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Decision Making, Stress Assessed by Physiological Response and Virtual Reality Stimuli

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REVIEW ARTICLE

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Abstract

Many decisions must be made under stress; therefore, stress and decision-making are intrinsically related not only at the behavioral level but also at the neural level. Additionally, virtual reality tools have been proposed as a method to induce stress in the laboratory. This review focuses on answering the following research question: Does stress assessed by physiological variables of a subject under virtual reality stimuli increase the chances of error in decision-making? The reviewed studies were consulted in the following databases: PubMed, IEEE Xplore, and Science Direct. The analysis of the consulted literature indicates that the stress induced in the laboratory using virtual reality tools and the physiological response of the central and autonomous nervous system are complementary subjects and allow the design of training and support systems for the decision-making process.

***Keywords*:** decision Making, Physiological Response, Virtual Reality, Stress, Risk Taking.

Toma de Decisiones, Estrés Valorado mediante la Respuesta Fisiológica y Estímulos en Realidad Virtual

Resumen

Muchas decisiones deben tomarse bajo estrés, por lo tanto, el estrés y la toma de decisiones están intrínsecamente relacionados, no solo a nivel conductual sino también a nivel neural. Además, las herramientas de realidad virtual se han propuesto como un método para inducir estrés en el laboratorio. El presente trabajo de revisión temática se centra en responder la siguiente pregunta de investigación: ¿El estrés evaluado mediante variables fisiológicas de un sujeto bajo estímulos de realidad virtual aumenta las posibilidades de error en la toma de decisiones? Los estudios revisados fueron consultados en las siguientes bases de datos: PubMed, IEEE Xplore y Science Direct. El análisis de la literatura consultada indica que el estrés inducido en el laboratorio, por medio de herramientas de realidad virtual, y la respuesta fisiológica del sistema nervioso central y autónomo son temas que se complementan y permiten el diseño de sistemas de soporte y entrenamiento para el proceso de toma de decisiones.

Palabras clave: toma de decisiones, respuesta fisiológica, realidad virtual, estrés, toma de riesgos.

Many decisions are made by individuals in their daily activities, in different contexts and during high stress situations. In the military context, for example, the following scenarios can be considered: (a) decide when to shoot during a military infiltration action; (b) give an order loudly in a counter-ambush. It is probable that the execution of these actions also induces stress in the exposed person. Thus, Decision Making (DM) and stress are intimately related, and the influence of the latter is of special interest in the quality of a decision. These processes have been identified at the brain level, in specific areas of the brain and their associations are being studied in greater depth during the last decade. For instance, decisions under some degree of uncertainty are associated with the striatum, a brain region involved in feedback processing and reward (Watanabe, Bhanji, Ohira, & Delgado, 2019). It has also been reported brain regions involved in rational-analytical (prefrontal cortex) and emotional-intuitive (limbic and basal ganglia) decision making. The literature points to specific mechanisms in the DM process, among which the following stand out: strategic application, adjustment based on an automatic response, and feedback processing depending on the reward or punishment (Starcke & Brand, 2012).

The effect of stress on DM has an impact that depends on the specific situation when a decision is made. In general, stress manifests itself mainly as a combination of dysfunctional use strategy with a reduction of adjustment from an automatic response, reduction of learning according to feedback, and also a high sensitivity to short-term reward (Buchmann et al., 2010; Juster, McEwen, & Lupien, 2010; Lemmens, Rutters, Born, & Westerterp-Plantenga, 2011; Lupien, Maheu, Fiocco, & Schramek 2007). These effects are also relevant to public health (Bracco, Váldez, Wakeham, & Velázquez, 2018). The negative ones are well documented, it is thought that stress increases the risk of cardiovascular, psychosomatic or psychiatric diseases and that it promotes behaviors of unhealthy lifestyles, such as smoking, drinking, and bad eating habits (Juster, McEwen, & Lupien, 2010; McEwen, 2008; Schneiderman, Ironson, & Siegel, 2005; Thomas, Bacon, Randall, Brady, & See, 2011). Thus, stress can also have indirect effects on health, and these can cause the individual to choose the less correct decision for their welfare, perhaps due to an immediate reward, with a long-term negative consequence (Starcke & Brand, 2012).

