Applied Ergonomics 45 (2014) 55–60

Contents lists available at SciVerse ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

Putting mind and body back together: A human-systems approach to the integration of the physical and cognitive dimensions of task design and operations

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ARTICLE INFO

Article history:
Received 8 September 2012
Accepted 21 March 2013

Keywords:
Human-systems integration
Ergonomics
Human factors
Biomechanics
Cognitive engineering

ABSTRACT

As human factors and ergonomics professionals we should be considering the total context within which the person must operate when performing a task, providing a service, or using a product. We have traditionally thought of the person as having a cognitive system and a physical system and much of our scientific literature has been myopically focused on one or the other of these systems while, in general, totally ignoring the other. However, contemporary efforts have begun to recognize the rich interactions occurring between these systems that can have a profound influence on performance and dictate overall system output. In addition, modern efforts are beginning to appreciate the many interactions between the various elements of the environment that can influence the components of the human systems. The next level of sophistication in the practice of human factors and ergonomics must begin to consider the totality of the human-system behavior and performance and must consider systems design interactions which result from these collective effects. Only then will we be able to truly optimize systems for human use.

1. Introduction

What makes a human factors specialist or ergonomist different from say a physiologist, psychologist, bioengineer, kinesiologist, physical therapist, industrial engineer, product designer, or sociologist? After all, each of these respective disciplines consider the human being relative to some aspect of their environment; yet human factors and ergonomists (HF/E) professionals are different and identify themselves as unique relative to these other groups of professionals. Special professional organizational structures and scientific societies have evolved across the globe to support the intellectual pursuits of the HF/E community. Obviously they feel their needs and their focus are unique compared to each of the other cited groups and professions, although it is also clear that there is much overlap between each of these respective pursuits. Yet we still need to identify what specifically distinguishes the HF/E professional from members of these other disciplines? What special or unique services are offered by the HF/E professional that can't be provided by any of the others? What aspects of science and research are truly unique to HF/E? For example, do we still need to clarify whether we are a foundational discipline or a hybrid science? Answers to such questions are essential as we continue to further establish and justify our role in an ever-changing technical world.

One could argue that the answer to these questions is centered on the ability of the ergonomist or human factors professional to analyze and consider the human situation in context. According to the Merriam-Webster online dictionary, context is defined as the *interrelated* conditions in which something exists or occurs (environment, setting). Furthermore, the Merriam-Webster Learner's Dictionary defines context as *the situation in which something happens: the group of conditions that exist where and when something happens*. In other words HF/E professionals consider the system within which the human must operate when performing some task, whether that task is performing a mentally or physically demanding task or interacting with a new product or design. The two key concepts associated with these definitions of context are "interrelated conditions" and "situation" in which something happens. A lay element of this interaction, as we shall see is the integration of the physical and cognitive aspects of human response (see also Hancock and Diaz, 2001).

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0003-6870/$ – see front matter
http://dx.doi.org/10.1016/j.apergo.2013.03.025

However, as a group of professionals do we ever really consider the full complexity of all relevant interrelated conditions or more colloquially the entire situation? From the origins of our field one could argue we have not. Human Factors evolved primarily from the United States aviation efforts during World War II (Chapanis, 1999). The original focus of these efforts was related to human error in military aviation where the cognitive behavior of the pilot was the major motivation for these efforts (see, e.g., Fitts and Jones, 1947). While these efforts were eventually expanded to include dimensions such as anthropometry and strength concerns (physical ergonomics), the majority of the efforts within the U.S. have traditionally revolved around cognitive issues.

In contrast, HF/E work outside of the U.S. and particularly within Europe has evolved from physical ergonomics and especially the bases in biomechanics (Grandjean, 1980) and exercise psychology (Astrand and Rodahl, 1970). Physical work effects on the human body formed the basis for much of this effort and go back to the vey origin of Ergonomics in its earliest conceptual and implementation phase (see British Industrial Fatigue Research Board, 1922; Jastrzebowski, 1857). These efforts have also expanded over time to now embrace cognitive concerns, but here again, the majority of the HF/E efforts are still thought of as physical in nature. Around the world, this still remains the majority perspective, on Ergonomics at least (IEA, 2012), although the precise profile is evolving differentially in varying countries across the globe.

