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RELATION BETWEEN HUMAN FACTORS AND ERGONOMICS

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Abstract: Ergonomics offers a wonderful common ground for labor and management collaboration, for invariably both can benefit managers, in terms of reduced costs and improved productivity, employees in terms of improved safety, health, comfort, usability of tools and equipment, including software, and improved quality of work life. Of course, both groups benefit from the increased competitiveness and related increased likelihood of long-term organizational survival that ultimately is afforded. Clearly, to enable our profession to approach its tremendous potential for humankind, the professional human factors against ergonomics community, must better document the costs and benefits of their efforts and proactively share these data with their colleagues, business decision makers, and government policymakers. It is an integral part of managing their profession.
Keywords: Human factors, ergonomics, areas of application, theories and models, methodologies

INTRODUCTION

The first initiatives of the new discipline was found in 1914. The design of new machines revealed the importance of taking into account the characteristics of people who should operate them. It was found that many people had difficulties to operate with more complex machines. This led the community to recruit psychologists who were assigned the task of developing and administering tests to select personnel and to assign them to different tasks. These applied psychologists were the first human factors laboratories. But in 1940 ergonomics was developed as a discipline with industrial and academic recognition.

The focus of ergonomics is to be found in industry and it has been linked to an interest in improving worker performance and satisfaction. The discipline began with an emphasis on the design of equipment and workplaces although in principle themes were related to biological, rather than to the psychological aspects. In this way, studies began on anthropometry, work medicine, architecture, lighting, etc. In the 1980s, the ergonomists began to worry largely about advanced psychological aspects and therefore, they emerged leading to a confluence of interests with human factors and cognitive science professionals.

The definition of ergonomics is extended today to all human activities in which artefacts are implemented. Ergonomists are in a permanent search for comprehensive approaches in which physical, cognitive, social and environmental aspects of human activities can be considered. Although ergonomists often work on different economic sectors or particular tasks, these application domains are constantly evolving, creating new ones and changing the perspective of the old ones.

Accordingly, one can recognize today four main domains of expertise which are crucial for investigating interaction between humans and socio-technical systems which are: physical ergonomics, cognitive ergonomics, Neuroergonomics and social or organizational ergonomics.

APPLICATION DOMAINS

— Industrial areas

≡ Human Computer Interaction

In most of the cases, computers are only parts serving to the functioning larger technical systems, so our interaction with them is not as explicit as when a personal computer is in use. For this reason, one should talk rather about Cognitive Ergonomics of Human Machine Interaction and rethink interaction with computer as interaction with everyday computerized artefacts (Sellen et al., 2009).

≡ Control processes

A processing industry is one where energy and matter interact and transform one into another (Woods, O'Brien and Hanes, 1987). There is one ergonomically relevant characteristic that distinguishes among processing industries.

One can say that the various process industries differ in the degree of dependence on the artefacts that play a mediating role between the operators and the physical processes that they control. In many cases, there may be a relatively direct relationship between human control operations of the physical process.

Therefore, in general terms, in the process control domain one or more persons work to control a physical system using one or more artefacts. These individuals interact directly with the mediating artefacts, but not with the physical system that they are controlling.

Unlike what happens in the interaction of a person with a computer when she is writing a text, in process control there is an external world which is the physical industrial system that the persons perceive and control through the mediating artefact, which, of course, can be a computer (Ken'ichi, Kunihide, Seiichi, 1997).

— **Intervention areas**

≡ **Design**

Design is the core of the profession of ergonomists (Dowell and Long, 1998). The design of a new system is the process that happens from the conceptualization of the artefact until when it is used by the people for whom it is intended. From the point of view of cognitive ergonomists, there are two aspects of interest in system design (Carroll, 1991). On the one hand, they are interested in the process of design itself. That is, cognitive ergonomists want to understand how people devise a new system, and what are the individual and group factors involved in making decisions that lead to certain solutions defining the system.

Furthermore, cognitive ergonomists would like to know whether the solutions adopted suit the needs and characteristics of users. Their main role in this sense is to describe the human being at all levels of functional organization appropriate for the system being designed (Velichkovsky, 2005; Wickens and Hollands 2000). Therefore, cognitive ergonomists are interested in the human being who designs and the humans being interacting with the system that has been or has to be designed. The work of cognitive ergonomists in the design process has undergone serious changes over the last decades.

