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Cognitive ergonomics: it's all in the mind

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In this paper a distinction is made between classical ergonomics as dealing with the quality of working and cognitive ergonomics as dealing with the quality of work including the joint system products. It is argued that classical ergonomics can be seen as embracing a dualism, where the effects of work on the body are considered separately from the effects of work on the mind. This continues the mechanistic tradition of Western psychology. The aim of cognitive ergonomics is to describe (1) how work affects the mind, as well as (2) how the mind affects work. Work is all in the mind in the sense that the quality of work depends on the person's understanding of the situation (goals, means, constraints) and in the sense that the design of a worksystem depends on the designer's understanding, in particular the conceptualization of the people in the system. In cognitive ergonomics, the reliability of performance—and in particular the reliability of cognition—become central issues. The differences between classical and cognitive ergonomics are illustrated by considering two typical areas: risks at work and human-computer interaction. It is concluded that classical and cognitive ergonomics represent two complementary views of work that must be combined to meet the challenges of present day work environments.

1. Introduction

The basic meaning of ergonomics is the science or study of work. In modern language, a common definition of ergonomics is 'a body of knowledge about human abilities, human limitations and human characteristics that are relevant to the design of tools, machines, systems, tasks, jobs, and environments for safe, comfortable and effective human use'. A slightly different view is taken by the definition that ergonomics is 'the applied science of equipment design, as for the workplace, intended to maximize productivity by reducing operator fatigue and discomfort'.

Either definition emphasizes two main aspects of ergonomics, the one having to do with the situation of the human at work, and the other having to do with the results or outcomes of work as well. The two aspects are clearly dependent, in the sense that the latter, the quality of the outcome (as, for example, maximum productivity) cannot easily be accomplished in the absence of the former, the quality of working. This is reflected by the second of the above definitions. The two aspects also correspond to two different perspectives of ergonomics (figure 1). One, which is here called *classical ergonomics*, is concerned with the *quality of working* and the focus is the human at work. Classical ergonomics, sometimes referred to as 'industrial ergonomics' or 'occupational biomechanics', concentrates on the physical aspects of work and human capabilities such as force, posture, and repetition. The other, which is here called *cognitive ergonomics*, is concerned with the *quality of work*, the focus being on the outcome or product that results from the efforts of the work system as well as work in itself. (In both cases 'work' should be taken in a

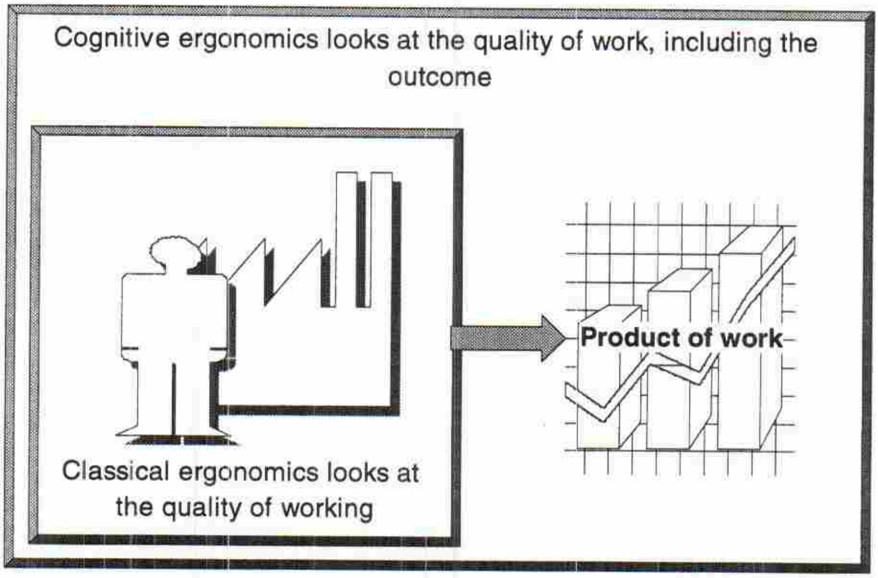

Figure 1. Classical and cognitive ergonomics.

broad sense, as meaning any physical or mental effort or activity directed toward the production or accomplishment of something, rather than in a restricted sense, as for example, manual labour.) Cognitive ergonomics, sometimes referred to as 'human factors engineering' or just 'human factors', is oriented to the psychological aspects of work both in how work affects the mind and how the mind affects work.

