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Towards a Not Obtrusive Low Cost Biosystem to Assess Risk Perception in Workplace Through Stress Detection

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Abstract. The main aim of the article is to build a method to assess risk perception in real time in order to early detect and prevent risk behaviors and possible human errors. To this end, the relation between mental workload and stress as critical factors affecting risk perception has been investigated. In particular the mental-physical activation generated by an increment of the workload has the effect of reducing the resources needed to perceive risk increasing the worker vulnerability. The complexity of the stress phenomenon suggested the adoption of an integrated view. The Functional Model has been adopted to for its holistic perspective (body-mind integration) and for the capability of being operationalized with physiological computing. In fact, limits of the current self reporting and subjective assessment methods prevent the possibility to have timely information to take decison. Finally a preliminary overview of how to implement a low cost not obtrusive biosystem to detect stress and assess in real time risk perception is presented.

Keywords: mental workload**,** stress**,** functional model, risk perception, biometric data, open hardware

1 Introduction

Conventional risk management approaches focus on physical conditions and work processes, often overlooking the integral 'people element'. In fact, individuals have different perceptions of the work environment, the tasks at hand, their skills and capabilities. Based on such perceptions, they take decisions on how they are going to behave. At both statistical level and in terms of the seriousness of the consequences, there is a distinct contribution of the human in the dynamics of accidents. Estimates concur in attributing to human errors 60-80% of accidents [1] and only the rest is due to technical failings. Therefore, in order to ensure effective prevention of harmful events, the risk assessment process needs to address the fundamental understanding of risk-related judgments and to identify the factors contributing to perceived risks.

The risk is perceived as "*the risk we envisage, which results from how we assess the likelihood of a particular type of accident happening to us and how concerned we are with such an accident*"[2].

Each worker has the capability to perceive hazards that help them to manage dangerous situations, sometimes results in near-miss accidents [34]. The classic psychological theories suggest people's decision on risk-taking behavior is negatively correlated with their risk perception [31]. Thus, individuals who are weak in risk perception or tend to misestimate the risks are vulnerable to safety hazards. For example, has been found that 74% of accident victims had believed they were running no risk [40]. Therefore, if the risk perception ability of workers can be monitored in real time, the vulnerable individual could be timely identified and appropriate countermeasures can be applied [34].

In projects as INSULA [11] promoted by the INAIL (Istituto Italiano per la sicurezza contro gli infortuni sul lavoro) more then 8000 employees and 1000 employers was interviewed covering the most part of the work sectors to investigate the worker risk judgment and the relationship between workers perceived risks and the factors related to the nature of risks. The period of interview last 6 months (June-Dec. 2013) while the final report has been published in June 2014, thus after one year. Even if this kind of project are useful to gain an wider overview of the issues at hand, their result are not immediate available for timely decisions in a operational scenario. Extensive surveys require time and the costs for data collection and processing. Moreover the self-reporting method presents several biases. In fact employees tends to answer to the questions according to the social expectation instead of revealing their usual behavior or attitudes. According to psychological theories of attribution there is a general tendency for people to attribute their own behavior to external causes, but to see other people's behavior as internally caused [6].
Moreover, as presented in [8] despite being widely accepted, self-report by recall, for instance, has an intrinsic problem; because of biases (e.g. mood states), people are not able to accurately recall past experience, in particular those experiences that are frequent, mundane, or irregular [12]. On the other hand it is not possible to derive an evaluation of risk perception using only tools like NASA-TLX [30] that are currently used for assessing mental work load given a specific task or the DSSQ (Dundee Stress State Questionnaire). In fact, even if there is a positive correlation between mental workload and risk perception, it is not possible to identify or infer the individual risk perception level during the execution of a given task.

The article is organized as follow: in section 2 the relation between mental workload, risk perception and stress is discussed; in section 3 the Functional Model and its relevance for risk perception assessment is presented; section 4 introduce an overview of a generic portable biosystem to support real time risk perception assessment; conclusions are reported in section 5.