In the early times of human factor engineering, they were called to explain why the particular design had not worked. Later on, they were called to intervene directly in the design process (Wickens and Hollands, 2000).

Today, the processes of innovation requires that ergonomists proactively supply ideas and empirical data for the design of future artefacts improving human performance and public acceptance of new technologies (Akoumianakis and Stephanidis, 2003; Kohler, Pannasch and Velichkovsky, 2008).

≡ **Technological innovation**

The concept of user centered design was developed during the 1980´s in the design of technologies (Norman, 1986). User centered design aims at describing the human being who interacts with the system from the viewpoint of cognitive science. Then, based on those characteristics cognitive ergonomists provided engineers with a set of principles to be considered in the design.

This paradigm has led to the establishment of usability research that has contributed greatly to the effectiveness, efficiency and satisfaction of users in their interaction with the technologies and to a better interaction between users through technology (Holzinger, 2005).

The change is motivated by the design of new applications and services under the influence of increasingly fast convergence of nano, bio and information technologies with cognitive science (NBIC Report, 2006).

≡ **Safety and accident investigation**

The objective is to predict the likelihood of human error and evaluate how the entire work system is degraded as a result of this error alone or in connection with the operation of the machines, the characteristics of the task, the system design and characteristics of individuals (Swain and Guttmann, 1983). This approach has led to a considerable progress in the efforts to predict the occurrence of human error. However, it has been criticized as insufficient. (Reason, 1992) particularly notes that the main difficulty is the estimation of error probability. In designing new systems, there are no prior data on the error probabilities.

One can count on data from simple components, such as errors that are committed to read a data into a dial or enter them into a keyboard, but not the errors that may be committed by interacting with the system. The second approach was adopted from cognitive psychology. In this, ergonomics seek to know the mental processes responsible for committing an error (Norman 1981; Reason, 1992). They assume that errors are not caused by irresponsible behavior or defective mental functioning. They may be rather the consequence of not having taken into account how a person perceives, attends, remember, makes decisions, communicates and acts in a particularly designed work system.

This standpoint suggests investigating the causes of human errors by analyzing the characteristics of human information processing. Here, the first step has been the classification of errors according to the level of processing involved in the behavior that led to the error. Although there are more elaborated classifications today, it is possible to make a synthesis based on the classical scheme proposed by Jens Rasmussen (1983).

He distinguishes three types of errors depending on the level and degree of cognitive control involved in the erroneous behavior. The three types of errors can be largely attributed to the familiarity that the person has with the system are: Errors based on skills, Errors based on rules and Errors based on knowledge. Another approach has been developed recently to combine the reliability analysis developed by engineers with cognitive modeling. This approach starts from the basic assumption that the behavior of a person is determined by the context in which it occurs.

The work system creates dynamic, ever changing situations. It is therefore necessary to take into account the context and all levels of organization that contribute to system safety: the system's technology, the individual, the group, the organizational management and cultural factors. In other words, it is not sufficient to estimate errors only from the perspective of human information processing (Wilpert, 2001).

According to this new approach, the person and the working environment should be considered as a highly interactive joint cognitive system (Hollnagel and Woods, 2007). The interaction between the two components is of a crucial importance for any ergonomic analysis. Based on these assumptions, several authors have proposed methodology for estimating the probability of human errors depending on specific situation in which human machine interaction occurs.

The methodology presupposes two steps of analysis: to identify the types of errors that are possible for a specific task in a given scenario of event development; to classify these types of errors by their ranges of probability to identify which are the most probable and which are the least probable within the given joint cognitive system (Cacciabue, 2004).

THEORIES AND MODELS

In their everyday practical work ergonomists may well be more interested in improving what people do rather than what people know or feel.

However an enduring improvement of performance seems to be possible only if the underlying cognitive representations as well as attitudes and competences of participating persons are known. This is why, the Chomskian distinction between competence and performance become very important for cognitive ergonomists (Amalberti, 2001).

In addition to this theoretical distinction, influential concepts are being borrowed, on the one hand, from ecological psychology and activity theory (Gibson, 1979; Leontiev, 1978) and, on the other hand, from the rapidly growing field of cognitive neuroscience (Hancock and Parasuraman, 2003).

