicators such as eyelid closure percentage, blink frequency, fixation duration, saccades, pupil diameter, saccade number, scan rate, or gaze direction (Galluscio & Fjelde, 1993; Rosch, & Vogel-Walcutt, 2013). For instance, they are useful to study relations between task demands and pupil diameter. Indeed, the increasing of the pupil diameter has been correlated with the increasing of the demands of the tasks to be performed. Thus, the higher the cognitive load, the more the pupils tend to dilate (Beatty, 1982). Similarly, the difficulty of a problem to be treated causes an increase in pupil diameter. However, it has recently been shown that this hypothesis is true when it concerns cognitive requirements but that an increasing of physical demands reduces this diameter (Fletcher et al., 2017). In addition, this hypothesis is confronted with various problems such as the variation of ambient luminosity, the consumption of drugs, or the emergence of strong emotions. Similarly, facial recognition systems cannot detect emotional dissonances, i.e. conflict between expressed emotions and felt emotions. Another example concerns the study of eye blinks: their frequency reduces when workload increases (Fogarty & Stern, 1989; Benedetto et al., 2011) but it increases when a secondary task is required (Tsai et al., 2007; Recarte et al., 2008). Eye-trackers are a useful means to analyze foveal vision or overt attention rather than peripheral vision or covert attention. Indeed, for instance, when a subject looks at a given point on a scene, the analysis of the corresponding eye movement supposes that the attention focuses on this point, i.e. overt attention, whereas attention can also focus on other points without any eye movement, i.e., covert attention (Findley, 2003). Variations in heartbeat are usually linked to a variation in the level of workload, stress or emotion (Tealman et al., 2009; Geisler et al., 2010; Pizziol et al., 2011; Hidalgo-Muñoz et al., 2018). As humans do not hear their heartbeats at rest, except after physical exercise, high stress or strong emotion, a new hypothesis consists in considering that perceptive ability can be impacted by synchronization between dynamic events and heart rate. A recent study demonstrated that when human subjects are facing flashing alarms correlated with their heart rate, the solicitation of their insula decreases, and their abilities to detect alarms correctly are degraded (Salomon et al., 2016). The insula is the part of the brain dedicated to human perception abilities and human consciousness.

The proposed non-conscious erroneous control study focuses on the study of this new scientific hypothesis, Figure 1: synchronization between dynamic events as visual and auditory alarms with heart rate may impact human perception process, and may affect unconsciously the control of dynamic events in terms of application of skills or possibility to act. It uses non-intrusive means such as a connected watch to generate alarm occurrences related the heartbeat and an eye-tracker to record eye activities on the alarm occurrence area during the experiment duration. Events to be controlled occur on a same touchscreen and a push button has to be activated when people perceive specific alarms that occur synchronously or asynchronously with a heartbeat. The controlled process displays dynamic events on the touchscreen and presents different levels of difficulty to study the impact of task difficulty on the availability of human resources of the combination of two variables, i.e. the workload due to the difficulty of the tasks and the attention related to the synchronous or asynchronous alarms with heartbeats.

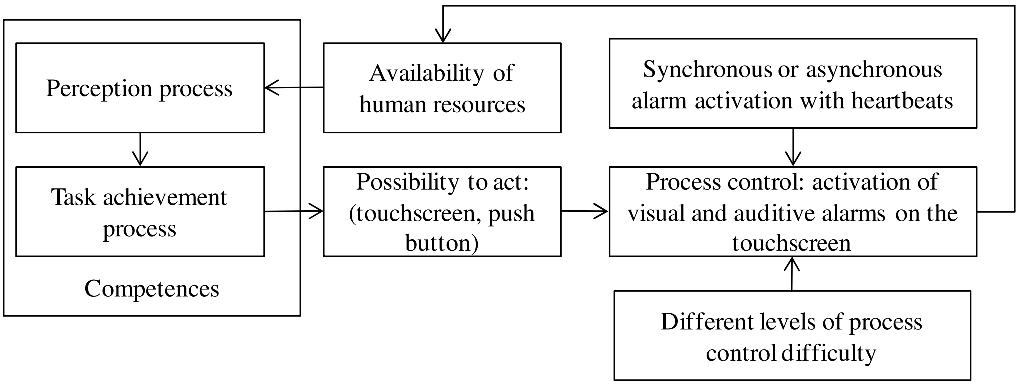


Figure 1. Study of non-conscious errors in control based on process difficulty and synchronization of alarms with heartbeats.

A methodology for studying this hypothesis is then proposed by taking into account subjective feelings on workload and emotion, and other quantitative data. To achieve the conceptual goals of the study, this methodology aims 1) to make the attention of the subjects focused on primary or secondary tasks; 2) to activate alarms at unexpected times; 3) to generate the occurrence of the alarms by synchronizing or desynchronizing them with heartbeats; 4) to increase the level of difficulty; and 5) to record qualitative and quantitative data during the experiments.

3. Study of non-conscious errors in the control of dynamic events synchronized with heart rates

This study was based on the application of the methodology presented on Figure 2.

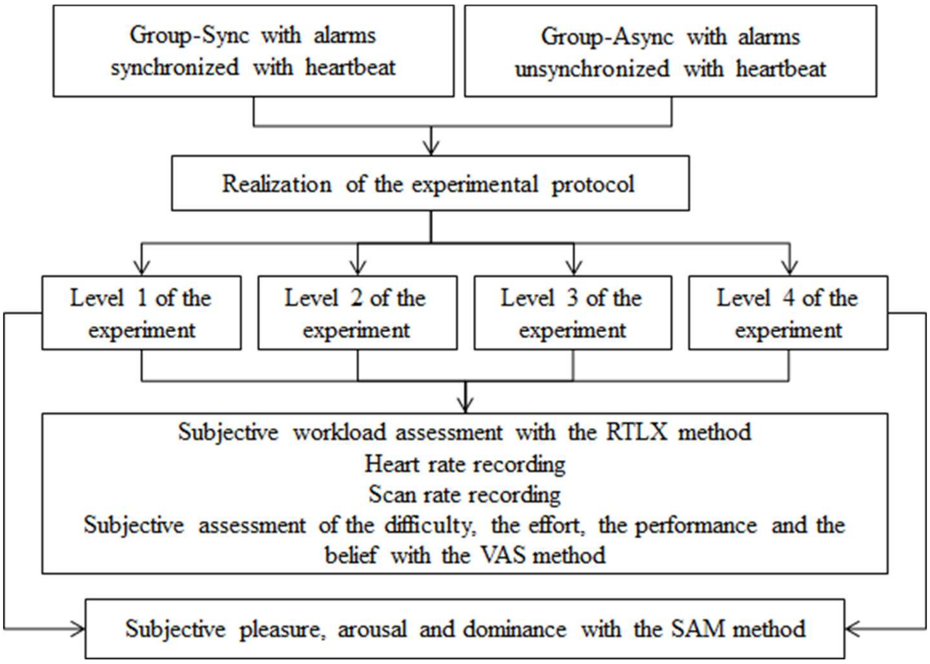


Figure 2. Methodology to study non-conscious errors in control of dynamic events synchronized with heartbeat.

The first step of the proposed methodology consisted in defining two groups of subjects: a group for which alarms were activated synchronously with the current heart rate of the subjects (i.e., Group-Sync), and a group for which the alarms were activated without being synchronized with the current heart rates of the subjects (i.e., Group-Async). The experimental protocol included four experiments of increasing difficulty, see Figure 3.