Stress commonly affects key regions of the brain that are associated with DM such as the anterior cingulate cortex, dorsolateral prefrontal cortex, orbitofrontal cortex, and ventromedial prefrontal cortex (Starcke & Brand, 2012), and can be induced in the laboratory by means of virtual reality (VR) stimuli. On the other hand, studies in DM and the analysis of the behavior of physiological variables during exposure to stress in military scenarios are particularly rare, when compared with civil environments and memory performance under stress (Wolf, 2009) .

The physiological response can be studied by the analysis of biological data, such as electroencephalogram (EEG) signals, near infrared spectroscopy (NIRS), electrocardiogram (ECG), Electrodermal Activity (EDA), body temperature, cortisol hormone levels in saliva, blood pressure, and functional magnetic resonance imaging (fMRI). During a VR experience, the subject physiological response may change and patterns associated with the DM process can be identified (Baumgartner et al., 2006; Egan et al., 2016). Electrophysiological signals, such as the EEG, the heart rate variability (HRV) are registered easily and provide a valuable source of information about the physiological response of the central and autonomic nervous systems. Nonlinear methods have been used to quantify dynamic patterns in brain electrical activity (Mosquera-Dussán, Botero-Rosas, Cagy, & Henao-Idarraga, 2015). The electrocardiogram signal and the heart rate variability analysis has been proposed as a useful non-invasive method to quantify patterns in the autonomic nervous system (Botero et al., 2010). Additionally, the relation between EEG and HRV was studied during cognitive observation and learning process, a significant increase in theta activity on the EEG signal (p<.01) and a decrease in the high frequency band on the HRV signal were reported. Data showed a reduction in parasympathetic activity and an increased sympathetic activity associated with theta activity in the orbitofrontal cortex, using a connection with the central nucleus of the amygdala (León-Ariza, Botero-Rosas, & Ramírez-villada, 2017).

The next section describes the literature research protocol. The purpose is to summarize the findings of studies about the impact of stress, which could be induced in the laboratory by virtual reality stimuli, on DM by analyzing the physiological response.

Methodology

This review addressed works published during the period between the years 2000 and 2017, it involves studies under stress with measurement of physiological signals in VR environments and DM in humans. The present review analyzes the relationship between the following topics: decision-making, physiological response, stress, and virtual reality, the following research question was proposed: "Does stress assessed through physiological variables under stimuli from virtual reality environments increase the probability of error in decision-making?"

The literature search focused on three databases (PubMed, IEEE Xplore, and Science Direct). The search strategy included published documents such as research, review and referenced papers. The search engine was used with the following terms: 'virtual reality', 'physiological response', and 'stress'. Each term was combined with 'Decision Making' using the conjunction 'AND'. Studies with the defined terms in the title or the abstract were considered for the revision. We excluded studies related to stress and physiological response at the cellular and molecular level and studies that consider non-physiological stress, for instances mechanical stress. Figure 1. shows a schematic of the research protocol.

The keywords: Virtual Reality AND Decision-Making produce 60 documents on Science Direct, 48 on IEEE Xplore, and 68 on PubMed. Physiological Response AND Decision-Making produce 23 documents on Science Direct, 25 on IEEE Xplore, 7 and 10 on PubMed. Stress AND Decision-Making produce 936 documents on Science Direct, 78 on IEEE Xplore, and 1303 on PubMed. Following a documents analysis and depuration, a total of 60 documents were included in the revision.

The reviewed literature was summarized in three sections: "Decision making under stress", "Physiological response and decision making", and "Virtual reality and induced stress". Finally, conclusions of the review are presented.

Decision Making Under Stress

In daily life, most decisions must be made at least between two options. In fact, decision-making can be classified into at least two categories: decision-making under ambiguity and decision making under risk (Brand, Labudda, & Markowitsch, 2006). In DM, one option can be an action and the other can be not to do anything. In many cases, two or more options that provide different outcomes are available.