1.1. *Technology and amplification*

Ergonomics, or human factors engineering, came into being as an independent discipline in the late 1940s. At that time the need to design machines, operations, and work environments to match human capabilities and limitations had been clearly recognized, mainly because of the accelerated technological developments during World War II (Swain 1990). These developments had created work demands, in terms of, for example, speed, precision, and endurance, that could not easily be met by the unaided human. The consequence was a growing number of operational problems and incidents, often leading to unwanted consequences, which typically were attributed to the inability of people to meet the demands from the technology. Toward the end of the twentieth century the problems still remain, despite the considerable efforts that have been spent and the many solutions that have been proposed in the intervening time. The problem may in actual fact have become worse, due to the ever increasing complexity of the technological working environment.

The late 1940s saw the culmination of a development that had been conspicuous since the beginning of the industrial revolution, although the roots go even further back. This development can be described as the amplification of human working abilities that, in general, had the result that physical work had become simpler and less demanding. The industrial revolution that took place in England in the late eighteenth century, brought about an extensive mechanization of production systems that resulted in a shift from home-based hand manufacturing to large-scale factory production. One ingredient of that was the amplification of power that made it possible for humans to use their efforts to control machines that did the work, rather than doing the work themselves. This is often referred to by saying that 'muscles were replaced by machines'. Other improvements were in speed and in precision (improved product quality and reduced production costs).

The information revolution, for lack of a better description, that took place in the 1950s and 1960s extended the amplification to other domains of human activity, in particular to those dealing with regulation and control. As a result, practically all the elementary sensory-motor activities have now been taken over by technology, with the result that the nature of human work has changed dramatically. Instead of physical endurance, vigilance and sustained attention have become important. Instead of strength, problem-solving skills have become important. Instead of physical dexterity, planning and reasoning have become important. In the pre-industrial and early industrial times the human was predominantly a user of mechanical tools. Towards the end of the twentieth century, many human capabilities have become replaced by prostheses, first addressing functions of the body, later extending to functions of the mind.

2. The dualism of classical ergonomics

Classical ergonomics is concerned with the quality of working and has thereby become the science of designing for the body or for the physical aspects of work. This has implicitly created a dualism in the sense that the aspects of work that have to do with the mind are readily overseen. It may be a dualism in a pragmatic rather than in a philosophical sense, but it is a dualism none the less. The consequences of this implicit dualism have become more serious in recent years, as the nature of work has changed from work with the body to work with the mind—i.e. thinking rather than doing.

From its very beginning classical ergonomics has been concerned with how work affects the body. This is consistent with the Western tradition of empirical science and the importance of measurements. The ethos of classical ergonomics, and indeed of natural science, it to measure and to try to make everything measurable. There is an irresistible logic to this. Surely, work has obvious effects on the body in the short term (fatigue, soreness) as well as in the long term (strain, injuries, disabilities). The effects on the body may obviously be detrimental to work, and it is therefore reasonable to find out as much as possible about them: in other words how to measure and analyse them. Only by understanding the effects of work on the body shall we be able to do something about it, that is to develop solutions that will reduce the adverse effects—for the good of ourselves as well as the quality of work. Ultimately, the objective is to reduce operator fatigue and discomfort, thereby maximizing productivity. However, being measurable and being important are not the same thing.

It is also clear that work affects the mind. Again, there can be both short- and long-term effects, ranging from workload and stress to sleeping disorders, nervousness, etc. It is, however, less easy directly to measure the effects on the mind and in many cases it has been necessary to infer them from the more readily observable bodily effects. To the extent that the emphasis is on the effects of work for the person as an individual, short-term mental effects are often neglected to the benefit of long-term effects, perhaps because the former are transitory while the latter are stable. However, if the emphasis is changed to include also the effects on the outcome of work, then the short-term mental effects of work can be considerable. If we consider the effects of work on the quality of actions rather than on the body, and in particular realize the possibility for the occurrence of erroneous actions or performance failures, then the short-term effects become very important. This is a field where classical ergonomics has been supplemented by cognitive ergonomics, although it has not been as widely recognized as the study of the somatic effects of work.