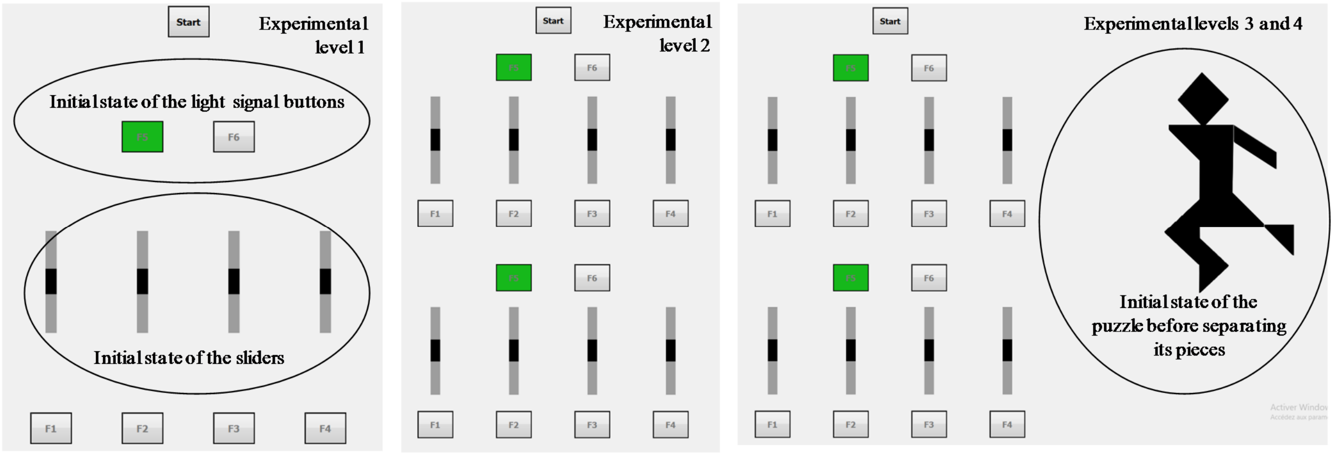


Figure 3. The four experimental levels of the methodology.

The tasks involve controlling light signal buttons and cursor drifts, and activating a push button when alarms occur. These alarms are synchronized or unsynchronized with the heartbeat of the participants of Group-Sync or Group-Async, respectively. The subjects have to control four cursors and two light signal buttons during the 180 seconds of the experimental level 1 that implemented eleven tasks to be realized. The other experimental levels took 360 seconds to perform 34 tasks related to the control of eight cursors and four signals.

The cursors moved vertically. When one of these sliders reached the extremity (i.e. low level or high level), the participants had to press the touchscreen on the corresponding function key (i.e., F1, F2, F3, F4) to return the process to its initial state. If the subjects took more than 5 seconds to react when the slider reached an extremity, they were warned by an auditory signal and the process returned to its initial state automatically. Regarding light signal buttons, one or two buttons were initially switched on (i.e., buttons with green background color) and the others were switched off (i.e., buttons with white background). When one of the buttons changed its state (i.e., the background changes), the subjects had to press the corresponding function key (i.e., F5 or F6) to make the process return to its initial state.

During the last two levels, the workload increased by implementing a secondary task: solving a Tangram puzzle (Chinese puzzle comprising 7 pieces). The movement speed of the puzzle pieces was greater during experimental level 4. The subjects had to rebuild it as it was by touching and moving the pieces using the touch screen. At the same time, they had to continue to control the sliders, light signal buttons and alarms.

In addition, visual and auditory alarms appeared during each experimental level: six alarms for experimental levels 1 and 8 for the other levels, see Figure 4. The visual alarm corresponded to the display of two flashing squares (3cm x 3cm each) accompanied by simultaneous auditory alarms. When the subjects detected them, they had to activate a push button. The alarms disappeared after 10 seconds. False alarm-type reactions and omissions related to this push button activation could thus be assessed.

During the four levels of the experimental protocol, the participants were wearing a Mio™ watch and a Tobii™ eye-tracker is used. The Mio™ watch aimed to capture the heartbeats "live" and to activate the alarms for Group-Sync and Group-Async subsequently. The data from the Tobii™ eye-tracker aim to identify and assess the scan rate of the alarm areas. The next steps of the proposed methodology involved recording several types of data. These were quantitative performance assessment measures related to omissions or false detection of alarms, heart rate recording and subjective data. The subjective Raw Task Load indeX (RTLX) and the Visual Analogue Scale (VAS) methods were applied after each experimental level. The RTLX method, that is an adaptation of the Task Load index method (Hart & Staveland, 1988), aimed to assess a global workload by combining six parameters: mental demand, physical demand, temporal pressure, performance, effort and frustration (Byers et al., 1989). For each parameter, a scale from 0 to 100 was proposed to the subjects who had to indicate their feeling. The average of the selected values gives a global workload level. The VAS method proposes different subjective scales from 0 to 100 to assess different factors (Crichton, 2001): the perceived difficulty of the performed task (i.e., 0 means very easy and 100 very difficult), the provided effort to realize it (i.e. 0 means no effort and 100 very great effort), the performance (i.e., 0 means very low and 100 very high), and the belief about the integrity of previous subjective evaluation (i.e., 0 means low level of belief and 100 high level of belief). After the experimental levels 1 and 4, the Self-Assessment-Manikin (SAM) method is applied to assess emotions such as pleasure, arousal and dominance by using pictures (Bradley & Lang, 1994). For each emotion, a scale is presented to the subjects who have to select one pictogram upon 9 pictures, noted from 0 (i.e., low level of emotion) to 9 (i.e., high level of emotion).

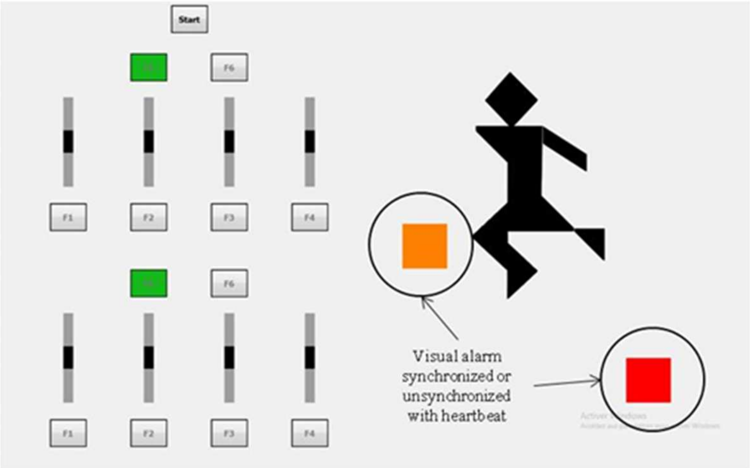


Figure 4. Example of the activation of visual alarms to be detected.

This methodology was applied in Biarritz in France. Group-Sync was composed by 15 subjects and Group-Async by 12 subjects. Results of the experiments are developed hereafter. Two kinds of analysis, an ANOVA analysis and a Fisher-Snedecor test (i.e., an F test) are proposed to study the impact of the experimental conditions for each group and each experimental level. Figures 5 to 10 of results display average values with confidence intervals at 95%.

4. Results

4.1. Workload, heartbeats, scan rates and human errors

Figure 5 gives the results obtained by the RTLX method. It shows that there was a difference of 2.50 points on the global mental workload between Group-Async (Average: 51.10, Standard Deviation: 3.60) and Group-Sync (Average: 48.56, Standard Deviation: 3.19). On the other hand, for all the subjects, the increase in workload evaluation between the different experimental levels (i.e. from Level 1 to Level 4) is significant (*F* (3,78) = 54.58, *p* < .001).