2. Mental workload, stress and risk perception

Usually, there was no escalating accident process, because the accident appeared without warning and was not perceived until the injury was felt or observed. This can be compared to the larger organizational accidents, which were described as appearing “out of the blue”[1]. Several factors mainly related to individual and the context [4][24] could impact people’s risk perception ability and the mental workload is one of the most important. In psychological research, mental workload has been proved as one of the best indicator of people perceptional ability [32][33], especially for people involved in complex tasks [34]. Workload is usually defined in terms of “processing resources” where processing resources are demanded by a task to the extent that the performance of a second. Independent task performed concurrently deteriorates from its single task level; and changes in the objective characteristics of a task will vary the processing resources demanded by its performance at a constant level [33].

Thus when task demands, increase, the central nervous system increases the supply of resources necessary to perform the task [26]. Thus when a person dedicates too much attentional resources, he/she has less resources to focus on other stimuli failing to identify them. This could result in the inattentional blindness phenomenon [25].

Hence, accidents could happen because of the operator fails to detect the risk, being so absorbed with the work at the time [7]. In fact, according to [26][28] each individual exhibits a limited capacity in information processing because of the mental activities share the same resources.

Moreover the way in which human limits on information processing is manifested is task dependent. For instance, has reported in [27], the automatic processing induced by the driving task should be more observed for experienced drivers than for the novice ones in simple and monotonous situations. Conversely, in complex situations, the controlled processing induced by the strategies and maneuvers should be more observed for novice drivers than for the experienced ones. Thus the same driving situation requires a lower mental workload for experienced drivers than for novice drivers. According to [36] seems that young novice drivers have a risk of accident 2-4 times higher than experienced drivers. As stated in [27], an explanation could be identified in the subjective safety model [37] that reveals that the strategies of adaptation are setup as a function of the situation characteristics (context) and of the drivers (individual). They particularly depend on the degree of precision in the perception of the situation complexity, of the task demands and of the cognitive capacities [37].

Another critical aspect that affects the capability to perceive risk is the stress. Stress is usually defined as a feeling of strain and pressure [16] but can be defined also as a mental and physical reaction of the organism to external events (stressor)with adaptation. According to [33], stress is not intrinsically related to the multiple task environments as the mental workload. In fact, in relation to dual task performance, stress will normally increase with the imposition of additional tasks, and with increases in their workload. On the other hand, objective changes in task difficulty, not necessarily reduces performance, even if they may produce higher levels of stress. Such an absence of effect can result from the well known ability of the operator to compensate the increased demand by increased mobilization of resources in order to maintain constant performance (adaptation)[33]. Hence when such capacity to compensate fails, accidents and injuries may happen.

This evidence might explain why trained employees that are aware about the safety roles are affected or involved in unexpected accidents and injuries on job site.

In [3] stress is also seen as a moderator, affecting safety behavior negatively. This is substantially confirmed in [38] where is shown that the negative affect and the state of stress might have a meaningful impact on risk perception. Moreover, in [2] is reported that risk perception and behavior are related through stress. Findings presented in [5] show that people in the alert stage had less risk perception and the results obtained in [41] reveal that acute stress impairs the intention-based attentional allocation and enhances the stimulus-driven selection, leading to a strong distractibility during attentional information selection.

It is valuable to notice also that stress is not negative *per se*. In fact it represents an adaptation, a defense, against certain environmental stimuli (eustress); but if such an activation becomes chronic, this reaction becomes dysfunctional respect to environmental requirements and potentially harmful to the body (distress).
Thus to better understand the factors affecting the capacity of perceive risks it is necessary to consider mental workload as well as both eustress and distress in the analysis. The critical point is to determinate when and to what extend the organism adaptation capacity is no longer able to cope with the stressor. Waiting to detect the visible effects as the performance degradation might be not acceptable, in particular for high velocity tasks as piloting an F-1 vehicle or the intensive mental workload tasks as the medical surgery. Thus it is necessary to identify a method for the early detection and warning to allow a timely reaction and prevention.