— Conceptual developments

With reference to Herbert Simon (1969), cognitive ergonomics had an enormous influence on the development of the discipline in the early 1970s. It was argued that cognitive science must have its own area of application. Cognitive engineering deals with the problems of designing an effective mental work and the tools with which this work is done (Hollnagel and Woods, 1983).

Therefore, the object of cognitive ergonomics is formulated around the concepts of mental work and cognitive tool. Donald Norman (1986) was the one who also argued for a combination of knowledge from cognitive science and engineering to solve design problems. According to him, the objectives of such a strategy would be twofold: to understand the fundamental principles of human actions that are relevant to the development of principles of engineering design, and to build systems that are pleasant to use.

The first goal suggests a slight change in accents with respect to the original proposal of Simon. In fact, it put the discipline in line to the vision of some advanced experts in engineering (Vincenti, 1990): the establishment of cognitive engineering as a discipline of human action independent from albeit related to cognitive science from which it could borrow knowledge about cognitive processes.

However, this proposal remained unattended for a decade, and ergonomics evolved according to Simon's idea of understanding the cognitive engineering as an applied pendant to cognitive science. An example of this view can be found in some textbooks on human factors engineering (Wickens and Hollands, 2000), which are organized according to topics of human information processing. In this way, the list of sections is the same as the list of sections that can be found in any textbook of cognitive psychology.

In the classical conceptualization, the artefact and the human being were considered independent from the context where the interaction between them took place. These considerations have been laid down into paradigm of the joint cognitive systems (Dowell and Long, 1998; Hollnagel and Woods, 2007).

The main message of the proponents of this approach is a broad interactionism: for a solution of cognitive design problem human behavior must be modeled as activity, in its interaction with the environment and with other cognitive systems – both human and artificial – that there are in the environment.

Therefore, in this new conceptualization of cognitive engineering the meaning of cognition itself is being reformulated in more dynamic and situational terms.

— Definition of cognition

In the traditional understanding, cognition refers to the acquisition, maintenance and use of knowledge as examples of operations within the realm of human information processing. However, within dissident conceptions such as the joint cognitive paradigm, cognition should be understood in a broader sense, exceeding the limits of individual's brain or body.

An example is the Gibsonian notion of affordance, which refers to all aspects of the environment supporting specific actions of individuals (Gibson, 1979). This notion is of obvious significance for cognitive engineering, to such a degree that some authors declare the design of affordances to the main goal of human factors engineering (Vicente, 1999). In a similar vein, Norman (1986) stresses the importance of external memory.

Under influence of these ideas, the meaning of cognition in cognitive ergonomics now refer to a highly organized distributed systems such as the military, air traffic control, aircraft cabins or navigation systems for large ships.

Both people and artefacts are jointly regarded as agents within such a system. The focus is placed on the transfer and processing of information within and between agents. In this framework, cognition is viewed as a phenomenon that emerges from the work of the system as a whole (Hutchins, 1995).

One consequence of this redefinition has been the incorporation of theories that have been developed outside the mainstream cognitive research. This is the explanation for a discovery of activity theory (Leontiev, 1978), which has its roots in the European romanticism and Marxist philosophy. Activity theory, with its focus on sociocultural origins of human thought and action, is now considered as a promising starting point for doing research in cognitive ergonomics (Nardi, 1996).

Accordingly, there are no sharp distinction between consciousness and behavior, and thus between external actions and internal thoughts, a distinction that is common for traditional cognitive science and ergonomics. Thoughts without external actions are considered as internalized social actions, similar to corresponding external actions (Vygotsky, 1978). As soon as the socio-cultural context is considered, the scope of analysis becomes broader than in cognitive science.

The incorporation of new approaches and theories of cognition into ergonomics let to a discussion on the relative merits of macro and micro theories whereby the dominating view stressed the importance of the overarching explanations. Cognitive ergonomists should create macro theories that incorporate all the complexity of interaction within a socio-technical system.

Simultaneously to this holistic trend, one can testify a growing influence of concepts borrowed from the field of cognitive neuroscience. Being closely related to the progress in methods of brain and behavioral research, the second trend recently let to development of Neuroergonomics (Parasuraman and Wilson, 2008; Velichkovsky and Hansen, 1996).

This tendency is especially evident, in the analysis of several traditional topics of human factors studies which are discussed below.