There is, however, a third aspect that has gained increasing importance in recent years. That is how the mind affects work; or to be more precise, how the characteristics of human cognition affect the quality of work. Examples are found in relation to thinking, reasoning, understanding, diagnosis, cognitive control, memory heuristics, etc. The interest for this aspect of ergonomics has grown significantly over the last 20 – 30 years, not least due to a growing number of serious accidents (Reason 1990). These accidents have occurred within every industrial domain, and have with a growing frequency been put down to the cause of 'human error'. A little reflection, however, easily makes it clear that 'human error' is a rather complex phenomenon that deserves the full attention of ergonomics (Hollnagel 1993, Senders and Moray 1991).

2.1. *The mindless body*

With a little exaggeration one could say that classical ergonomics views the body as being without a mind, i.e. as being fundamentally a mechanism. This is entirely consistent with the dominant metaphors both in physiology and psychology. Even the much used analogy between the mind and an information processing system is based on a mechanical metaphor, and assumes that cognition is an epiphenomenon of information processing. Work is, however, never mindless. On the contrary, work is all in the mind.

2.1.1. *It's all in the mind (1):* Work is always work with the mind or by the mind. Even for simple physical work there is a need to plan and organize, hence a need to be in control. Classical ergonomics was focused on establishing and extending physical control, in terms of, for example, reach, speed, power. As mentioned above, the main effect of the industrial revolution was an amplification of the human capability to do physical work. This striving has been an unmitigated success, to the extent that it now has become necessary to extend amplification from the realm of the physical to the realm of the mental. In other words, it has become necessary to amplify cognition.

One of the major developments has been the merging of ergonomics with cognitive psychology, which is commonly referred to as cognitive ergonomics. Acknowledging the significance of human-machine interaction in almost all situations of interest, a definition might be that cognitive ergonomics is system design with the characteristics of the *joint cognitive system*, i.e. the operator and the computer, as a frame of reference (Hollnagel and Woods 1983). Cognitive ergonomics puts the focus on the way we think rather than the way we act, in particular on how people maintain control over their work. Cognitive ergonomics therefore requires that we learn how to measure the fit between work and mind in the same way that we can measure fit between work and body. The same descriptions may be used in both cases, such as stress, disturbances, lack of support, difficulties in interacting, but the meaning will be different. The emphasis is on the coupling between the technological workplace and people, rather than on the effects of one upon the other. It is worth noting that attenuation is a by-product of amplification. Just as the amplification of physical work has meant that there is less need for bodily strength, hence that there is an atrophy of the muscles, so automation and amplification of cognition may lead to an atrophy of mental skills and cognition. The loss of skills leads to a dependence on machines, which on the whole makes the system more vulnerable.

2.1.2. *It's all in the mind (2):* The conceptualization of work determines performance as much as the physical conditions do. This refers both to the people who do the work and the people who design the work environment. With regard to the first interpretation, the psychological and ergonomic literature is replete with examples of how actions depend on a person's understanding of a situation rather than on what it 'objectively' is. A spectacular example of that is the tail-first crash of China Air 140 into the runway at Nagoya on 26 April 1994. The final report from the accident investigation concluded that the crash was the result of the pilots fighting the autopilot, and that the pilots were inadequately trained in the 'use and operational characteristics' of the autopilot. It also faulted Airbus Industrie's cockpit design, specifically the position of the autopilot's Take-Off/Go-Around lever beneath the throttle; and 'unclear writing' in the Flight Crew Operations Manual. Another case is the Torrey Canyon disaster in 1967 where the collision was due mainly to the captain's incorrect understanding of the control mode of the autopilot (Casey 1993). To these can be added innumerable cases that occur every day but which, fortunately, have less spectacular outcomes.