Stress can be considered a natural response of an organism to a physical, psychological or emotional threat. The ability to provide a stress response is critical to survival. However, chronic exposure from repeated or chronic stimulation leads to allostatic load, which is maladaptive to the body. Dis-adaptive stress affects cognitive behavior through the modulation of structural and functional brain networks and can lead to psychiatric conditions such as acute stress disorder in response to exceptional physical or psychological stress (McEwen & Gianaros, 2011), although the stress is severe, such reactions usually subside within hours or days. The stress may be related to an overwhelming traumatic experience (e.g. accident, battle, physical assault, rape) or unusually sudden change in social circumstances of the individual, such as multiple bereavement.

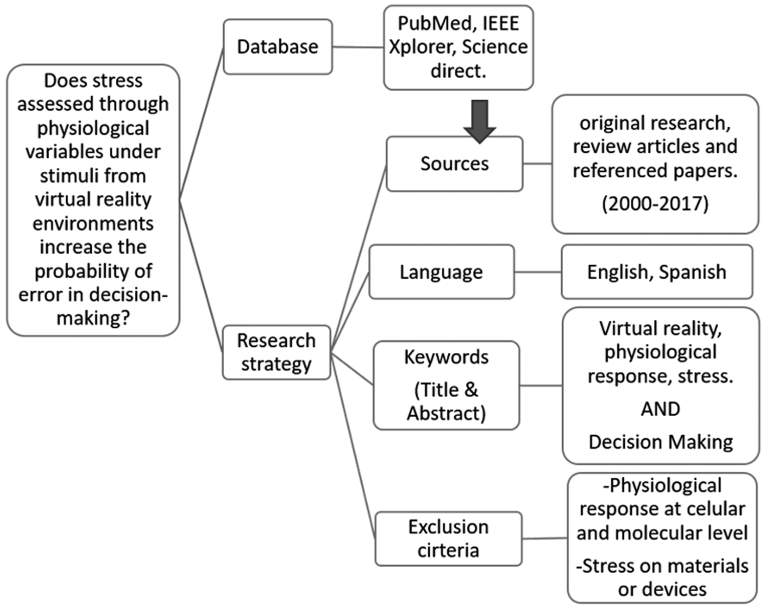

Figure 1. Literature research protocol based on the research question: does stress assessed through physiological variables under stimuli from virtual reality environments increase the probability of error in decision-making? Source: Developed by the authors.

The procedure that is required for DM have been described in five processes (Wu, Zhang, & Gonzalez , 2004); it is based on the existence of theoretical models of DM in psychology and computer science. Most models in these disciplines implicitly assume that all processes are carried out after the human evaluates the decision. The first of the five processes involves the representation of decision problems, this implies identifying internal states (for example, level of thirst), external states (for example, level of threat), and potential courses of action (for example, follow an instruction). In the second process, the different actions under consideration are weighted with a determined value according to the probable benefits of each action. In the third process, the different values are compared so that the person is able to select an action and make a decision. Once the decision has been implemented, in the fourth process, the brain needs to evaluate the results. Finally, the fifth process consists of the feedback of the results to update the other processes, improving the quality of future decisions, associated with the learning process. The mentioned processes are not static or strictly sequential, different permutations can be presented. For example, it is not known if the weight allocation (second process) must occur before selecting the action, or if the process is done in parallel (Rangel, Camerer, & Montague, 2008).

The DM and stress are related in terms of the brain response, events of daily life that could be perceived as a potential threat, they are mediated by the hypothalamic-pituitary-adrenal axis (HPA), the autonomic nervous system, and frontostriatal circuits (Cerqueira, Mailliet, Almeida, & Sousa, 2007; McEwen, 2000; Sousa et al., 2000). It has been suggested that these brain regions sensitive to stress are critically involved in DM throughout the lifespan on the brain (Lupien, McEwen, Gunnar, & Heim, 2010; Mather & Lighthall, 2012).