To this end, this article is to identify a theoretical framework able to adopt an integrated perspective considering all the factors in place while at the same time to support its operationalization with the use of biometric sensors. Some integrated approaches that adopt an integrated view of the human, are emerging (e.g. like Psiconeuroendocrinoimmonology- PNEI). Among them the Functional Model represents a promising and comprehensive approach capable to explain the organism dynamics and to estimate the response capacity.

3. The Functional Model approach

The first important consideration that should be done related to the stress phenomenon, is that it involves many human operation's elements. One of these is the vegetative autonomic nervous system. In fact it is one of the regulators of the entire body and it controls many other psychosomatic systems. Emotions are equally important in the stress as regards the relationship with the self and the outside world and have a close connection with the apparatus of neurotransmitters, which play a fundamental role in the stress phenomena. In fact neurotransmitters implicated in stress are also numerous: the CRF, ACTH, serotonin, cortisol, norepinephrine; there is a GABA circuit; and so forth. Even receptors are numerous and spread throughout the body (not only in brain): the spinal cord, brainstem, cerebellum, with obvious connections to the limbic areas and cortical areas (emotions and rationality). Thus stress cannot be approached from neurochemical, emotional, autonomic or muscles

perspective separately. Instead it should be analysed considering all these components at the same time through an holistic view.
The Functional Model [9][10] (FM) is an holistic model elaborated in the context of Functional Psychology that aims at measuring the psycho-body functions along all their complex interactions. A person is considered as a integrated entity composed by 5 interdependent and fully connected systems (see Figure **1**): central and peripheral nervous system, neurovegetative system, endocrine and immune systems, sensorimotor and perceptive-expressive systems and emotion-thoughts.

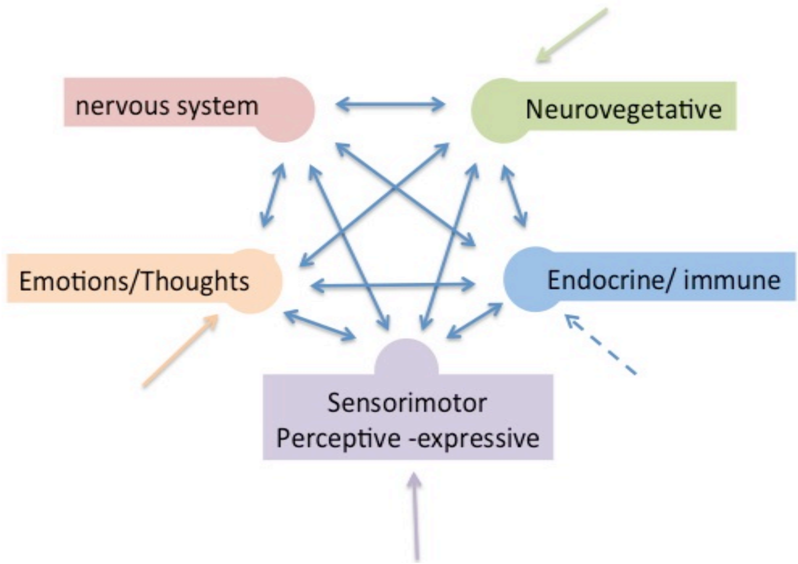

Figure 1 Integrated system

Such integrated system is organized in a number of functions called Basic Experiences of Self (BES). BES are organized in four classes:

- Cognitive (rationality, memories, fantasies...),
- Emotional (feelings, emotions, motivations....),
- Physiological (internal body Systems and Internal body mechanisms...),
- Postural-Muscular (movements, body-shape, postures...).