In cognitive psychology the importance of how people conceptualize their work has been captured by the so-called perceptual circle described by Neisser (1976). The essence of this is that people's actions are determined by their understanding of the situation. This acknowledges that people may see the situation quite differently from what others, for example, the designer, expect or assume. The understanding is, in turn, modified by or adjusted to the information and feedback that is available, and that in turn is to a significant degree determined by the actions taken (figure 2).

The second interpretation points to how the work environment is basically determined by the designer's conceptualization of work, in particular the assumptions about the people who do the work. This conceptualization decides the design, hence also the nature of work. In cognitive ergonomics this is usually referred to as the designer's model of the user—particularly for systems where the work is composed mainly of human-computer interaction (Hollnagel and Woods 1983). On an even more fundamental level the design of the work environment reflects the fundamental philosophy about the nature of people, what characterizes their work, and what maintains their motivation to work. Such assumptions may not always be explicitly acknowledged, but rather remain embedded in the cultural stereotypes. Here industrial psychology, and by default also classical ergonomics, has during the twenthieth century embraced widely different philosophies about the nature of man. The most famous—and perhaps also the most influential—is that of Taylor's Scientific Management Theory (Taylor 1911). According to this view, tasks should be specified and designed in minute detail and workers should receive specific instructions about how the tasks should be carried out.

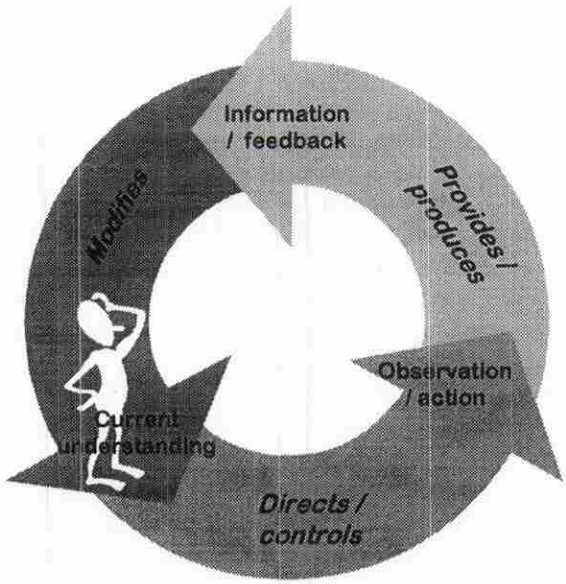

Figure 2. The perceptual circle (after Neisser 1976).

2.2. *From Taylorism to human information processing*

Taylorism was fortunately rather explicit in describing its basic premises and the assumptions about people at work. The basic attitude of scientific management was that people should be treated as machines, and that they effectively were part of the machines that carried out the process. This approach had to be relinquished when demands on human performance could no longer be met, unless tasks were broken down into steps that were ridiculously small. Classical ergonomics changed the view promoted in scientific management by emphasizing that people worked with machines rather than as part of them, and that man-machine communication could not be meaningfully discussed apart from the total man-machine system within which it occurred.

Whether one likes it or not, the design of work systems implies some assumptions about the nature of individuals. People can be seen as rational or emotional, as driven by rewards or by a need for self-actualization, and their actions can be described from a behavioural or a phenomenological standpoint. These issues have been widely debated in social and organizational psychology, but less so in ergonomics—although the impact on ergonomics is just as important. In our own time, and in particular in the last half of this century, the dominating philosophy has been that of the human as an information processing system. This can be summarized as follows:

- Human capacity for learning and adaptation is insufficient to meet the technological demands. This principle is a simple statement of fact that technology had made it possible to produce machines of all kinds that require faster or more complex reactions than people can normally provide.
- Human capacity for processing information is decisive for the capacity of the joint system (input-output relations). The analogy between the computer and

the brain appears to offer some fundamental explanations of the main functional characteristics of the human sensory and motor systems in terms of sensory ranges and thresholds, discriminability, reaction times, etc. Classical examples are Attneave (1959) and Miller (1967), the latter (in)famously known for the introduction of the 'magical number seven, plus or minus two' (Miller 1956), as a capacity limit for human short-term memory.