The literature has reported that acute stress influences cognition, and growing evidence shows that stress biases decision-making; stressors result in hasty and unsystematic decision-making that lacks consideration of the whole of available options (Galvan & McGlennen, 2012; Lighthall, Mather, & Gorlick, 2009; Porcelli & Delgado, 2009).

The stress itself can be considered as a physiological response, characterized by an increase of the sympathetic nervous system activity. This physiological response can also improve decision making, since an alert organism is one that is most willing to respond to the environment. It has been shown that a light tension introduced while the participant is under a particular level of excitation facilitates his performance (Bourne & Yaroush, 2003). That is, stress, while it is not chronic, can produce positive effects in decision-making. The specific level of excitation that is optimal for performance differs between tasks, tending to decrease as the difficulty of the task increases. However, a deleterious effect on the quality of information processing due to acute stress depends on the intensity of the stressor, excitement level, the ability of the decision-maker and other individual differences (Bourne & Yaroush, 2003).

More recently, experimental studies suggest that stress can exacerbate behavioral biases in decision-making by inducing choices that are more conservative for those who are generally more risk-prone and riskier for those who tend to seek risks (Porcelli & Delgado, 2009). Other studies (Ben Zur, Breznitz, 1981; Lighthall et al., 2009; Mather & Lighthall, 2012; Van den Bos, Harteveld, & Stoop, 2009) have reported similar findings and have shown that there are gender differences in the effects of stress on decision-making. For example, higher stress levels (measured by cortisol levels in saliva) induce worse decision making in the Iowa Gambling Task (IGT) and more risks in men, while women show better IGT performance (Van den Bos et al., 2009), and a lower risk taking with greater stress (Lighthall et al., 2009). This finding may be due to a faster decision speed in men, but a slower decision speed in women, under stress conditions (Mather & Lighthall, 2012).

Some evidence suggests that there are differences according to gender in the neuronal effects related to stress, however the literature reports contradictory results (Mather & Lighthall, 2012; Wang et al., 2007). Acute stress in men has been associated with increased activation of the prefrontal cortex (PFC) during a risky task, while women show greater activation in limbic regions, including the ventral striatum, putamen, insula, and cingulate cortex. (Wang et al., 2007). A separate study showed that being acutely stressed during a risk-taking task increased activation in both the insula and the putamen in men, but activation in these regions decreased in women (Mather & Lighthall, 2012).

It can be summarized that the effect of stress in DM depends on the condition and intensity, while it is not chronic, can produce positive effect such as an increase in alertness and awareness of the environment. However, it is also highlighted that acute stress results in a poor DM performance, since it impairs the evaluation of available options producing hasty and unsystematic decisions. The level of excitation that can produce a positive effect depends on the specific task, tending to decrease as the difficulty of the task increases.

Physiological Response and Decision Making

The physiological response in terms of the recording and analysis of biological data in response to a given environment provides a rich source of information related to DM process. In this section, the physiological response according to environments, situations of stress and emotions involved in the decision-making process are explored. Electrophysiological signals are rich sources of information, it has been proposed that brain activity and indicators of autonomic response from the analysis of heart rate variability, allow characterizing and evaluating the experience in a virtual world (Meehan, Insko, Whitton & Brooks, 2002).

It has been reported that stress plays an important role in decision-making, a study investigated the effect of chronic and acute stress in making consecutive decisions (Lenow, Constantino, Daw, & Phelps, 2017). The authors considered DM situations in which a currently known and available option must be weighted and considered against an unknown alternative. This type of decision is characterized by being highly sensitive to stress. The authors evaluated the DM under the effect of two types of stress, chronic and induced. Stress was measured in two independent ways: (a) response of cortisol to acute stress manipulation; (b) questionnaire about perception of a lifestyle with chronic stress. The authors concluded that both types of stress (acute and chronic) introduce a bias in decision making towards overexploitation of currently known options. This overexploitation can be an adaptive response to situations that represent a threat to homeostasis, they also highlight the importance of assessing the quality of the environment in making consecutive decisions, and so they propose that stress also introduces a subjective bias in the appreciation of the quality of the environment (Lenow et al., 2017).