— Conceptual topics

≡ Situation awareness and attention

One of the reasons for this rapidly growing interest to situation awareness is instability of human performance related to the automation of work processes. The problems or ironies of automation were first noted by Lisanne Bainbridge in a seminal paper (Bainbridge, 1983).

With a high degree of automation, human operator is out of loop of controlling processes. As a result, operators are less well practiced in their abilities to take over the process when an automatic unit fails. This deterioration results from the fact that the manual and cognitive skills decline due to the absence of active participation in the process.

Furthermore, it becomes more difficult with progressing automation to gain access to knowledge about the system behavior.

Many authors see the solution of such problems in adaptive automation, which could take the current state of knowledge of human operator into account and, in this way, support a better division of labor between humans and machines.

However, the solution presupposes reliable and timely feedback information about human understanding of the situation. This is the area where Neuroergonomics seems to have serious chances for a success (Parasuraman and Wilson, 2008). In particular, neurocognitive studies of attention build the main source of knowledge about mechanisms of situational awareness.

These studies have elucidated three different attention networks in the human brain (Posner, Rueda and Kanske, 2007) and up to six levels of cognitive organization (Velichkovsky, 2005). Changing balance of these networks can explain fluctuation in the level of human performance over time, as in the case of driver's behavior in hazardous situations (Velichkovsky et al., 2002).

There seems to be a new understanding in the ergonomics that some degree of attention and situational awareness is always required to control the performance of any task, no matter how seemingly simple and safe it is. Today this is a topic of vital importance in many areas of ergonomics from military applications, industry, and transportation to the work of medical professionals.

A recent world health organization founded study has shown that the rate of postoperative mortality in a number of hospitals across the world could be reduced by nearly 40% if before the surgery medical personnel answered questions like the determination the right place, the right patient and the type of operation needed (Haynes et al., 2009).

≡ Mental models

When interacting with a system, people normally have some knowledge of its structure and functioning. This small scale subjective representation of system's structure and functioning is called a mental model (Johnson-Laird, 1983).

Taking into account the peculiarities of users' mental models in the design of artefacts is considered to be crucial for an efficient interaction. Therefore, the investigation of mental models is one of the central themes in cognitive ergonomics (Cañas, Antolí and Quesada, 2001; Ken'ichi, Kunihide, and Seiichi, 1997).

Computational analysis of mental models complexity has been widely used to predict the understanding of instructions that describe how to deal with a technical system. Finally, in the area of HCI, researchers have consistently proven that when a person interacts with the computer she acquires knowledge about its structure and operation.

Interestingly, this acquisition may be less efficient with relatively easy to use graphical user interfaces than with old fashioned command line interfaces. Other research has shown that acquisition of an adequate mental model of the computer facilitates learning a programming language (Cañas, Bajo and Gonzalvo, 1994; Kieran and Bovair 1984; Navarro and Cañas, 2001).

≡ **Decision making**

Ergonomists have been using several terms that could be considered at least partial synonyms: command and control, dynamic decision making, distributed decision-making, natural decision-making and decision science (Artman, 1998; Brehmer, 1992; Zsambok and Klein, 1997).

The training of professionals, which is based on formal algorithms of decision-making, can be rather misleading as the need to take a quick and obvious solution leaves no time to contract it with other theoretically possible moves (Salas, Cannon-Bowers, and Johnston, 1997).

The combination of time pressure and the highly significant outcomes explains the interest that decision science demonstrates to 'hot', i.e. affectively loaded, rather than to 'cold' cognition (Kahneman, 2003).

≡ **Mental workload and stress**

It would be important to have an exact and measurable definition of human cognitive limitations during engineering of new systems allowing designers to predict which implementation will maximize the effectiveness and still leave the user a residual capacity to cope with unexpected demands (Yeh and Wickens, 1988).

In addition, the labor legislation of industrialized countries recognizes that mental workload affects the mental and physical health.

Therefore, the law requires companies to evaluate the mental workload to which workers and employers are exposed. It has been argued that many of the mistakes made when interacting with a computer are caused by an excessive load of working memory (Olson and Olson, 1990; Gevins et al., 1998). There are some persistent problems with the notion of mental workload. First, this is an overtly mentalist concept. Second, the nature of cognitive resources and their relations to structural and operational constrains of processing remain unknown.