- The human operator can be described by terms that are appropriate for a technical system. Machines and processes have long been described in terms of flows of information and control, and the introduction of information processing psychology seemed to make it possible to describe the operator in the same way. Cybernetics and General Systems Theory (Ashby 1956, MacKay 1968) had achieved some success in explaining the brain as an adaptive system, and human performance as goal-driven rather than feedback driven. Together it appeared reasonable to describe the human operator as a complex information processing system.

Despite the growing sophistication of the assumptions about the psychological fabric of people, all these philosophies retain a basic mechanical flavour. In particular, the person is seen as a reactive 'machine', with the implication that a complete understanding can be achieved by following the principles of empirical science. This is, however, wrong. The quality of work depends on what the person intends, understands, expects, etc., as well as on the ability to learn and generalize. These aspects must therefore be included in a science of cognitive ergonomics.

3. Classical ergonomics

For the present discussion it is not necessary to enter into a detailed characterization of what classical ergonomics is or entails. Such descriptions can be found in a number of textbooks and guides. The purposes or goals of classical ergonomics characteristically address issues of a very tangible nature such as how to reduce occupational injury and illness; how to improve productivity; how to improve work quality—meaning the quality of working as such; and how to reduce absenteeism. These goals are pursued by a combination of methods that typically involve an appreciation of work site factors and the identification and quantification of conditions that may endanger these goals, followed by recommendation of appropriate engineering and administrative procedures and controls. At its present level of development, classical ergonomics has come a long way from F. W. Taylor's adage of 'fitting the person to the task'. Today the emphasis of the profession is rather the opposite, that is to 'fit the task to the person' (Chaffin and Andersson 1984). Even so, the profession of ergonomics assumes the classical type of workplace description, where the work setting is characterized by an interaction between the following parameters (figure 3):

- a worker with attributes of size, strength, range of motion, intellect, education, expectations, and other physical/mental capacities;
- a work setting comprised of parts, tools, furniture, control/display panels and other physical objects; and
- a work environment created by climate, lighting, noise, vibration, and other atmospheric qualities.

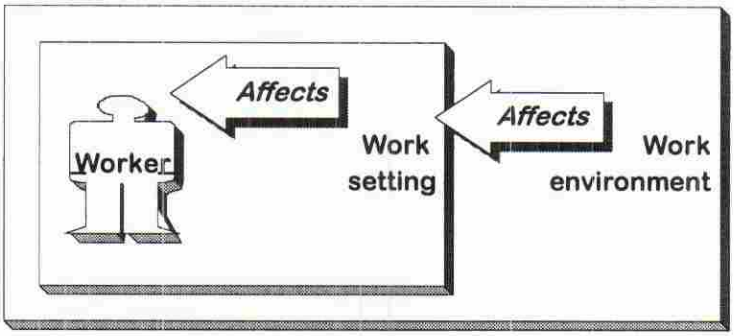

Figure 3. Workplace description in classical ergonomics.

The focus of this description is on the somatic aspects of work, and the influence is mainly seen as going in one direction. There is little explicit concern for the psychological work environment or for the organizational context of work. The work environment is described in terms of tangible, physical characteristics. The more comprehensive notion of a socio-technical work environment is therefore not easily reconciled with the classical description. This alternative, which is characteristic of cognitive ergonomics, sees work as taking place at the intersection of the technological work environment, the organizational work environment, and the psychological work environment of the person's conceptualization of the work (figure 4). In this view an understanding of the context as a whole as a product of the interaction among the three main aspects is a pre-condition for comprehending—and describing—the human at work.

4. Cognitive ergonomics

In cognitive ergonomics, the focus is on the reciprocal influence between work and mind. Although cognitive ergonomics has much in common with cognitive psychology, the purpose is not to try to understand the nature of human cognition but rather to describe how human cognition affects work and is affected by work. The characteristic topic areas of cognitive ergonomics include co-operative work, user interface design, modelling of users and systems, problem solving, learning and system design—especially the design of automation. A particular concern is the occurrence of situations that may negatively affect the outcome of work. Cognitive ergonomics should serve both to reduce the opportunity for such situations to occur, and to improve the possibility of compensating for them or reducing their impact when they occur. In this particular area the agenda for cognitive ergonomics is:

- to identify or predict the situations where problems may arise;
- to describe the conditions that may either be the cause of the problems or have a significant effect on how the situations develop; and
- to prescribe the means by which such situations can either be avoided or their impact reduced.