The effect of emotions in decision-making has also been considered. In a study conducted with 10 brokers, statistically significant differences were found in the skin conductance between subsequent market events and control periods, defined by the absence of such events. Changes in cardiovascular response were also reported in relation to market volatility. The authors also suggest that the differences identified may be systematically related to the level of experience of the broker (Lo & Repin, 2002). In another study, skin conductance and heart rate were used to detect emotions in financial decision-making. This was possible with the implementation of a decision tree that allowed the classification of two emotions "happy" and "regretful" associated with commercial decisions consequences (Hariharan & Adam, 2015).

In another study, surgeons described how emotions experienced after adverse events in the surgery room could cause lack of clarity of judgment, clinical skills, and subsequently wrong DM. However, on the other hand some surgeons reported taking extremely careful attitudes after the adverse effects, in order to avoid the repetition of them (Luu et al., 2012).

Emotions have been considered as a dynamic process that affects social relationships and influences the mechanisms of rational thinking and decision-making (Khan & Lawo, 2016), a way of incorporating emotions into a computer system is through the extraction of characteristics from a variety of physiological signals, and from the analysis and identification of patterns to infer the corresponding emotion. Researchers from the University of Bremen proposed the development of a system for recognition of emotions using the e-Health platform (Khan & Lawo, 2016). The emotions were categorized into two groups, positive (Joy, normal) and negative (sadness, disgust, stress). Three physiological sensors were used: blood pulse volume, galvanic response of the skin, and skin temperature. The developed system (Khan & Lawo, 2016) was able to recognize the emotional states mentioned previously with high accuracy (around 95%), both in the problem of two classes (positive, negative), and in the six classes (taste, normal, sadness, disgust, stress, no-idea) using classification algorithms based on decision trees.

The analysis of emotions represents a great challenge, given the inherent difficulty of accurately measuring the degree of a person emotional state. The American Physiological Association reported in 2011 that about 53% of Americans reported stress as the reason behind personal health problems (American Psychological Association, 2011). Emotions are the feelings that influence human organs, it has been reported that negative thoughts or depression can have adverse effects on health (Rush, Beck, Kovacs, & Hollon, 1977). In this sense, technology for the recognition of emotions can contribute to this problem, allowing tracking of the emotional state of the individual, this type of systems can also issue alarms to a person when the negative emotional state has a prolonged duration or notify caregivers or family members.

The phase-amplitude coupling between the Electrodermal Activity (EDA) and EEG signals of the temporal lobe has been identified while the research subject was experimenting with music videos. Given that the temporal lobe is associated with the auditory cortex, the authors concluded that music has a greater weight in emotional experience compared to video content; the authors propose that the coupling evidenced is mainly due to emotional processes instead of processes of cognitive appreciation (Kroupi, 2013). The above, suggests that audio quality is a relevant aspect in the design of virtual reality environments.

Electroencefalogram, pupil dilation, heart rate, and response time has been used to predict the decision confidence and accuracy in two side-tasks occurring throughout a three-hour experimental session. One side-task was an auditory task, the other a visual task. The authors reported that joint EEG and pupil dilation information provided the best performance in a classifier with dual-layer logistic regression. The researchers highlight the possible implications, since in a non-invasive way the dynamics of a complex neural circuit composed of the Locus Coeruleus (LC), anterior cortex of the cingulum (ACC) and the dorsolateral prefrontal cortex (d1PFC), associated with the formation of decisions could be inferred. (Shih, Zhang, Kothe, Makeig, & Sajda , 2016).

It has been proposed to consider DM based on the physiological response of a group of individuals. In a study funded and supported by the Unite Kingdom's security and defense program, (Valeriani, Poli, & Cinel., 2015) it was found that a classifier of brain machine interface based on electrical brain activity of a group, improved the decision error up to 3.4%, depending on the size of the group, compared to decisions taken by majority vote. Additionally, the system was integrated with information about eye movements and blinking, which increased its performance significantly (Valeriani et al., 2015). It is possible that the integration of brain computer interfaces with another type of biological information (electrocardiogram, respiratory rate, skin conductance, among others) improves the performance in DM.