Given these continuing biases in the orientation and practice of HF/E around the globe, do we really consider the human in full context with the world around them? The systems perspective protests that human considerations must include the essential and necessary interconnection between cognition and body (see e.g., Carayon et al., 1999; Clark, 1998). Yet, the practice of our science, until perhaps the most recent decade has typically considered almost exclusively the interplay between the operator cognition and the environment or the person's physical abilities and their environment. Two sides of this quintessential triangle are ubiquitously featured but the way in which the body affects cognition and cognition itself is embodied by its very nature are patently missing from our present approach. Given the contextual distinction in the definition of our uniqueness it is then highly problematic that we consider the human in context to the situation at hand but still separate out mind (brain) and body as if they were discrete elements. In short, why do we still split our consideration of the human at the neck?

As a result of the forgoing observations we believe it is now essential that we consider the entire human system and not just individual subsystems at play. If we do not, we will always be sub-optimizing our understanding. Therefore, this paper issues a specific call for our profession to move toward an integrated consideration of the entire human being in the context of the entire environmental system. In pursuit of this goal, we present a high level overview of the types of systems that must be considered in order for the HF/E community to fulfill its stated obligation and fulfill its unique attributional debt in considering the entire human-system in context.

2. The systems framework

The advantage of considering a situation via a systems framework is that one can consider, in a principled and organized manner, how all the components and subsystems of the system behave and interact (Dul et al., 2012; Vincent et al., 2012). It is only through an analysis of the systems behaviors that we can identify all the potentially significant parts and understand how these each interact to influence the system performance. It is important and gratifying to note that a more general tide toward the overall systems approach has reached and begun to impact our collective science; a trend that has been championed by a number of researchers and groups (see e.g., Carayon et al., 2013; Dul et al., 2012; Hendrick and Kleiner, 2002; Wilson et al., 2007, among others).

While we advocate for and applaud this macro-level strategy, we still have to consider manageable boundaries for effective analysis. In the human-systems context that we focus on here, we therefore consider three major components (see Fig. 1). First, the environmental context in which the person must operate should be evaluated and considered in terms of its potential influence on the human. Such environmental properties themselves range from physical sources of stress and their influences (e.g., Hancock et al., 2007; Hancock and Vasmatzidis, 1998; Szalma and Hancock, 2011) to specified physical task demands (Granata et al., 1996) to social considerations of the work environment (Leplat, 1991; Rasmussen et al., 1987). Given the origins and current foci of HF/E, the second major component involves the cognitive behavior of the human in the system. Third, is the physical behavior of the human within the system which thus comprises the final major component to be considered.

The long term goal of considering the human-system interaction should be to understand, describe and/or model the behavior of each of these interactive components and their combined effects on human perception of the environment and associated workload. We do not believe, of course, that this triad represents an exhaustive description of the wider socio-technical systems in which action occurs, since such even broader conceptions have already been articulated (see e.g., Carayon et al., 2013; Hancock, 2012) However, as our purpose here is to weld a much closer association between the physical and the cognitive dimensions of human performance in context, we are content to focus on these specific levels of description.

3. The task environment subsystem

The task environment consists of all the elements within that environment that play a role in the response of the human within that particular context. Typically, such an environmental context is formed by the profile of physical parameters but more and more it is seen as being contingent upon the cognitive appraisal of work. Humans respond according to how they interpret the conditions under which they must labor. Therefore, it is important to consider the influence of any and all environmental conditions that may

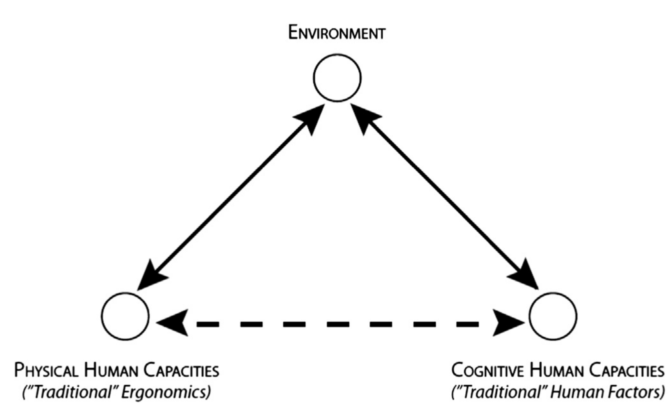

Fig. 1. Simple triadic representation of the present system linkages of concern – the strong links between physical capacities and the environment ("traditional" ergonomics) and cognitive capacities and the environment ("traditional" human factors) are contracted with the weak link (dotted line) between bodily effects on cognition and cognitive influences on physical capacities.

influence such appraisal and the outcome behavior. In particular, the social and cultural influences affect both explicit and implicit dimensions of such appraisal.