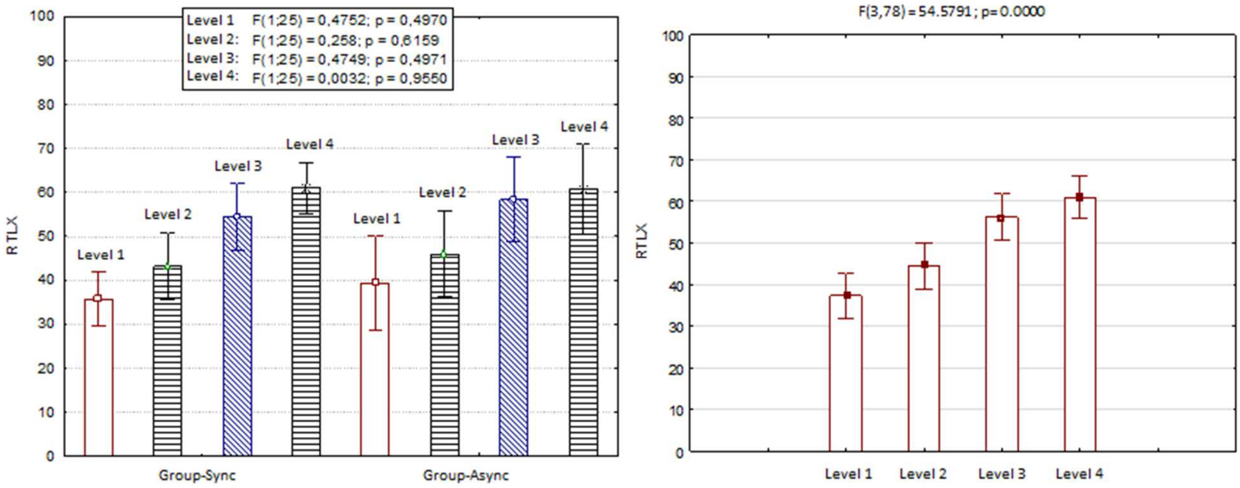


Figure 5. Impacts on global workload with RTLX (Left picture: Differences between groups at each level; Right picture: Differences between levels).

Related to the global workload, results on heartbeat data confirmed that the experimental protocol was valid from the point of view of the increase of mental workload, Figure 6. The heart rate is expressed in beats per minute (bpm). Even if Group-Sync (Average = 84.77 bpm, Standard Deviation = 18.83) has an average heart rate slightly greater than Group-Async (Average = 82.93 bpm, 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* = .0002).

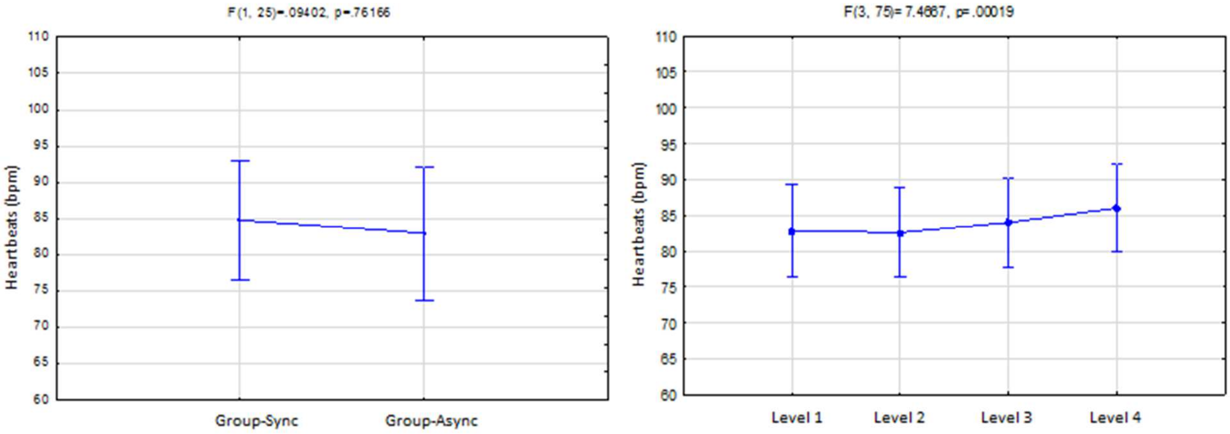


Figure 6. Impacts on heartbeats (Left picture: Differences between groups; Right picture: Differences between levels).

Whatever the experimental condition, the scan rate of the alarm zone decreased gradually according to the level of mental load, Figure 7.

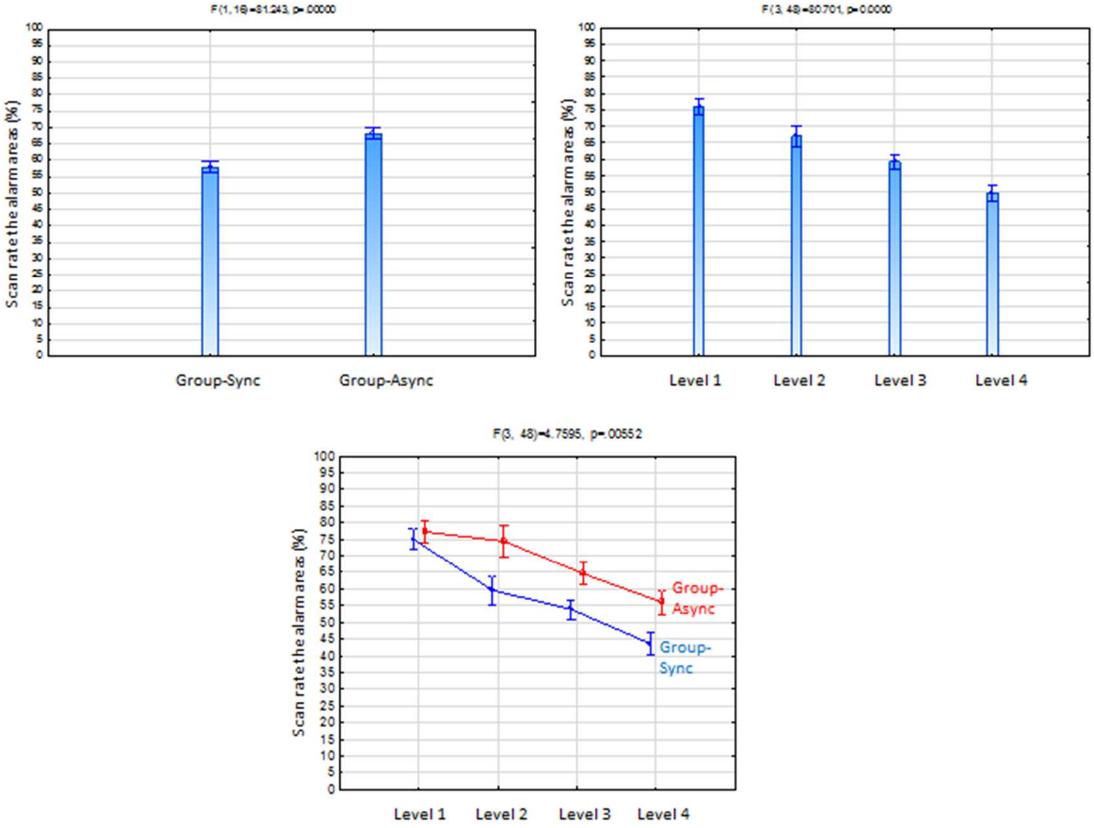


Figure 7. Scan rate of alarm areas (Top left picture: Differences between groups; Top right picture: Differences between levels; Bottom picture: Differences between levels for each group).

The higher the mental workload, the less the subjects tended to look towards the area where the alarms were 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 tended significantly to look less at the alarm areas than subjects from the asynchronous condition. This observation increased regarding the workload level of the experimental condition.

Human errors concerned mainly errors of omission when the alarms appeared, see Figure 8. Their statistical analysis indicates that subjects of Group-Async make about 13.30% of errors of omission (Standard Deviation = 8.53) whereas subjects of Group-Sync produce about 23.11% of errors of omission (Standard Deviation = 9.14). The Fisher-Snedecor test showed that this difference between Group-Sync and Group-Async was significant (*F* (1,25) = 8.15, *p* = .008). The impact of the experimental levels on human error occurrence was also significant (*F* (3,75) = 7.23, *p* = .0002).