It has been reported that autonomic nervous system activity correlates with cognitive and emotional processes (Salvia, Guillot, & Collet., 2012). The autonomic response has also been proposed in terms of cardio-acceleration as a predictor of decisions, particularly decisions taken in the "ultimatum game", where criteria of justice and equity are involved (Osumi & Ohira, 2009). Electrodermal activity (EDA) has also been used in conjunction with registered hemodynamic activity with functional near-infrared spectroscopy (fNIRS). The authors concluded that fNIRS signals, but not EDA, are useful in the study of individual risk attitude and task performance in dynamic risky DM. (Holper, ten Brincke, Wolf & Murphy, 2014).

The physiological response has also been taken as an analogy for the implementation of a system called "Autonomic Logistic" for the administration of a system of military weapons, in which reference is made to the autonomic nervous system in the development of reaction plans (Dreyer, 2005).

Sleep duration is another important component to consider in DM under stress, a study from the University of California has shown that insufficient sleep is associated with increased risk taking and poor DM influenced by the physiological response to stress. In the study conducted, it was reported that regardless of age, individuals who received greater sleep hours took fewer risky and disadvantageous decisions during high stress episodes, in relation to those who received less sleep. It is interesting to note that the duration of sleep was not associated with risky behavior in a context of low stress situations (Uy & Galvan, 2017).

Stress itself can be considered a physiological response, and it can be estimated by measures of salivary cortisol level, skin conductance, heart rate, pupil dilation, and brain electrical activity (Figure 2). Two other factors are included in the DM considerations, emotions, and sleep. Emotions are the feelings that influence human organs, negative thoughts or depression can have adverse effects on health and affect the DM process, the physiological response along with algorithm and technological development may be used in the recognition of emotions. In the other hand, it has been shown that insufficient sleep is linked to risky decisions and poor DM under stress.

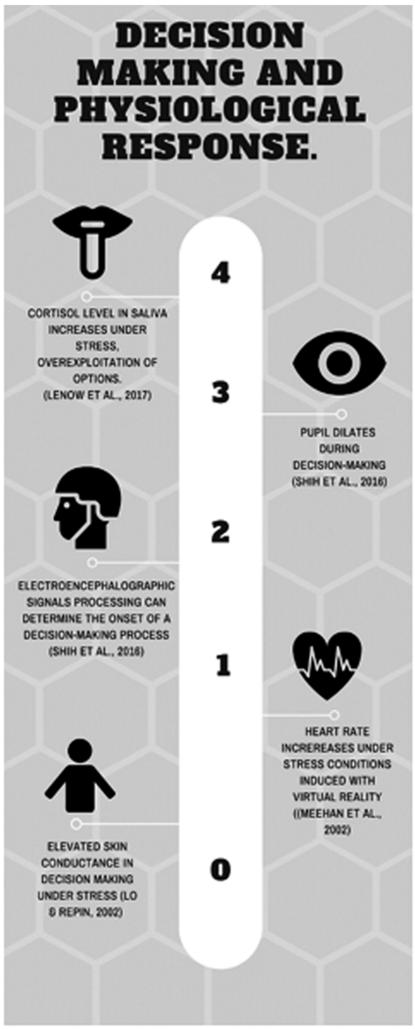

Figure 2. Decision-making and common physiological responses: 0) skin conductance, 1) Heart Rate, 2) Electroencephalographic signals, 3) Pupil dilation, 4) Cortisol level in saliva. Source: Developed by the authors.

Virtual Reality and Induced Stress

The newly developed virtual reality tools help to create a VR experience of vivid scenarios. Usually, the immersive virtual reality set up contains a real-time tracking and a panoramic system, which can provide a stressful controllable environment in real time. Nowadays, being immersed in a virtual world is a fact; this allows representing different situations, places and performing different actions; these virtual environments are created based on the real world, which involves the manipulation of some of the senses, such as vision and hearing. Which makes believe that what is being experienced is real (Navarro-Haro et al., 2017). These actions trigger other components, the physiological and psychological reactions that arise because of the situation in which the subject is immersed (Tepljakov , 2016).