Each EBS are referred to the entire person (mind-body) and are defined as those experiences which are fundamental for a person to maintain its integrity, health and well-being. Currently, the model identifies 22 BES (e.g. Calm, Contact, Control, Negativity, Autonomy, Consistency, Vitality, Creativity, Love, Sensation, etc.). Each BES refers to the entire organism, and its alteration has effects on the all 5 sub-systems. All the 22 BES compose the Perceptual Functional Filter (PFF) (see Figure 2). The PFF represents the way in which the individual as a whole (mind-body) addresses the stressful event activating emotions, cognitive status, the status of the symbolic function, etc.; but also with his breathing, muscle condition, postural condition, the physiological condition, that is connected to the vegetative and biological hormone and neurotransmitter circuit. Through all of them, stressor can be perceived as manageable or unmanageable, as an ordinary or dramatic event.

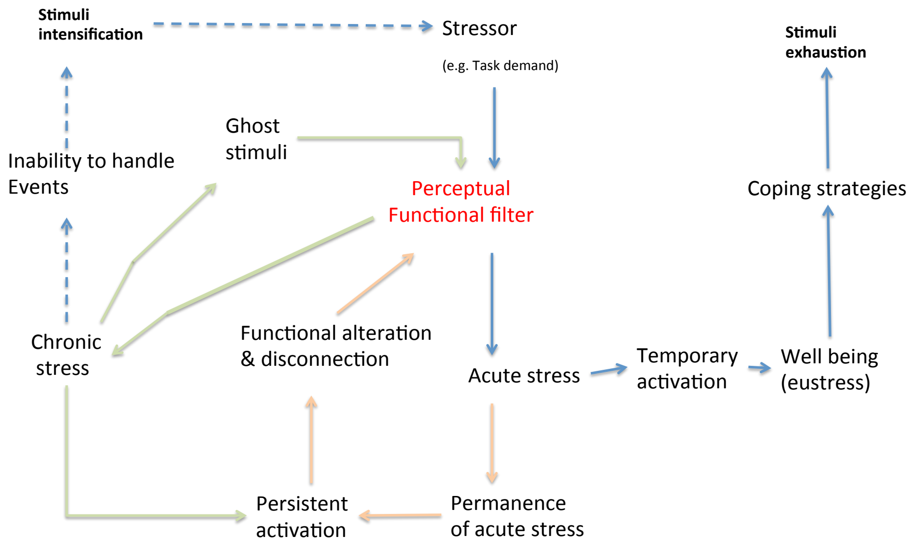

Figure 2 Cronich Stress - Wellbeing flow

If the PFF works properly, the stress is managed as acute stress resulting into a temporary activation of the organism and a consequent efficient allocation of the resources needed to perform a task without performance degradation and/or a reduction of the capacity of perceiving the risk. However if the stressor persists for a long time, the organism is no longer able to bounce back to the normal state (deactivation). Such a permanent activation alters the PFF normal functionalities. A PFF altered means that a number of BES involved in the stressor response result altered and that all the stressors received, even if related to normal events, are experienced as alarming, dangerous, highly stressful. Thus stressful events effects are not exhausted but remain in the organism beyond the event as ghost stimuli as well as permanent activation. This is what is so called chronic stress where stressed organism cannot cope with stressful events even they are mild in intensity. The permanence of such mind-body activation prevents the release of the engaged resources used to respond to the pervious stressor demand.