Although cognitive ergonomics requires some concepts about human cognition and some theories about how the human mind works, the proper pursuit of these matters is a task for cognitive psychology or cognitive science rather than cognitive

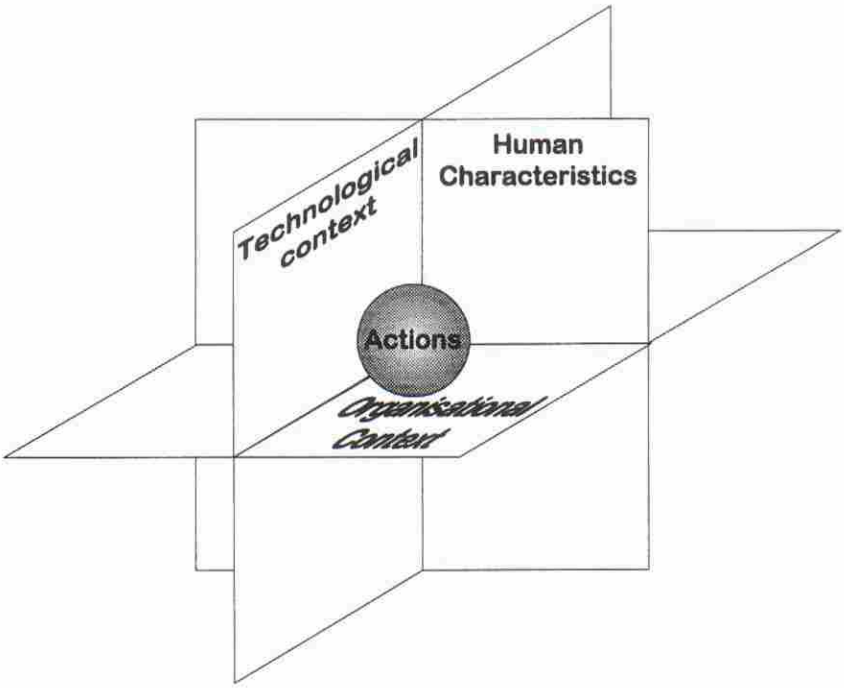

Figure 4. Work description in cognitive ergonomics.

ergonomics. The purpose of cognitive ergonomics is instead to improve system design with the characteristics of the joint cognitive system (the operator and the machine/computer) as a frame of reference. Cognitive ergonomics is thus very much concerned with the design and use of tools, and with the design of the work situation as a whole.

4.1. *The reliability of cognition*

The purpose of improving system design is both to advance the working conditions for the person and to increase the efficiency and safety of the overall system function. With regard to efficiency, cognitive ergonomics can build on the foundation laid by classical ergonomics and extend it to cover the socio-technical system as a whole. With regard to safety, the situation is a little different. Safety does not mean only the protection of the person doing the work, but also—and more often—the maintenance of overall system safety. Keeping in mind that the unsolved problem is the occurrence of unwanted consequences, one central concern must be how situations leading to such consequences can be reduced.

Unwanted consequences can occur for a number of reasons. One of the main categories is 'human error', which simply means that the cause of the unwanted consequence has been attributed to the human part of the system rather than to something else. In the absence of a clear taxonomy for human action, hence also for 'human error', one can use the concept of human reliability to capture the essence of the problem. The reason for using another concept on the same level of generality as 'human error', instead of a more specific term or a decomposition towards more fundamental functions, is that the latter would require a proper theory of human action. Although several such theories have been proposed, none of them are sufficiently developed to be of practical use.

A highly reliable system is one that performs according to the requirements of the task across a range of different initial conditions and different working conditions. This is quite important because we do not always know in detail all the conditions under which the system may be called upon to function. Human reliability is therefore clearly related to the lack of unwanted, unanticipated and unexplainable variance in the performance. In other words, it signifies the degree to which it is warranted to assume that human performance (under given circumstances) will be stable and correct. Cognitive reliability denotes the effect of cognition on human reliability; alternatively, it may be seen as the reliability of cognition (as a process) *per se*.