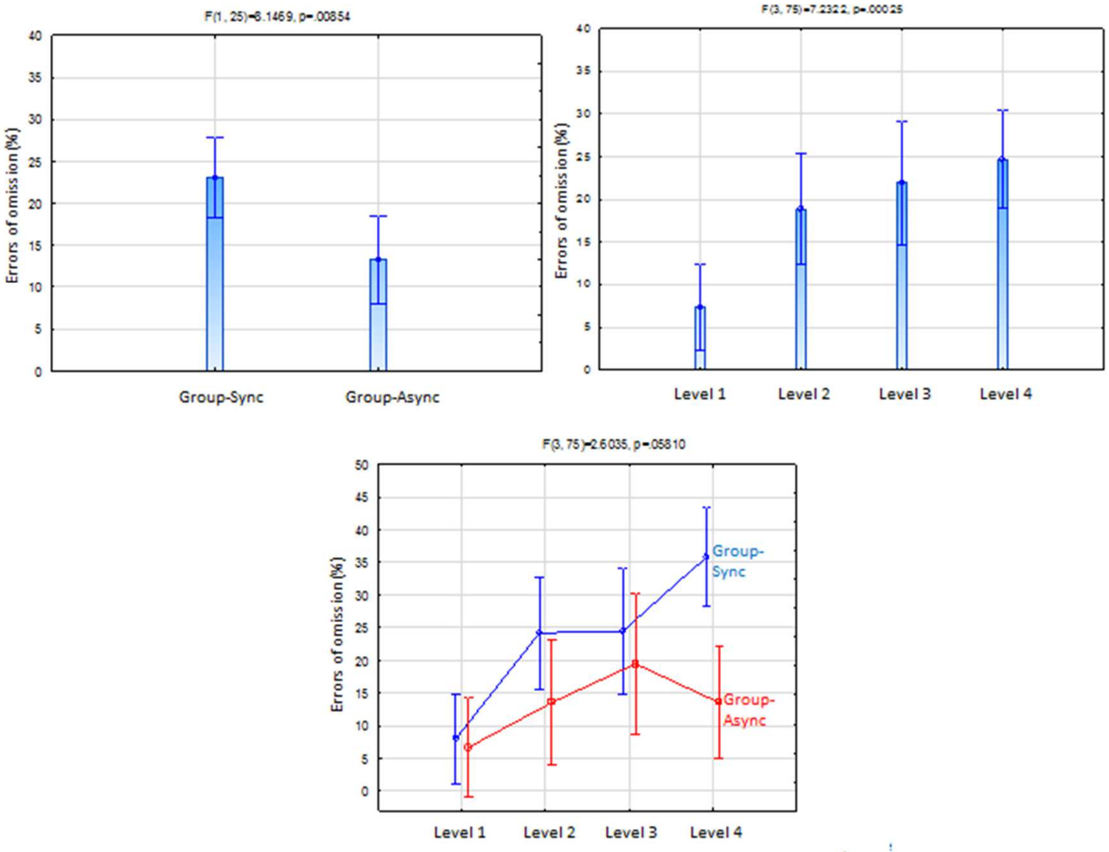


Figure 8. Impacts on errors of omission (Top left picture: Differences between groups; Top right picture: Differences between levels; Bottom picture: Differences between levels for each group).

4.2. *VAS and SAM results*

Regarding the VAS results, the statistical analysis indicated that differences between Group-Sync and Group-Async were not relevant in terms of difficulty, effort and belief scores. On the other hand, it was relevant for the performance parameter at the levels 2, 3 and 4. The subjects from Group-Sync considered their performances as worse than those of Group-Async, see Figure 9. The variation of the evaluation of the performance was very different between Group-Sync and Group-Async. Indeed, concerning the Group-Sync, a high performance evaluation for level 1 was observed, and it decreases for level 2 and level 3, but increased for level 4. Concerning Group-Async, the evaluation remained relatively homogeneous from one level to another. Thus, the subjects did not seem to be aware of the real evolution of their performance in terms of the occurrence of errors of omission.

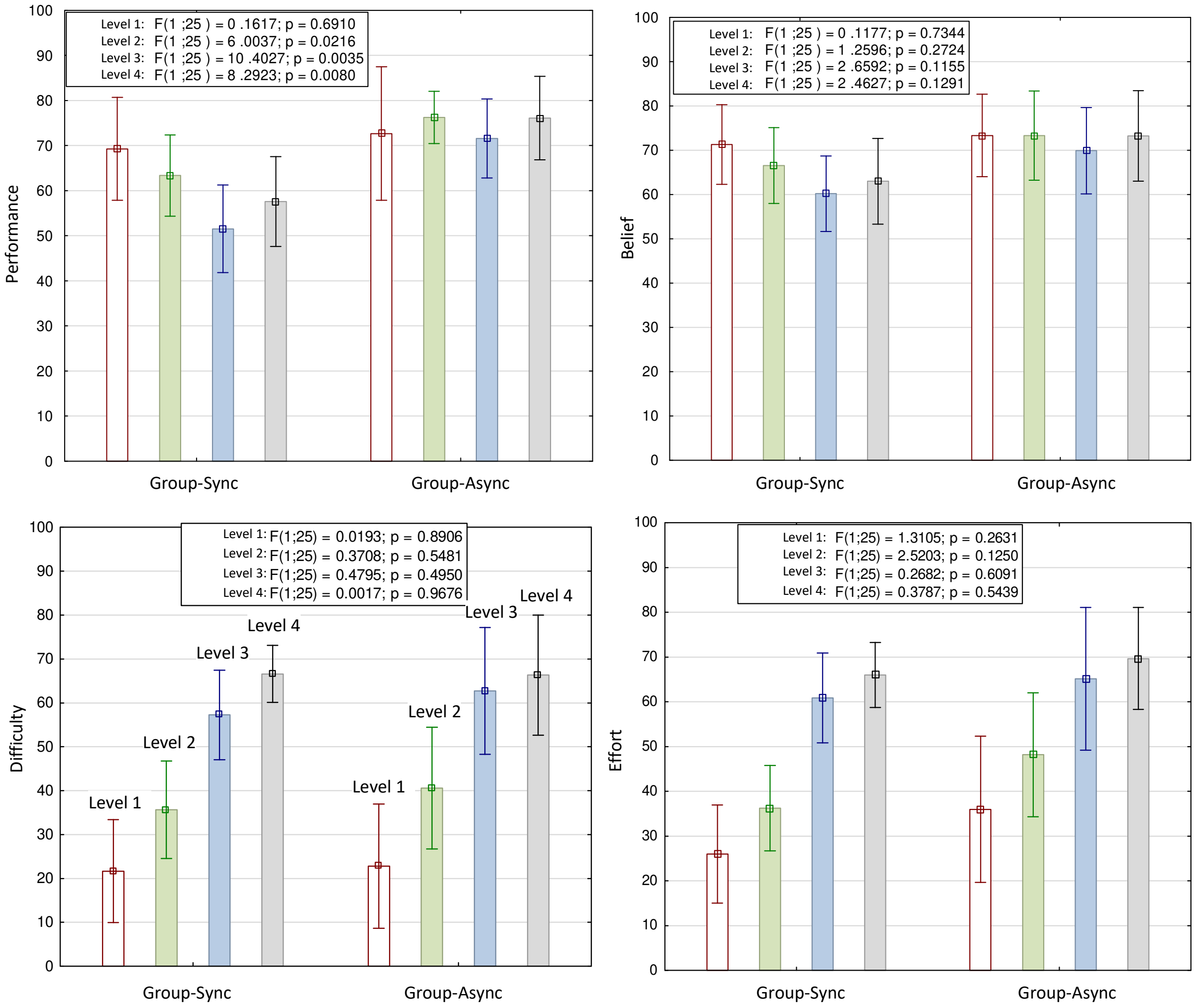


Figure 9. The VAS results and differences between levels for each group (Top left picture: Performance score; Top right picture: Belief score; Bottom left picture: Difficulty score; Bottom right picture: Effort score).