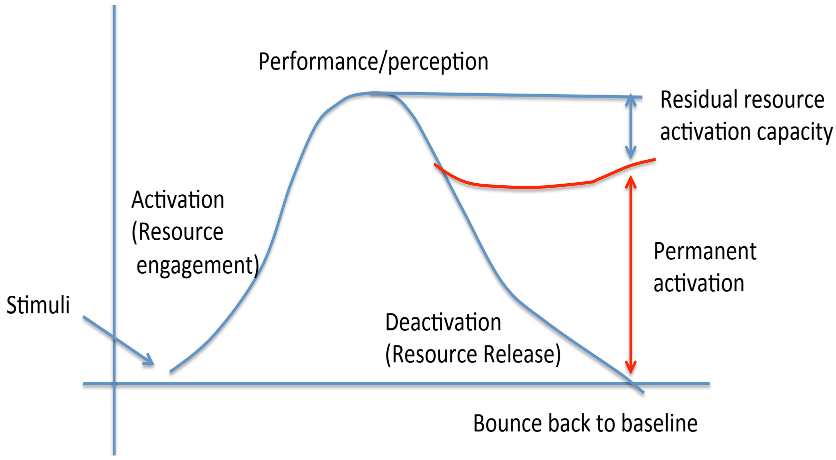

Figure 3 Activation - Deactivation curve

Thus, since the resource to cope with a stressful event are limited, a person affected by a chronic stress will not be able to perceive risk because of the lack of the personal resources availability needed for a proper risk perception at the moment they are required (see Figure 3).
The person affected by chronic stress exhibits a deep disorder at BES levels, for instance:

- **Cognitive**: lack of planning imagination (difficulties in defining new strategies to cope with life's events), alteration about previous memories (success/failure), fixation on inability thoughts, control alteration, alteration about temporal perception ("time is never enough");
- **Muscular-Postural**: muscular stiffening that leads towards a difficulties to execute reactive movements, with ineffective use of the force and with an amplification of sensations about alarm and danger;
- **Physiological**: there are an altered breathing (no diaphragmatic one), chronic sympathetic system (increasing perspiration, tachycardia, insomnia, autonomic nervous system diseases...), increasing threshold of pain up to anesthesia and general sense of chronic fatigue;
- **Emotional**: the main emotions are imminent fear, regret, discouragement, discouragement and weakness feelings.

In FM the measure of psychological, physiological and biological level is "integrated". This means that a multidimensional assessment method is defined.
Up to now measurements are based only on selected stressful episodes evaluated with expert judgment inside the personal life whether or not an high chance for the person to be affected by stress exists. In the FM approach, five are the significant factors more related to stress and that are measured:
1. Psychological measure (tested with the MPS);
2. Behavioral variables (body attitudes and breathing);

3. Physiological variables (muscular tension, beat frequency and cortisol level);
4. Level of somatotropic hormone and cutaneous conductance;
5. Levels of prolactin and testosterone and marginal temperature.

In particular, the psychological factors are measured with the self-assessment Test MPS (Measure of Perceived Stress) [9] which evaluates six clusters: control loss/nervousness; psyco-physiological perceptions; awareness of mental effort/confusion; depressive anxiety; pains and physical diseases; hyperactivity/acceleration of behaviors. The Physiological variables (directly related to the operation of autonomic nervous system) considered are: breathing, heartbeat frequency, blood pressure, cutaneous conductance, electric potential of some muscular areas and secretion of salivary glands. About behaviors and body attitudes, all posture, movement and voice variables have been detected through observation and a research form. About neuroendocrine system, values of more stress-related hormones (cortisol, prolactin, somatotropic hormone and testosterone) are considered with laboratory tests. Currently the evidences/data supporting Functional Model are sensed through the Zed-X2 device[1]. This is an obtrusive hardware/software system which is able to perform a psycho-physiological evaluation and an objective stress baseline measurement but in a stress-frees setting. Unfortunately, it cannot be considered for a real time assessment during a task execution because of the portability issue and the kind of measurement performed that require in-lab analysis. Hence, it is necessary to identify a subset of metrics that can be measured with low cost and portable devices that can be used for both baseline assessment and real time assessment while maintaining the needed level of accuracy and sensibility.

4 Towards FM operationalization with a low cost biophysics system

The physical work environment is becoming more and more saturated with computing and communication devices that interact among themselves, as well as with users: virtually everything is enable to generate data and respond to appropriate stimuli (Internet of Everything-IoE). In this scenario, real-world components interact with the cyberspace via sensing, computing and communicating elements, thus moving towards what is called the *Cyber–Physical World* (CPW) convergence where humans are deeply immersed in the information flows from the physical to the cyber world, and vice-versa. In this article we use the physiological computing, a CPW related technology. We assume that the real time and naturalistic monitoring in a work setting will provide bias free and cost effective parameters enhancing and automating the risk perception assessment. Physiological computing can be defined as the field, within physical computing, that deals with the study and development of systems that sense and react to the human body [12].