Numerous hypotheses, models and theories have been proposed to clarify these issues (Meyer and Kieran, 1997). One of the widely accepted is the model of multiple resources by Christopher Wickens (1984).

Accordingly, there is more than one kind of resources such as enabling verbal and non-verbal processing. The hopes on a progress in understanding limitations of human information processing are currently related to functional brain imaging studies (Hancock and Parasuraman, 2003).

Any limitation in performance should also be considered from the perspective of a variety of human functional states such as fatigue, monotony and stress (Leonova, 1998).

METHODOLOGIES

— **Ethnographic method and field studies**

The ethnographic method is applied when ergonomists have to analyze a completely unknown situation (Garfinkel, 1967). Being initially used in anthropology and sociology, it represents a kind of immersion of the researcher in the environment to describe and explain the observed phenomena.

The emphasis is on observation relatively free of theory and on a 'qualitative' rather than 'quantitative' description of what is observed. This approach emerged to replace methods based on structural interviews and questionnaires.

Researchers using the ethnomethodology often argue that their observations are not driven by any assumptions.

However, it is difficult to believe that ergonomists could be able to shed all their prior knowledge to observe a situation without bias (Shapiro, 1994). Without going into details of a methodological discussion that storms in the philosophy of science, many ergonomists prefer to use a well-established method, called field study, in which as in the ethnographic method, one observes and describes a situation without seriously interfering with it, but the observations are guided by assumptions that are explicitly established from the outset.

— **Standards and evaluation testing**

When introducing a new software application within the common platform of graphical user interface, one has to consult the corresponding guidelines on the designing dialogues and overall requirements to human-computer interaction (Karwowski, 2005). Even if the application of standards is not immediately possible, the theoretical and empirical development of human factors and ergonomics allows doing analysis of artefacts by use of known principles and data without carrying out experimental research.

There is sufficient documented knowledge about human sensory and motor systems that make unnecessary to conduct a new experiment every time there is a need to design a new display or a mouse (Boff, 1986). In addition, there are a large number of reference sources that responds to the growing need for specific instruments and methods for testing the usability of human-system interfaces (Charlton and O'Brien, 2002; Holzinger, 2005).

— Experiment

Still, there seems to be no method in the immediate and middle-term perspective that could better fulfill the task of scientifically-based human factors and ergonomic research than experiment.

Paradoxically, one can achieve a higher applicability of experimental data by a more in-depth laboratory research. The promises of Neuroergonomics are related to establishing the brain mechanisms of different forms of attention (Posner, Rueda and Kanske, 2007).

The success of direct diagnostics of their state of activation and emerging techniques of brain computer interfaces depends on the progress made in cognitive science. In a longer run, one can hope to replace the most of real experimental work by running computational experiments with virtual artefact and virtual users.

— Simulation

Ergonomists study complex behaviors that are difficult to dissect (Klein et al., 2003). They are also interested in a broad range of phenomena to predict human behaviour and functional states under sometimes hazardous conditions. In addition, many industrial artefacts now-days are firstly produced in a fast-prototype manner, as a virtual mock-up suitable for some forms of usability testing.

An ideal counterpart of this partially virtual world would be, of course, a virtual human dummy that implements some of the essential characteristics of potential user. The contemporary efforts along these lines concentrate themselves on the biomechanical and optical features of human beings (Duffy, 2008).

CONCLUSIONS

The future agenda of human factors research and applications is set up by how technology will be developed and used in society. At the high-end of technological development, there will be many options to meet the human factors challenges as they were carefully listed on eve of the new millennium (Nickerson, 1992).

First of all, it will inevitable come to a further convergence of the basic technologies with the resulting enhancement of human performance. One can expect that usability evaluation will be soon evolved to a more scientifically based and predictive endeavor.

Another expectation is that of a proliferation of completely new forms of interfaces. Some of them may have nano-dimensions fulfilling their roles within the molecular machinery of human cognitive-affective processes. With a high probability, Neuroergonomics will not long have the status of the youngest science of artificial perhaps being combined with something like computational ergonomics.

Due to uneven pace of these processes, there however, will be regions and domains, where people will still have to perform hard, dirty, unpleasant physical tasks round the clock and without proper gratification.

Here human factors experts and ergonomists, along with politics and social workers, should seek to improve the work environment of such individuals with more traditional means (Hancock and Parasuraman, 2003).

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