Numerous factors then influence the perception of the task at hand. Among the factors to be considered are:

1) Consideration of the physical environment should include everything that can influence perception. These include visual conditions, the auditory environment, thermal conditions, olfactory stimulation, as well as tactile and haptic information. Information regarding the interaction between these perceptual dimensions is also needed to properly consider their collective influence. Thus, as with the classic "Hawthorne effect," the environmental context of the work predicates both the nature and quality of that work. (and see Parsons, 1974).
2) The physical demands and associated stresses of the work or task at hand should also be considered since they define the extent to which the capacity of the human will be challenged (Hancock and Warm, 1989). Factors such as strength, energy expenditure, precision or acuity of manipulation, speed and repetition demands, required stability, kinematics and kinetics all need to be understood and expressed, most usefully on some common scale. In addition, it is important that we understand how these demands are interpreted and perceived by each individual operator within the system. Some work is teletic in nature and so perceived as hedonomic or welcome (Csikszentmihalyi, 1990). However many forms of work generate aversive appraisals from in both physical and cognitive sources.
3) Cognitive demand also needs to be understood in order to appreciate the system contextual effect. Demands such as mental processing, decision-making, multitasking, memory, problem solving, and the perception of each of these demands must necessarily be considered. We must also be cognizant of the fact that humans have a limited ability to process information. Therefore, when mental capacity for information processing is exhausted, these demands can be perceived of, and in reality become, overwhelming. Thus, as with all other factors, one must consider the interactive nature of these various dimensions of cognitive demand and the way they may lead to fatigue and exhaustion (Matthews et al., 2012).
4) Psychosocial dimensions includes factors such as perceived job demands, decision latitude and control, stimuli received from work, social support, job satisfaction, perceived stress, perceived emotion effort, ability to return to work and perceived risks associated with the work (see e.g., Carayon et al., 1999; Karasek and Theorell, 1992).

How these various factors independently influence perception of the environment is somewhat known however, our understanding of how they interact to influence perception of the world is far less understood. Understanding and resolving the interaction complexity challenge has become a major theoretical and methodological issue in many forms of complex system investigation (see Hancock, 2012).

As illustrated in Fig. 2, all these compared elements must be considered both independently and interactively in a holistic fashion if we are to appreciate how the environment influences the worker's perception and, ultimately, their interpretation of the task at hand. While there are rich bodies of literature describing the behavior of some of these individual components and their impact on performance, others have been less thoroughly explored. It is also fair to say that literature describing the interaction of such systems is only limited at best.

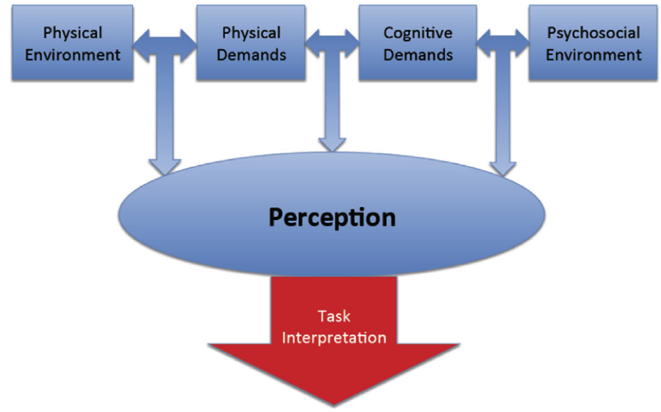

Fig. 2. The task environment subsystem components - these systems components must be considered interactively and collectively in their influence on perception and their role in task interpretation.

4. The human physical subsystem

Environmental demands are perceived and interpreted by the worker and one primary dimension of this impact is on their physical structure. This subsystem is presented schematically in Fig. 3. While this system is, for illustrative purposes, presented independently from the cognitive subsystem it must be particularly emphasized for our present purpose that there are critical interactions and interdependencies between these major subsystems and they are shown independently here only for the purposes of presentational clarity and not from a systems organizational perspective.