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[1] http://www.benessereaziende.it/index.php?option=com_content&view=article&id=55&Itemid=64

A preliminary overview on how to implement such a biosystem is provided as a result of the assessment carried out in the SensiRISK project[2]. The validity of low cost sensors has been positively verified in [15]. The research concludes that a simple low cost heart rate monitor device can detect features that change significantly under the influence of mental stress. A number of other researches based on open hardware as BITalino [12] seem to be promising solutions thanks to its level of integration of the sensors with the mother board and the diversity of sensors available. In particular BITalino kit includes all the sensors needed to detect the physiological parameters foreseen by the FM. In Table **1** are reported the Bitalino sensors needed and the metrics to be assessed according to the FM.

Table 1 Sensor parameters and indicators

Bitalino Sensors Parameters	**Sensitivity**	**Indicators**
EMG electromyography	Stress	-
ECG electrocardiography	Stress	- Heartbeat Rate - Variability HR
EDA electrodermal activity	sudden rise after arousal occurrence [39]	- # of peak - sum of amplitude - sum of duration of peak in the time interval
EEG Electroencephalography	MWL and Stress[39] [29]	- Alpha wave variability
PZT Respiration 1.thoracic 2.abdominal	Stress	- average of Amplitude breathing - average of duration breathing - P1 pause of thoracic respiration - P2 pause of abdominal respiration S/D – ratio of time Inspiration and exhalation toracic T/D - ratio of time Inspiration and exhalation dyaframmatic diaphagmatic - Frequency of breath

Body behavior detection requires sensors able to implement at least six degree of freedom (DOF). According to [14], the motion characteristics of an object, such as a human subject, can be described by six independent variables: roll, pitch and yaw are rotational movements with respect to the three perpendicular directions. In order to accurately measure the motion characteristics of an object, a sensing system with six degree-of-freedom (DOF) sensing capability is required. Secondly the sensors need to acquire samples at the right rate: for instance the frequency range of human body motion is around 10 Hz [13]. In order to implement a body motion solution able to

[2] SensiRISK http://www.logos-ri.eu/2016/11/07/approvato-progetto-sensirisk/

track the expected variables has been selected the UDOO Go board with 9 axis[3] that integrate accelerometer, gyroscope and magnetometer. All the sensors should work in low energy mode to reduce the dimension of the battery installed on the wearable chips to achieve the expected level of intrusiveness (very low). An open challenge to complete the FM parameter sensing is represented by the cortisol measurement. Current methods for testing cortisol levels include the saliva test [17], the Fluorometric assay [18], Fluorescence Polarization [19] and Reverse Phase Chromatography [22]. These methods are, however, limited in sensitivity, time of analysis and cost [21][22]. None of these methods are rapid and portable thus the cortisol parameter cannot be detected in real time yet. Anyhow in [23] has been demonstrated the feasibility of using impedance based biosensor architecture for a disposable, wearable cortisol detector. This means that as soon as such a type of sensors become available at market level, could be possible to integrate them easily in the biosystem following the open hardware approach.