Cognitive ergonomics must offer practical guidance for the design of working environments where unexpected events are minimized, where there is proper and timely feedback so that the consequences of actions can be realized, where there is a possibility for either undoing or mitigating incorrect actions, and where the functioning of the system—including automatic safety measures and barriers—is comprehensible to the people working in the system, either by training or by workplace design. The reliability of cognition is about the quality of the performance of the joint system, rather than the reliability of an isolated, hypothetical process. In order to accomplish this, cognitive ergonomics must address both how the mind is affected by work and how work is affected by the mind. It requires an account of how the dynamics of the interaction between people and the working environment (technology, processes, computers) determine the overall quality of the outcome, in positive as well as negative directions.

5. Differences between classical and cognitive ergonomics

Classical and cognitive ergonomics have many similarities but also many differences. This can be illustrated by considering the different descriptions given of two important topics: the occurrence and effect of risks, and human-computer interaction (HCI).

5.1. *Risk in classical ergonomics*

In classical ergonomics, risks refer to the work characteristics or factors that may affect the quality of doing work (of working). These include task physical characteristics, posture, force, velocity and acceleration, repetition, duration, recovery time, heavy dynamic exertion, segmental vibration, environmental characteristics, heat stress, cold stress, whole body vibration, lighting, noise, etc. Through decades of empirical research, strong associations have been developed between risk conditions and worker injury, and it is generally accepted that as the physical demands of a task increase, the risk of injury increases until it is inevitable.

Just as there are many risk conditions, so there are many analytical tools. In any specific case the method used depends on the managerial philosopy of the organization (e.g. getting workers involved through a participatory process versus top/down process), the level of analysis (one job versus company-wide evaluation) and personal preferences. The methods are frequently orientated to a specific type of work (e.g. manual materials handling), or particular body part (e.g. wrist, low back). The methods may also vary greatly in their style of conclusions, from recommending a load weight limit for lifting to a quantification of activities associated with increased risk of injury or providing job prioritization for intervention.

Evaluation of ergonomic risk conditions generally involves the identification of the existence of risks followed by quantification of the degree of risk. Once the presence of risk factors has been established, the degree of risk associated with those factors is evaluated. It is the responsibility of the examiner to determine which analytical tool is best for evaluation of the identified risks based on an understanding of the tool's application, strengths, and weaknesses. Although most analytical tools at best provide only an approximation of the degree of risk, and despite the fact that many tools have not been tested adequately for reliability and validity, they still are able to provide a sufficiently accurate assessment of the risk.

5.2. *Risks in cognitive ergonomics*

In cognitive ergonomics, risks refer to those aspects of the working conditions that may lead to unwanted outcomes. Although risks usually have to be quantified, just as in classical ergonomics, it is also important for cognitive ergonomics to develop methods that can produce a comprehensive qualitative analysis of the risk conditions. Without this as a basis the quantification of risks easily becomes the 'mechanical' application of mathematical procedures that are conceptually empty.

The study of risks in work has traditionally been pursued in two different directions. One has been concerned with the analysis and explanation of accidents that have occurred. The other has been concerned with assessing the probability of accidents, specifically human erroneous actions. The former is known as the study of human error (Reason 1990, Senders and Moray 1991) while the latter is known as human reliability analysis. Human reliability analysis has for many years been practised by specialists with an engineering rather than an ergonomics/psychological background (Dougherty and Fragola 1988), but has in the last decade been studied also from a behavioural science background (Hollnagel 1993). This has resulted in making the engineering analyses more realistic, as well as emphasizing the necessity of seeing human actions in the larger context of the work system, rather than as nodes in a logical event tree.