Based on the SAM results, there was no significant difference between Group-Sync and Group-Async for all the assessed parameters, see Figure 10. However, at a descriptive level, the evaluation of the pleasure parameter at the end of the experiment was slightly lower for the subjects of Group-Sync (6.50 points for Level 1 versus 6.20 points for Level 4), whereas it was the opposite for the subjects of Group-Async (6.50 points for Level 1 versus 7.00 points for Level 4). Regarding the impact of the experimental levels, there is no relevant effect for the pleasure parameter, but there is an increasing of the evaluation of the arousal and dominance parameters, between the beginning and the end of the experiment, whatever the group of subjects and the effects were significant ($F(1,26) = 12.55$, $p = .002$ and $F(1,26) = 9.50$: $p = .005$ respectively). Therefore, here again, despite the increase in the occurrence of human error from Level 1 to Level 4 shown on Figure 8, the subjects felt that they were more in control and felt more vigilant during experimental level 4 than experimental level 1. They are not really conscious about their real performance level and the illusion of control or of attention described on section 2.1 appears.

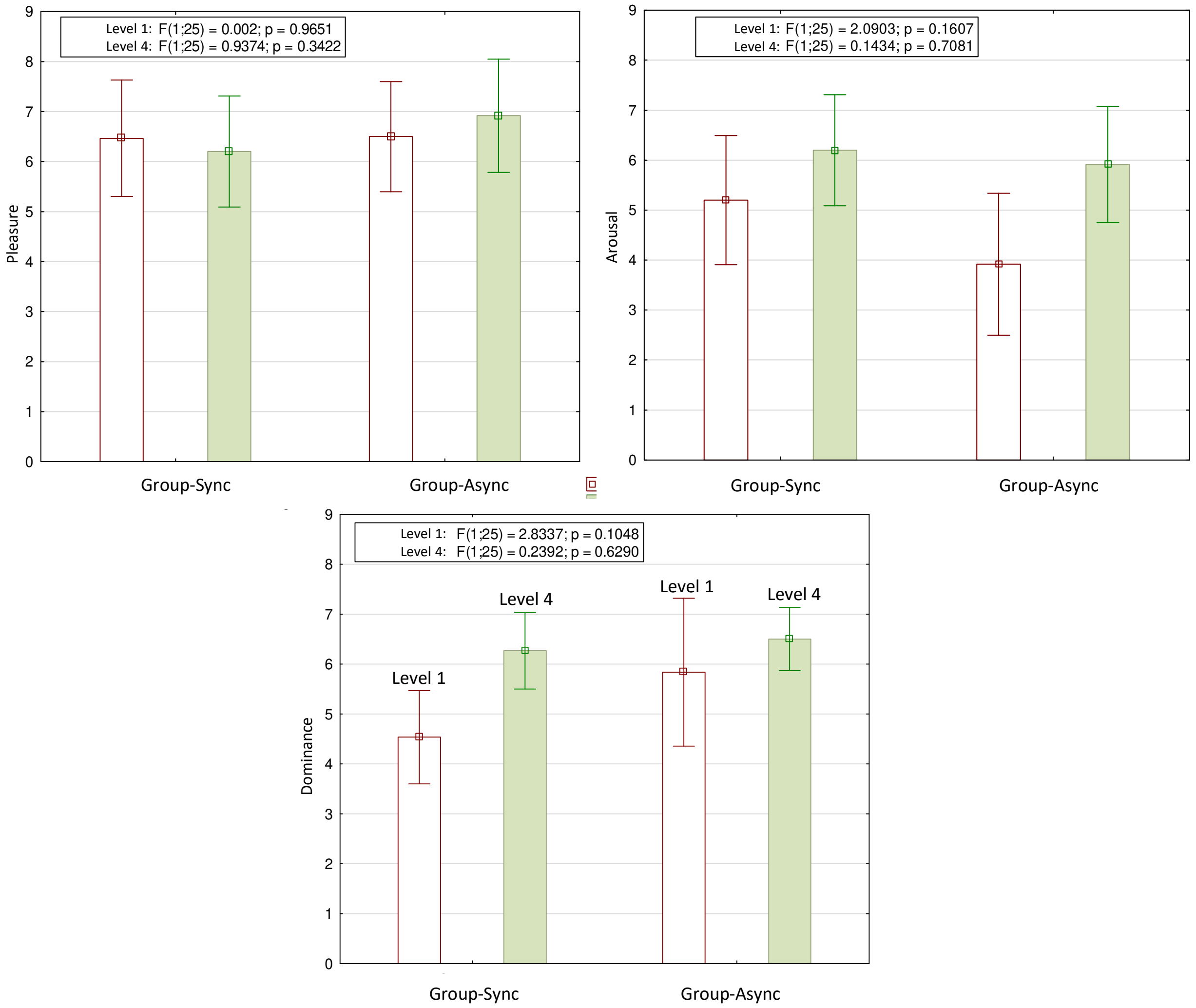


Figure 10. The SAM results on experimental levels 1 and 4 for each group ((Top left picture: Pleasure score; Top right picture: Arousal score; Bottom picture: Dominance score).

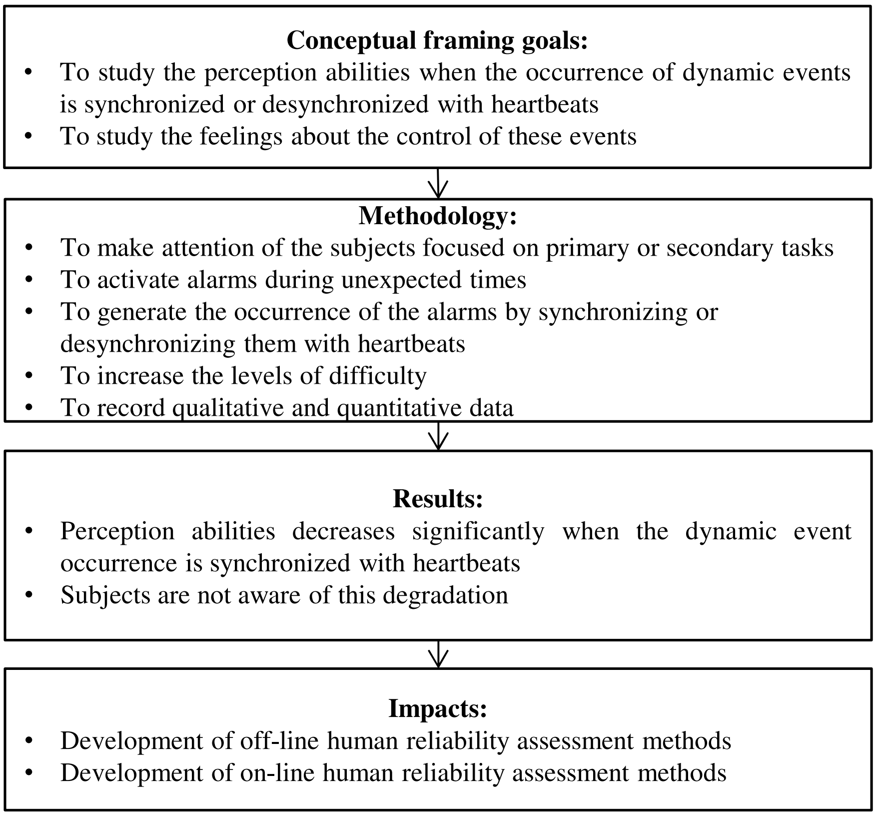
Conclusion

“It is only with the heart that one can see rightly; what is essential is invisible to the eye”, Saint-Exupéry, The Little Prince, 1943.