Once the sensors has been identified and integrated in the biosystem, all the signals should be synchronized and collected as a raw data. To collect data in a lab setting for the baseline analysis, it is sufficient a commercial laptop, while in a real workplace settings, a portable gateway like a smartphone is necessary. A smartphone has the computational capability and connectivity to manage wearable multiple sensors data collection, to apply pre-processing to clean and synch data streams and to transmit data to a central monitoring station. The monitoring station should be able to allocate computational resources on demand (e.g. if an anomaly is detected, a more tight control might be needed). A cloud based architecture respond to such requirement.
Finally, for each employee dynamic profiles should be computed. The monitoring station could be based on the Complex Event Processing (CEP) paradigm for real time event detection to analyze heterogeneous data streams generated by the human being (real time), the tasks under execution (static), the risk identified by the organization (static) as well as the status of the employee (FM baseline). Through the CEP approach it is possible to continuously evaluates the capability of the employee to handle stressor inferring risk perception capacity. According to adaptive rules defined to detect anomalies, actions can be timely triggered such as: a) suspending a task, b) reallocating tasks to other operator, c) allowing short work shift, d) providing salient signals through dedicated devices, e) balancing the arousal level to prevent damages/injuries just before it could be happened. A scenario to depict the risk perception monitoring system is provided.

Envisioning scenario in medical surgery

The solution proposed can be applied in medical surgery where the impact of a error might be fatal. The mental workload and stress can reach unsustainable level during the work because of the number as well as the difficulties of each intervention.

The pressure in terms of time and responsibility increases the magnitude of the stressor. Moreover, unexpected events like sudden drop of blood pressure may always happen and in such stressful situation the possibility to immediately recognize the causes might be prevented. Monitoring a surgeon during the operation task, has the

[3] http://www.udoo.org/download/files/datasheetsdatasheet_udoo_go.pdf

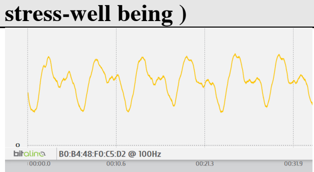
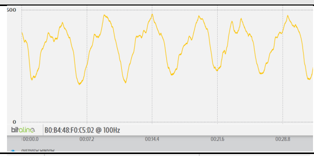
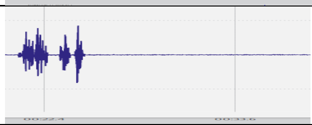
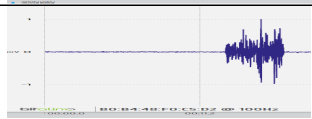
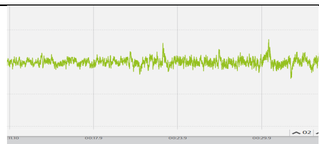
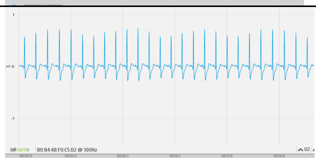
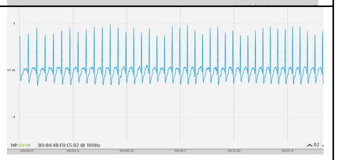
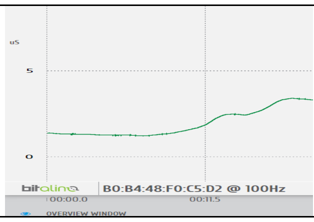
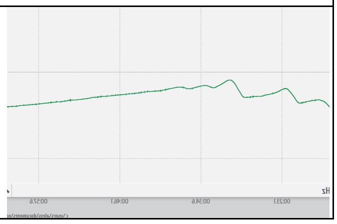
scope of preventing the error as soon as the targeted events (combination of signals) are detected by CEP. To set up the entire monitoring system it is necessary to define the baseline (chronic stress) of the surgeon in a stress-free in-vitro condition. Through this first assessment it is possible to know which is the current level of the permanent activation and the magnitude of the alteration of the BES involved. In chronic stress the BES affected are: Leave, Control, Calm, Well being, Vitality and it is characterized by:

- Peranent simaticotonia
- Thoracic Breath (in stead of diaphragmatic)
- Threshold of pain
- Negative images, fear
- High and chronic muscular tension