The cognitive approach to the study of risks at work is epitomized by the so-called 'anatomy of an accident' (Green 1988). This is a powerful graphical representation of the principle pathways in a system that may lead to an accident. According to this description an accident begins when an unexpected event occurs while the system is working normally. Unless the unexpected event can be immediately neutralized, it will bring the system from a normal into an abnormal state. In the abnormal state attempts will be made, by people or by automatic systems, to control the failure. If this control fails, then the system will enter into a state of loss of control that means there will be some unwanted occurrences. Usually, even this possibility has been anticipated and specific barriers or obstacles have been provided. It is only in the case where these barriers are missing or when they fail to work according to their purpose, that the accident actually occurs. The 'anatomy of an accident' provides a powerful way of describing how human actions may contribute to work risks, either as the initiating event or as part of the responses.

5.3. *HCI in classical ergonomics*

In classical ergonomics, human-computer interaction is seen mainly in terms of measurable relations between the video display terminal (VDT) workstation and the user. For instance, the American National Standard for human factors engineering of VDTs addresses such issues as the appropriate angle between the upper arm and the forearm, the appropriate angle between the torso and the thigh, and the appropriate angle between the upper and lower leg. The standard also provides great detail on VDT workstation dimensions such as range of adjustability of chair height, work surface height, and knee room height/width.

The focus is thus on the comfort of the person at work, i.e. on how the VDT is used rather than on what the information is used for. To this can be added the ease by which the person is able to read information, discriminate between symbols, exercise control (pressing buttons, handling devices), all in terms of how much physiological or psychological strain the use of the VDT introduces. However, ensuring that the person does not run any risks of injury in either the short- or the long-term by using the VDT is not enough. The VDTs, and information technology artefacts in general, serve as a means to accomplish something. It is therefore important to be able to describe how well they fulfil that role. This is considered to be part of HCI design, but should obviously also be a part of ergonomics and cognitive ergonomics.

5.4. *HCI in cognitive ergonomics*

In cognitive ergonomics, human-computer interaction is seen as a way to achieve a goal, and the interest is on how well this can be achieved. The focus has therefore usually been on issues relating to how to present the information. The adage has been that one should try to provide the right information, in the right form, and at the right time. This is, however, easier said than done.

Owing to the proliferation of computers in every walk of life, the pursuit of HCI has become a discipline in its own right (Dowell and Long 1989) and has therefore to some extent become detached from ergonomics. This is not altogether a desirable state of affairs, because it means that the wider perspective that is provided by ergonomics is often lost in the pursuit of HCI. From the view of cognitive ergonomics, the important issues in HCI design are display formats, display elements, and display devices, as well as alarms and warnings, error detection and correction, information management, information integration (across tasks), support systems, training, degree of automation, etc.

From a cognitive ergonomics perspective the design of HCI involves more than the design of the actual display formats or screens. It must also include a comprehensive task analysis, a risk and reliability analysis, navigation analysis, and dialogue design (Hollnagel *et al.* 1993). Technology is never value neutral, and a new tool is always more than a simple addition to the system. If a new tool does not meet the user's expectations, or if it has not been considered as useful, it may be applied incorrectly or even be ignored. The outcome of work depends not only on the information that is provided, but also on whether people trust the information (Muir 1988). The user should feel comfortable with the system, as well as be comfortable in the actual work. Cognitive ergonomics can help to ensure that the mind is as comfortable at work as the body.

6. Conclusions

The contention of this paper has been that classical and cognitive ergonomics, for mostly historical reasons, have embodied two different views on the nature of work and therefore also two different views on the nature of humans as workers. The reason why this distinction has become important is that the nature of work has significantly changed in the last half of the twentieth century due to the general technological development — in particular the information technology revolution. This change in the nature of work means that classical ergonomics is unable adequately to consider the full scope of work. Today work is thinking rather than doing, i.e. it depends on the characteristics of the mind rather than the body. Even if the body could be suspended in a cocoon in perfect balance and without any physiological or biomechanical stresses, the mind would still be affected by the work situation and would in turn determine the quality of performance. Since we are rapidly approaching the state where the physical interaction with the working environment is reduced to a minimum, it is important that ergonomics take heed of this situation and develop appropriate models and methods to deal with it. Cognitive ergonomics is the practical expression of this concern, but should not be seen as antithetical to classical ergonomics. Rather, they should be used together to address, understand, and solve the problems of work towards the turn of the twentieth century.

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