This paper focused on such a metaphor related to real ability to perceive dynamic situations in particular physiological conditions. While heartbeat is usually a measure used to make correlations between heart rate variation with stress, workload or emotion, it offered a means to study the synchronization between dynamic events with heartbeats and its impact on non-conscious errors in control.

The conceptual framework was based on the study of perception abilities when the occurrence of dynamic events is synchronized or desynchronized with heartbeats and on the study of the feelings about the control of these events (Figure 11). To achieve these goals, a methodology was proposed and involved an experimental protocol to make the attention of the subjects focused on primary or secondary tasks, to activate alarms at unexpected times, to generate of the alarms by synchronizing or desynchronizing them with heartbeats, to increase the levels of difficulty, and to record qualitative and quantitative data. Several hypotheses were validated. The first one concerns the unconscious reduction of the ability to detect unexpected dynamic events such as alarms when the attention is focused on primary or secondary tasks. The second one relates to the increased degradation of this perception ability when alarms occur synchronously with heartbeats.

To do so, two experimental groups of subjects were defined: one for which the activation of alarms was synchronized with the heartbeats of the subjects (i.e., Group-Sync) and one for which it was not (i.e., Group-Async). Each subject performed four experiments from Level 1 to Level 4 with increased difficulty of achievement, and Levels 3 and 4 included a secondary task. Levels 1 and 2 required mainly selective or focused attention to achieve primary tasks whereas Levels 3 and 4 involved the sharing of attention between primary and secondary tasks. Quantitative and subjective data were recorded during the four experimental steps. Results related to scan rate, heartbeats and workload showed that overt attention is affected by the increasing of the difficulty of the tasks to be carried out. Then, the less the participants scanned the alarm areas, the less they perceived them. However, comparisons between groups of participants showed that the participants of the Group-Sync did significantly more errors than the participants of Group-Async at each experimental level. Moreover, they felt they controlled better and felt more vigilant during the last experiment than the first one. Globally, there was no significant difference in results from participants in Group-Sync and those in Group-Async in terms of subjective workload assessment and heartbeat acceleration. When comparing the Level 1 or 2 with Level 3 or 4 of the experimental protocol, for each group of participants, subjective workload, the heartbeat and the human error rate increased, and the scan rate of alarm areas decreased. This confirmed the increased difficulty of the achievement of the experiments from Level 1 to Level 4. On the other hand, human error rate of participants from Group-Sync was greater than the rate of those of Group-Async. Similarly, the scan rate of alarm areas during the experiment duration was less good for participants of Group-Sync than the rate of those of Group-Async. Despite the increasing of human errors, participants felt they performed their tasks quite well. Both groups of participants were not really aware of their real level of performance in terms of human error or of their real capacity to control dynamic situations. Indeed, the subjective assessments of factors such as performance, arousal or dominance of the Level 3 or 4 of the experiment are globally superior to those of the Level 1 or 2. As a matter of fact, the synchronization between alarm activation with the heartbeat has a negative impact on focused and distributed attention. The experimental protocol did not take into account the sustainable attention because the duration of the experimental levels were quite short and there were no available data to distinguish overt attention from covert attention. Future research may then analyze the impact of other factors such as priority, commitment or memory on human attention during the achievement of simultaneous or serial tasks, for both short-term and long-term dynamic event control processes



Conceptual framing goals:

- To study the perception abilities when the occurrence of dynamic events is synchronized or desynchronized with heartbeats
- To study the feelings about the control of these events

Methodology:

- To make attention of the subjects focused on primary or secondary tasks
- To activate alarms during unexpected times
- To generate the occurrence of the alarms by synchronizing or desynchronizing them with heartbeats
- To increase the levels of difficulty
- To record qualitative and quantitative data

Results:

- Perception abilities decreases significantly when the dynamic event occurrence is synchronized with heartbeats
- Subjects are not aware of this degradation

Impacts:

- Development of off-line human reliability assessment methods
- Development of on-line human reliability assessment methods

Figure 11. Conceptual framing and results of the study about heartbeat impact on perception.

The experimental protocol described here was exploratory but showed that what people are supposed to see is not always what they have in mind. Future extended studies on cognitive blindness related to hidden dissonance, inattentional blindness or change blindness for instance are worth being developed in order to control the risks associated to the synchronization between dynamic events with heartbeats and to propose new on-line or off-line human reliability assessment methods. Off-line methods should assess the risk associated to the synchronization between dynamic events with heartbeats. The impact of synchronization should be integrated into the list of Performance Shaping Factors that are usually used in probabilistic assessment methods. On-line approaches will consist in defining support tools based on the detection of this synchronization and its associated risks in order to adapt the human-machine interaction. The design of future human-machine system may adapt interactions between decision makers regarding between-subjects and within-subjects variability of factors such as heart rate. The study of such factors is promising because they facilitate the occurrence of non-conscious errors in control when humans who seem to be not subject to any external or internal disturbances do not perceive nor react to explicit solicitations that occur in front of them. Hence, one of the main powerful impacts of this study is the design of future digital systems of alarms by taking benefits of heartbeats in terms of human reliability factor.

To do so, several medium-term objectives have to be developed to specify a future theoretical model of non-conscious errors in control focusing on the impact of the human resource availability control on competence application or the possibilities to act. The human resource availability control will depend on the focused or distributed attention when people have to control dynamic event on a single screen or on several screens respectively. The first medium-term objective is adaptating the exploratory study presented on this paper to centralized and decentralized process control environment integrating primary and secondary tasks, as shown in Figure 12.

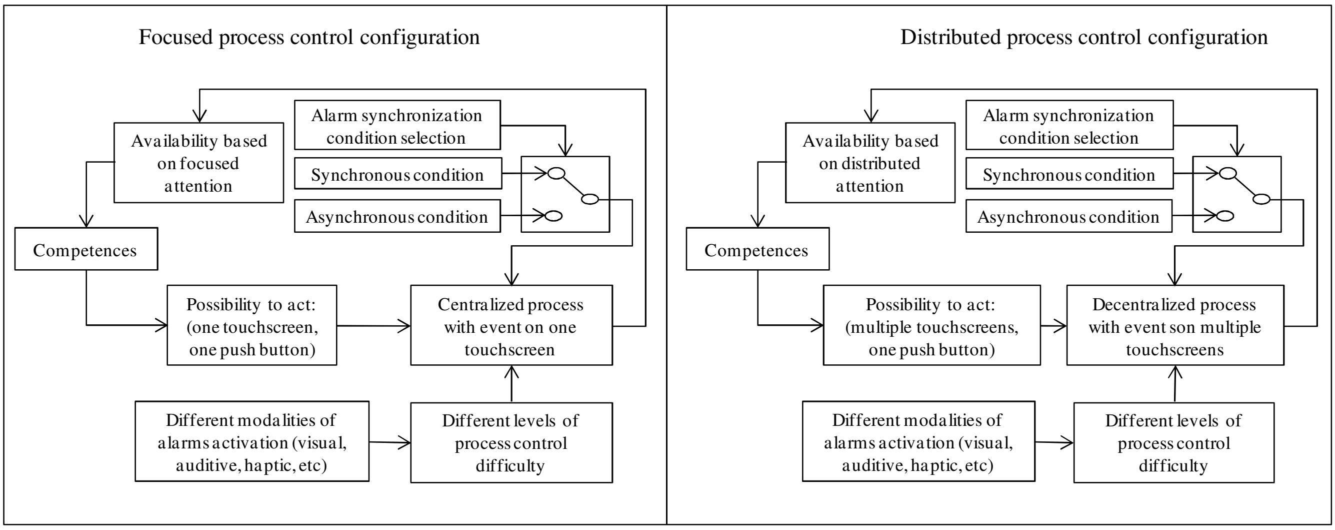


Figure 12. Toward a non-conscious error model in the control of dynamic events for focused and distributed configurations.