Virtual reality systems are currently used for specialized training, for instance, the fire department from the Public Safety Institute of Catalonia, implemented VR tools to improve decision making in the resolution of an emergency. There are two fire situations, one shows a fire of low magnitude, where one catches fire and extends towards a car and the second with greater magnitude already linking a house and an unconscious person. The virtual reality system was used to evaluate the behavior of firefighters and their decision-making, thus promoting their learning and reaction to situations of danger (Ríos et al., 2017).

Virtual reality tools are also used in medicine, in problems such as phobias, a study that involves a virtual reality challenge in participants with spider phobia, reported a prefrontal network that is activated by emotionally relevant stimuli, and supports the maintenance of adequate behavioral reactions (Deppermann et al., 2016).

There is a tendency to include new technologies for learning; a clear example is related to medicine students, because they require many practical activities to fulfil an appropriate preparation to make the right decision. In this context, virtual reality provides the tools that allows the safe practice of different complex medicine procedures, among these endoscopy, laparoscopy, and endovascular navigation (Vázquez-Mata, 2008). Virtual reality has also a great impact on neurorehabilitation with the help of immersion in virtual environments. Consider that repetition is the key to achieve a good rehabilitation, it is important for motor learning and for cortical changes to take place. Virtual reality can be thought as a versatile tool; it helps to control in a precise and repeatable way each one of the sessions, adapt the interface to motor limitations of each user, and recreate safe virtual environments to improve skills in situations with potential risks. There is also the possibility of developing tele rehabilitation platforms (Peñasco-Martín et al., 2010).

The use of virtual reality systems in military environments has also been reported (Lackey, Salcedo, Szalma, & Hancock, 2016), an example of this are the combat simulators developed by the company Bohemia Interactive Studio, such as Arma and a restricted-sale Virtual Battle Space (VBS) for military training purposes. VBS is a comprehensive training application that provides a high-fidelity 3D virtual environment for collective ground, air and maritime trainings. Several North Atlantic Treaty Organization (NATO) nations use VBS products in their simulation centers. Because of VBS's widespread use, NATO Allied Command Transformation (ACT), working with Bohemia Interactive Simulations, has negotiated an agreement providing NATO with the full capabilities of VBS3 ("Bohemia Interactive Simulations", 2018), VBS and Arma are interoperable with other simulations platforms such us virtual reality head mounted display and physiological sensors (Figure 3).

The Logistical Support Command of the Spanish Army has invested in acquiring 250 licenses of 'Virtual Battlespace-VBS2', the military version of the video game 'Arma 2' (Elmundo.es, 2012). The US Naval Research Laboratory, integrates the VBS with a software called CTAnalyst®, they made simulations of tactical training for chemical gas attacks on a large scale with a specific focus on crowd management. The use of CTAnalyst® and VBS improves virtual training systems to provide support that is more realistic to the training communities (Moses, Obenschain, Boris, & Patnaik, 2015).

All these environments have something in common, each of them presents a decision-making process and this goes hand in hand with stress, which can be induced in the laboratory with virtual reality tools. Then it is observed that the level of

Figure 3. A standard virtual reality set-up implemented at the "*Centro de Investigación y Desarrollo en Simulación – CIDSI*", composed by: A.) electroencephalogram headset [Open bci], B.) head mounted display [oculus Rift], C.) headphones, and D.) weapon adapted as a peripheral input, the vr environment projected on displays is provided by the platform Virtual Battle Space.

stress can put the subject in a better situation or on the contrary in a worse one. Much of the level of stress is associated with the workload that has to be done, and the taste or ease depending on the personal abilities. One cannot simply put a person who does not have experience or skill in a job for which the person is not prepared, because the level of stress in this case makes it impossible to perform correctly.