The chronic stress the main input comes from the emotion in terms of concerns and fear even if they are not related to the current situation. However the muscular tension represents another input that might not be related to the situation. Such a tension fuels the emotion/thoughts sub-system in such a way to generate simpaticotonia. Simpaticotonia is strictly related to the adrenaline release and cortisol that in case of real alarm is an expected reaction while in case of relaxed situation reveal the presence of permanent activation and thus chronic stress. All these aspects are evaluated through parameter detections and subjective observations. The result of the targeted surgeon reveals a relevant alteration of the Control BES while no alteration has been detected on the rest. According to the FM, such an assessment reveals a reduced capacity of concentration. Once the chronic stress has been evaluated, the result should be included in the model used to assess the current level of stress (chronic + eustress). The model is composed by a number of rules in CEP for signal based event detection. In this way, a low heartbeat frequency during the surgery activity, that not necessarily reflects the capacity of the operator to cope with the stress might be detected as an alteration of the Control BES. In fact if the operators exhibits an alteration in the Control BES, a low HR then expected in the situation may reflect a difficult of giving the right attention to the task as well. Thus it is necessary to consider the two measures at the same time. In Table **2** is reported an example of parameter detection using Bitalino at 100Hz, during the in vitro baseline assessment and during the in vivo task execution. It is possible to notice the sensitivity of the sensors in identifying the signals variability in the two assessment phases.

Thus as soon as the CEP according to the parameters collected, detects in real time possibile critical events (e.g. stressor magnitude over the coping capability of the surgeon), the monitoring system triggers immediately pre-defined actions. For instance an alert for a substitution or suspension can be provided without waiting the self notification of fatigue from the surgeon. In fact, as we discussed above, he may be not able to perceive the risk of its fatigue and control reduction because of the reduced resource availability.

Table 2 Physiological parameters example

	Baseline assessment (Chronic stress-well being)	**Real time tracking**
PZT		
EMG		
EEG		
ECG		
EDA		

Conclusions and next step

The capability to perceive risks in the workplaces during a specific task is related to a complex stock of resources mobilized by a person to cope with a task demand. In fact the mental workload and in particular its induced stress is a complex phenomena that needs to be analyzed through an holistic framework in order to take into the account all the psycho-physiological variables involved. The role of chronic stress needs to be highlighted and considered to gain a better understanding of the risk perception factors. In fact, the chronic stress level gives the measure of permanent activation of an person. As we explained above, the permanent activation of the individual affect also the capacity of processing information because of the mental resources are permanently engaged by a phantom stimuli. Consequently the resources needed to perceive risk are significantly reduced resulting in a intentional blindness. Moreover the PFF is affected and the intensity of the external stimuli may be perceived as unmanageable.

Moreover, to assess and monitor employee risk perception in real time, it is necessary to identify a) a theoretical model able to be operationalized, b) a portable, not obtrusive low cost technology to track the human dynamics at work.
In the article the Functional Model is introduced as a holistic approach able to manage mind-body complexity. Such model has been selected because of its comprehensiveness as well as its capability of being operationalized. In fact, FM has already defined an assessment protocol including number of biometric parameters to be measured. However, the FM assessment is foreseen only in a lab and/or in a stress-free settings. This configuration is needed to define the individual baseline against the chronic stress-well being scale, but to implement a continuous assessment in daily work activity, it is necessary to define a portable and cost effective biosystem. Bitalino and UDOO platform has been identified as the most promising solutions to realize such a tracking system.

Knowing and monitoring in real time the level of chronic stress as well as the mental workload of a specific task, may open a new frontier of the work safety tools..
In the articile has been introduced a generic cost-effective architecture for a biosystem able to sense various parameters and to timeply detct anomalies in real time. The ultimate goal is to recognize weak signals of possible risk perception issues before the evidence of the performance degradation. Where possible, would be also important to determine the extent to which subjective reports of stress correlate with physiological measures. Likewise, it is important to see whether subjective or physiological measures of stress responses are reliable predictors of performance [35]. The next step of the current research is to operationalize the entire Functional Model in a concrete trial in order to validate the conceptual and technical solution.

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