Both focused and distributed configurations will aim to help perform similar experimental protocols and verifying the repeatability of the results. It concerns also the study of different modalities of alarm occurrence and transmission synchronously or asynchronously with heartbeats. The second medium-term objective is the feasibility of the design of means to control alarm systems by preventing or recovering the consequences of perception of alarms when they occur synchronously with heartbeats. These means can be based on learning approaches to learn from the impact of workload and alarm occurrence on perception. The third medium-term purpose of future research will consist in integrating a new performance shaping factor related to relationships between heartbeats and non-conscious errors in control on prospective, retrospective or cognitive approaches for human reliability analysis. It will concern for instance the assessment of the probability of human error by taking into account the synchronization of event occurrence synchronously or asynchronously with heartbeats and by combining it with a workload level.

Similarly to eye-blink based feedback systems that alert drivers when they get tired, future heart rate based attention monitoring systems could not only be able to supervise health indicators but also detect unconscious activity and warn drivers accordingly. Another application domain concerns the shared control between humans and machines and the definition of the degree of automation. As events that are repeated synchronously with heart rates may be not perceived or may increase the human response time, automated tools can take in charge some driving tasks during such conditions. Heartbeat based attention monitoring systems can also be used to facilitate the driver perception ability by adapting the interaction modes with regard to the actual driver's behaviors. Another example concerns the analysis of incidents or accidents due to errors of omissions. Causes of humans errors have to be studied and the analysis of industrial alarm systems or of other dynamic interaction supports might make a focus on possible presence of synchronization between event occurrence frequencies with workers' heart rates.

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References

Aguirre, F., Sallak, M., Vanderhaegen, F., Berdjag, D. (2013). An evidential network approach to support uncertain multiviewpoint abductive reasoning. Information Sciences, 253, 110-125.

Ballard, J. C. (1996). Computerized assessment of sustained attention: a review of factors affecting vigilance performance", Journal of Clinical and Experimental Neuropsychology, 18(6), 843-863.

Baraldi, P., Podofillini, L., Mkrtchyan, L., Zio, E., Dang, V. N. (2015). Comparing the treatment of uncertainty in Bayesian networks and fuzzy expert systems used for a human reliability analysis application. Reliability Engineering & System Safety, 138, 176-193.

Beatty, J. (1982). Task-evoked pupillary responses, processing load, and the structure of processing resources. Psychological Bulletin, 91(2), 276-292.

Benedetto, S., Pedrotti, M., Minin, L., Baccino, T., Re, A., Montanari, R. (2011). Driver workload and eye blink duration. Transportation Research Part F: Traffic Psychology and Behaviour, 14(3), 199-208.

Bevilacqua, M., Ciarapica, F. E. (2018). Human factor risk management in the process industry: A case study. Reliability Engineering & System Safety, 169, 149-159.

Bradley, M. M., Lang, P. J. (1994). Measuring emotion: the Self-Assessment Manikin and the semantic differential. Journal Behaviour Therapy and experimental Psychiatry, 25(1), 49-59.

Burns, K., Bonaceto, C. (2018). An empirically benchmarked human reliability analysis of general aviation. Reliability Engineering & System Safety, in press, https://doi.org/10.1016/j.ress.2018.07.028.

Byers, J. C., Bittner, A. C. Jr., Hill, S. G. (1989). Traditional and raw task load index (TLX) correlations: are paired comparisons necessary? In A. Mital (Ed.), Advances in Industrial Ergonomics and Safety, London: Taylor & Francis, pp. 481-485.

Cacciabue, P.-C. (2004). Human error risk management for engineering systems: a methodology for design, safety assessment, accident investigation and training. Reliability Engineering & System Safety, 83(2), 229-240.

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

Chen, J., Wang, R. Q., Lin, Z., Guo, X. (2018). Measuring the cognitive loads of construction safety sign designs during selective and sustained attention. Safety Science, 105, 9-21.

Cherry, E. C. (1953). Some experiments on the recognition of speech, with one and two ears. Journal of the Acoustic Society of America, 25, 975-979.

Chouchou, F., Mauguière, F., Vallayer, O., Catenoix, H., Isnard, J., Montavont, A., Jung, J. Pichot, V., Rheims, S., Mazzola, L (2019). How the insula speaks to the heart: Cardiac responses to insular stimulation in humans. Human Brain Mapping, 40(9):2611-2622.

Chtouroua, H., Briki, W., Aloui, A., Driss, T., Souissi, N., Chaouachi, A. (2015). Relationship between music and sport performance: Toward a complex and dynamical perspective", Science & Sports, 30, 119-125.

Corrigan, S., Zon, G. D. R., Maij, A., McDonald, N., Mårtensson, L. (2015). An approach to collaborative learning and the serious game development. Cognition, Technology & Work, 17(2), 269–278.

Crichton, N. (2001). Visual analogue scale (VAS). Journal of Clinical Nursing, 10 (5), 697-706.

Dalton, B. H., Behm, D. G. (2007). Effects of noise and music on human and task performance: A systematic review. Occupational Ergonomics, 7, 143-152.

De Waard D (1996) The measurement of drivers' mental workload. PhD thesis, University of Groningen. Haren, The Netherlands: University of Groningen, Traffic Research Centre.

De Waard D (1996) The measurement of drivers' mental workload. PhD thesis, University of Groningen. Haren, The Netherlands: University of Groningen, Traffic Research Centre, The Netherlands.

De Winter, J. C. F., Eisma, Y. B., Cabrall, C. D. D., Hancock, P. A., Stanton, N. A. (2018). Situation awareness based on eye movements in relation to the task environment. Cognition Technology & Work, in press, https://doi.org/10.1007/s10111-018-0527-6.

Dehais, F, Causse, M, Vachon, F, Tremblay, S. (2012). Cognitive conflict in human-automation interactions: a psychophysiological study. Applied Ergonomics, 43, 3, 588-595.

Dekker, S. W. A. (2017). The danger of losing situation awareness. Cognition Technology & Work, 17(2), 159–161.

Di Stasi, L. L., Contreras, D., Cañas, J.J., Cándido, A., Maldonado, A., Catena, A. (2010). The consequences of unexpected emotional sounds on driving behaviour in risky situations. Safety Science, 48, 10, 1463-1468.

DiDomenico, A., Nussbaum, M. A. (2005). Interactive effects of mental and postural demands on subjective assessment of mental workload and postural stability. Safety Science, 43(7), 485-495.

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, 2014.

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

Festinger, L. (1957). A theory of cognitive dissonance. Stanford, CA: Stanford University Press.

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.

Fletcher, K., Neal, A., Yeo, G. (2017). The effect of motor task precision on pupil diameter. Applied Ergonomics 65, 309-315.

Fogarty, C., & Stern, J. A. (1989). Eye movements and blinks: Their relationship to higher cognitive processes. International Journal of Psychophysiology, 8(1), 35-42.

Fond, G., MacGregor, A., Leboyer, M., Michalsen, A. (2013). Fasting in mood disorders: neurobiology and effectiveness. A review of the literature. Psychiatry Research, 209(3), 253-258.

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.

Gertman, D. I. (1993). Representing cognitive activities and errors in HRA trees. Reliability Engineering & System Safety, 39(1), 25-34.

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.

Hickling, E. M., Bowie, J. E. (2013). Applicability of human reliability assessment methods to human–computer interfaces. Cognition Technology & Work, 15(1), 19–27.

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.

Hollnagel, E. (1998). Cognitive Reliability and Error Analysis Method CREAM. Elsevier, Amsterdam, The Netherlands

Hollnagel, E. (2000). Looking for errors of omission and commission or The Hunting of the Snark revisited. Reliability Engineering & Safety System, 68(2):135-145.

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

Jones, D. G., Endley, M. R. (1996). Sources of situation awareness errors in aviation. Aviation, Space and Environmental Medecine, 67(8), 508-512.