As shown in Fig. 3, the task interpretation (appraisal) is the output of the task environment subsystem (Fig. 2). The task interpretation is a primary form of input to the necessary process of cognition. Here, interpretive information is considered and modulated by both state and trait characteristics including personality (predisposed drives), genetically-based biases, as well as prior task experiences and task training. Via the motor system, cognition mediates muscle commands and coordinated muscle activation and recruitment sequencing is engaged which result in the intended action in order to achieve task completion. Typically, coordinated muscular activation serves to achieve desired goals but

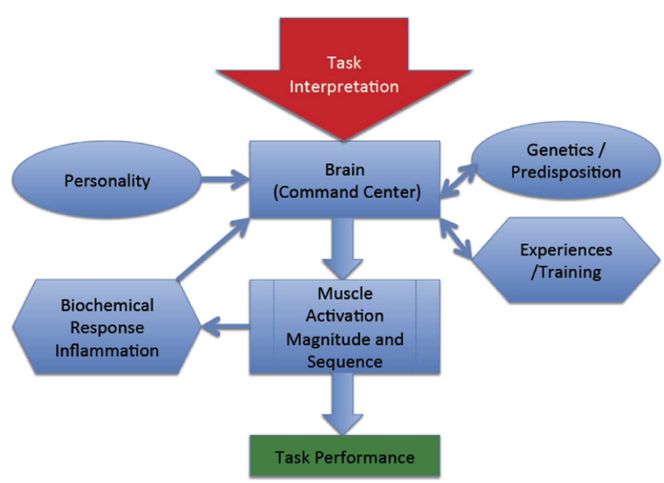

Fig. 3. Physical subsystem component organization – physical task performance response is influenced many non-physical factors as well as responses to the physical activity. All of these factors must be considered to understand physical reactions.

action in the world can also have inadvertent as well as intentional consequences.

There are multiple feedback loops present in all such systems. Activations of the human's physical plant also elicit biochemical responses. The biochemical system responds to many cues including infection, hormonal levels, genetic predisposition and mechanical forms of stress as well as critical acute, and chronic adaptations to the spectrum of environmental influences as we previously illustrated in Fig. 2. One important biochemical response, for example, involves pro-inflammatory cytokine responses to physical exertion. When muscles are overexerted a biochemical process is initiated that up-regulates pro-inflammatory cytokines. Increased cytokines make tissues much more prone to inflammation and thereby increase their sensitivity. This increased inflammatory reaction result in increased pain sensitivity and provides feedback to centers in the brain which in turn alter the muscle activation commands. Thus, this feedback loop can change the performance characteristics of the human as well as the experience of pain. Such feedback avenues are also related to both the physical and cognitive dimensions of fatigue.

We are beginning to understand the interplay between the various components of this individual physical subsystem in significant detail. As with the external task environment, this physical subsystem is conceived of as containing many important and necessary intra-subsystem interactions that serve to dictate overall response. It is important that we more fully understand these interconnections and better comprehend their hierarchical and holarcic nature (see Koestler, 1978). For example, we have yet to be able to fully describe the objective function of this system. While many have attempted to model this system conceptually as seeking the optimization of energy expenditure or of force production, real world validations of these nominal goals are still lacking. Some have proposed that satisfaction of intent and/or the perpetuation of comfort are the objects of optimization but these have also proved elusive to fully measure or quantify. Clearly, the corporeal system must subserve the goals of survival and procreation as they do with all other living systems. However, these are the elemental goals and the more complex and diverse aspirations that are derived from higher levels of cognition mean that simple, unitary forms (e.g., energy-use minimization) cannot represent the whole picture for the sophisticated human worker. This is why the systems-based integrative approach is not merely advisable but is critical as the next substantive step for our future progress. Unless we acknowledge and treat cognition and corporeality as one, we will always encounter terminal stumbling blocks to our understanding.

5. The human cognitive subsystem

The final major component of our focused level of analysis consists of the cognitive subsystem. As with the physical subsystem, centers in the brain consider a representative interpretation of the task at hand (Fig. 4). The system behavior is dictated by perceived cognitive demands relative to the available cognitive supply (Hancock and Meshkati, 1988). The ability to process information and make task decisions is dictated by the mental resources available to be dedicated to the task. Capacity can be limited by numerous sources of competing cognitive demand and there are also residual requirements to regulate the physical body in the vast majority of work circumstances. If a task requires extensive information processing, it becomes more and more difficult to dedicate sufficient cognitive resources to each of the task elements at hand. Fig. 4 also indicates that the relative balance of the demand versus resources can be biased by personality, certain generic dispositions, as well as training and experience. Such effects are also influenced by other energetic moderators such as stress and fatigue. If some of the required processing tasks are trained to automaticity, only residual cognitive resources are required to initiate task completion sequencing. More resources may then be dedicated to perform a major task at hand and such strategies are evident in incipient overload conditions (Hancock and Krueger, 2010). When supply exceeds cognitive demand then tasks are performed largely successfully but not flawlessly. In contrast when demand exceeds supply radical failure is evident. As with the physical system, this system can also be influenced by biochemical state. Low energy supplies can influence glucose levels and thus affect the ability of the system to process information (Fairclough and Houston, 2004; Gailliot, 2008).