In a virtual environment many kinds of situations can be generated to see the performance in each of them, the learning that is transferred from the experiences in VR seems to be particularly promising, as a conduit through which the training can be improved significantly (Hoareau, Querrec, Buche, & Ganier , 2017; Mracek et al., 2014). Therefore, VR can help to mitigate the stress that occurs when a person is going through situations that generate stress in an uncontrolled way; it also helps to know how to cope when there is a lot of difficulty in the task (Mu & Tan, 2017). The human being has the ability to learn and improve when it passes several times through the same situations, this helps to make better decisions.

Unfortunately, in real life situations there is usually only one opportunity to achieve a good outcome. Therefore, virtual reality may provide a solution to this problem, through adaptative learning. When people make a mistake in a decision-making process, it could be because they do not know how to act in a new situation or because of lack of practice. A person who constantly goes through a situation will have more ease than the one that never or very rarely does. An example of this is a group of firefighters who are implementing these systems, establishing a simulation model for rescue command and fire protection (Mu & Tan, 2017), this type of training can be perfectly extrapolated to all areas. Humans with their feedback capacity generate better results regardless of the circumstance or scenario in which they are. Virtual reality improves the learning through repetition of experiences (Wang, Shen, Tino, Welchman, & Kourtzi, 2017).

Virtual reality is a powerful tool, which can be used to provide a stressful controllable environment in real time. VR systems are currently used for specialized training in different fields such as complex medicine procedures and military training. The common point is the repetition of a specific task, considering that in a VR environment, many kinds of situations can be generated and different level of stress may be induced.

Conclusions

According to the literature reviewed, an intimate relationship between the physiological response of stress and decision-making is suggested at a neural level of behavior, since events that could be perceived as a potential threat, are mediated by the hypothalamic-pituitary-adrenal axis (HPA), the autonomic nervous system, and front striatal circuits, these brain regions sensitive to stress are critically involved in DM. There is also an increase in the use of virtual reality tools and the analysis of physiological signals. These tools provide an adequate way to induce stress at the laboratory level, recreate situations, and improves learning in decision-making. Therefore, it makes sense to set-up a training environment with virtual reality tools, such as head mounted displays (e.g, Oculus Rift, HTC Vive) and movement platforms (e.g, VirtuixOmni) integrated with physiological acquisition system to monitor the stress response and predict the performance of a subject in a specialized task.

The interrelation of the previously defined thematic axes: (a) the decision making under stress, (b) the physiological response, (c) virtual reality and induced stress, suggests an affirmative answer to the question "does stress evaluated through physiological variables under stimuli of virtual reality environments could increase the chances of error in decision making?". It was found that in general terms stress may lead to "allostatic load" and manifests itself mainly as a combination of dysfunctional use strategy and a reduction of learning according to feedback. Dis-adaptive stress also affects cognitive behavior through the modulation of structural and functional brain networks. However, stress, while it is not chronic, can produce positive effects in decision-making, since an alert organism is one that is most willing to respond to the environment. The specific level of excitation should be determined according to the specialized task in order to obtain an optimal learning experience.

There is currently an interesting gamma of simulators of virtual environments, highlighting those developed by Bohemia Interactive (Arma, Virtual Battle Space). These can be integrated with physiological acquisition systems, in order to quantify the stress response and provide a feedback that contributes to the continuous improvement of military training, implementing specific military operations that involve decision making in stress situations. The stress induced in the laboratory by means of virtual reality tools, and the corresponding physiological response of the central and autonomic nervous systems are fundamental thematic axes that allow the design of support and training systems for decision making in order to reduce the probability of error.

The stress response and behavior in a determined virtual reality can be quantified and provide a feedback in the training process. Combination of electrical brain activity, heart rate variability, and pupil dilation has shown promising results in classification problems. It is observed, that these emerging technologies are being implemented by countries around the world, investing resources for the use and implementation of technologies in different labor and security fields.

Future research integrating the development of immersive VR environments, artificial intelligence and machine learning algorithms of the physiological response along with sensors development, should provide a framework to preparation and monitoring performance in multiple fields, and may established a new training paradigm.

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