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

Kahai, S. S., Solieri, S. A., Felo, A. J. (1998). Active involvement, familiarity, framing, and the illusion of control during decision support system use. Decision Support Systems, 23(2), 133-148.

Kahneman, D. (1973). Attention and effort. London: Prentices Hall.

Kervern, G.-Y. (1995). Eléments fondamentaux des cindyniques (Fondamental elements of cindynics), Economica Editions, Paris.

Kirwan, B. (1997). Validation of human reliability assessment techniques: Part 1 — Validation issues. Safety Science, 27(1), 25-41.

Kottemann, J. E., Davis, F. D., Remus W. E. (1994). Computer-assisted decision making: performance, beliefs, and the illusion of control. Organizational Behavior and Human Decision Processes, 57(1), 26-37

Kubota, R., Kiyokawa, K., Arazoe, M., Ito, H., Iijima, Y., Matsushima, H., Shimokawa, H. (2001). Analysis of Organisation-Committed Human Error by Extended CREAM. Cognition Technology & Work, 3(2), 67–81.

Li, P., Zhang, L., Dai, L., Zou, Y., Li, X. (2018). An assessment method of operator's situation awareness reliability based on fuzzy logic-AHP. Safety Science, in press, https://doi.org/10.1016/j.ssci.2018.08.007.

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

Mackworth, N. H. (1961). Researches on the measurement of human performance. In H. W. Sinaiko (Ed.), Selected papers on human factors in the design and use of control systems (pp. 174–331). New York: Dover. (Reprinted from Medical Research Council Special Report Series 268, 1950, London: His Majesty's Stationery Office).

Mori, F. Naghsh, F. A., Tezuka, T. (2014). The effect of music on the level of mental concentration and its temporal change. Proceedings of the 6th International Conference on Computer Supported Education - Volume 1, Pages 34-42, Barcelona, Spain — April 01 - 03, 2014.

Naderpour, M., Lu, J., Zhang, G. (2016). A safety-critical decision support system evaluation using situation awareness and workload measures. Reliability Engineering & System Safety,, 150, 147-159.

Oken, B. S., Salinsky, M. C., Elsas, S. M. (2006). Vigilance, alertness, or sustained attention: physiological basis and measurement. Clinical Neurophysiology, 117, 1885–1901.

Onyper, S. V., Carr, T. L., Farrar, J. S. and Floyd, B. R. (2011). Cognitive advantages of chewing gum. Now you see them, now you don't. Appatite, 57, 321-328.

Ouedraogo, A., Enjalbert, S., Vanderhaegen, F. (2013). How to learn from the resilience of Human–Machine Systems? Engineering Applications of Artificial Intelligence, 26(1), 24-34.

Petruni, A., Giagloglou, E., Douglas, E., Geng, J., Leva, M. C., Demichela, M. (2017). Applying Analytic Hierarchy Process (AHP) to choose a human factors technique: Choosing the suitable Human Reliability Analysis technique for the automotive industry. Safety Science, in press, https://doi.org/10.1016/j.ssci.2017.05.007.

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.

Polet, P., Vanderhaegen, F., Zieba, S. (2012). Iterative learning control based tools to learn from human error. Engineering Applications of Artificial Intelligence, 25, 7, 1515-1522.

Prince-Paul, M., Kelley, C. (2017). Mindful communication: being present. Seminars in Oncology Nursing, 33(5), 475-482.

Qiu, S., Rachedi, N., Sallak, M., Vanderhaegen, F. (2017). A quantitative model for the risk evaluation of driver-ADAS systems under uncertainty. Reliability Engineering & Safety System, 167, 184-191.

Rangra, S., Sallak, M., Schön, W., Vanderhaegen, F. (2017). A graphical model based on performance shaping factors for assessing human reliability. IEEE Transactions on Reliability, 66(4), 1120-1143.

Reason J. (1990). Human Error. Cambridge University Press, Cambridge, UK.

Recarte, M. A., Pérez, E., Conchillo, Á., Nunes, L. M. (2008). Mental workload and visual impairment: Differences between pupil, blink, and subjective rating. The Spanish Journal of Psychology, 11(2), 374-385.

Rognin, L., Blanquart, J.-P. (2001). Human communication, mutual awareness and system dependability. Lessons learnt from air-traffic control field studies. Reliability Engineering & System Safety, 71(3), 327-336.

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., Faivre, N., Schallere, K., Blanke, O. (2018). Insula mediates heartbeat related effects on visual consciousness. Cortex, 101, 87-95.

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.

Samima, S., Sarma, S., Samanta, D., Prasad, G. (2019). Estimation and quantification of vigilance using ERPs and eye blink rate with a fuzzy model-based approach. Cognition Technology & Work, 21(3), 517–533.

Sanderson, P., Crawford, J., Savill, A., Watson, M., Russell, W. J. (2004). Visual and auditory attention in patient monitoring: a formative analysis. Cognition, Technology & Work, 6(3), 172–185.

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

Smith, A. (2010). Effects of chewing gum on cognitive function, mood and physiology in stressed and non-stressed voclunteers. Nutritional Neuroscience, 13(1),7-16.

Srinivasan, N., Srivastava, P., Lohani, M., Baijal, S. (2009). Focused and distributed attention. Progress in Brain Research, 176, 87-100.

Stanton, N. A., Young, M. S. (2005). Driver behaviour with adaptive cruise control. Ergonomics, 48(10), 1294-1313.

Stanton, N. A.; Chambers, P. R. G. & Piggott, J. (2001) Situational awareness and safety. Safety Science, 39, 189-204.

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.

Torretta, V., Radaa, E. C., Schiavon, M., Viotti, P. (2017). Decision support systems for assessing risks involved in transporting hazardous materials: A review. Safety Science, 92, 1-9.

Tsai, Y. F., Viirre, E., Strychacz, C., Chase, B., Jung, T. P. (2007). Task performance and eye activity: predicting behavior relating to cognitive workload. Aviation, Space, and Environmental Medicine, 78, 176-185

Vanderhaegen, F. (1997). Multilevel organization design: the case of the air traffic control. Control Engineering Practice, 5, 3, 391-399.

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

Vanderhaegen, F. (2001). A non-probabilistic prospective and retrospective human reliability analysis method – application to railway system. Reliability Engineering and System Safety, 71, 1-13.

Vanderhaegen, F. (2010). Human-error-based design of barriers and analysis of their uses. Cognition Technology & Work, 12, 133-142.

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

Vanderhaegen, F. (2016b). Mirror effect based learning systems to predict human errors - Application to the air traffic control. Proceedings of the 13th IFAC/IFIP/IFORS/IEA symposium on Analysis, Design, and Evaluation of Human-

Machine Systems, Kyoto, Japan, pp. 295–300.

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., 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, 14-18 May, 2018.

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

Vanderhaegen, F., Zieba, S., Enjalbert, S., Polet, P. (2011). A Benefit/Cost/Deficit (BCD) model for learning from human errors. Reliability Engineering & System Safety, 96, 7, 757-766.

Weiner, E. L., Curry, R. E., Faustina, M. L. (1984). Vigilance and task load: in search of the inverted U. Human factors, 1984, 26(2), 215-222.

Weyer, J., Fink, R. D., Adelt, F. (2015). Human–machine cooperation in smart cars. An empirical investigation of the loss-of-control thesis. Safety Science, 72, 199-208.

Yang, C.-W., Yenn, T.-C., Lin, C. J. (2010). Assessing team workload under automation based on a subjective performance measure. Safety Science, 48(7), 914-920.

Zhang, Z., Polet, P., Vanderhaegen, F. and Millot, P. (2004). Artificial neural network for violation analysis. Reliability Engineering and System Safety, vol. 84, n°1, pp. 3-18.

Zhao, M., Liu, X. (2018). Development of decision support tool for optimizing urban emergency rescue facility locations to improve humanitarian logistics management. Safety Science, 102, 110-117.