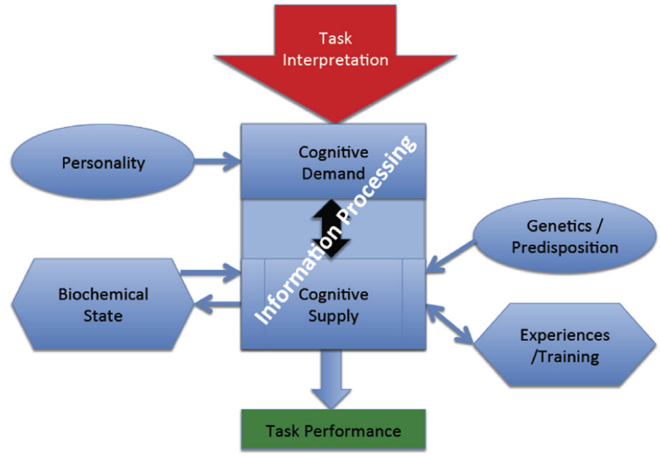

Fig. 4. Schematic representation of cognitive subsystem – significant interactions also influence the cognitive demand–supply relationship. These can be influence by perceptions, heredity, and physical responses byproducts.

Although there are many, and necessarily, intricate connections between the cognitive and the physical aspects of human capacities, perhaps one of the best ways to illustrate this interconnection is through the example of fatigue. From the genesis of our science, fatigue in its physical incarnation has been a subject of great concern. Long hours at work combined with heavy physical loads and punishing repetitions fixed the initial focus of attention on the problem of physical endurance. With the transfer in western societies to predominantly cognitive work, the center of concern has moved from muscle to cerebrum. Yet in both their expressions, the brain is the organ of mediation. In evolution, fatigue per se was a rare occurrence, since cessation of activity was under personal control most of the time (Hancock et al., 2012). Only under extreme compulsion could one reach the edges of personal tolerance (Hancock, 2009). And here there is a great balancing act. Does the brain continue to sustain physical effort when such effort could cause serious and potentially permanent injury and damage to the physical infrastructure. If the alternative is death or serious injury, then the answer is yes since apparently exhausted individuals can still put out an extraordinary level of residual effort if faced with destruction their incipient demise. If, on the other hand, the compulsion is a dilute one. (e.g., a telling off from one's supervisor for "slacking" or failure to gain extra class credit) then cessation is a much more appealing option. We see such trades today in arenas such as "two-a-day" sports training where coaches look to push their athletes to the very "edge" of endurance. Here, the coach also acts as a regulator beyond the brain of the individual athlete such that this social system encountering fatigue as a team rather than simply personal endeavor. What is of paramount interest for us is that even when individuals pass into unconsciousness (i.e., no conscious volitional action), the brain continues to function to protect the body from harm. Such examples illustrate the inseparable intimacy of brain and body which have often, and unfortunately been divided, largely for the convenience of reductionistic-inspired investigation, in the past history of our science.

6. Subsystem interactions

There are then significant interactions between the various components of the physical and cognitive subsystems. Indeed the fundamental nature of this global interaction has been the subject of philosophical debate for centuries. Sadly, our science has devoted insufficient attention to this vital debate. Even the psychosocial environment can interact with personality to interfere with muscle recruitment patterns. For example, one particular study showed how introverts when exposed to psychosocially stressful situations recruit their muscles in such a way that excessive loading occurs in the lumbar spine (Marras et al., 2000). Other studies have also demonstrated that tasks perceived to be mentally stressful result in a change in biochemical behavior within the physical subsystem (Yang et al., 2011; Splittstoesser et al., 2012). In these reports, when tasks were perceived as mentally stressful, muscle activities increases and thus initiating an increase in pro-inflammatory biochemical responses. These increases, in turn, may be anticipated to change pain sensitivity threshold after the manner in which muscles are recruited to perform a task. Many of these changes persist for days after the exposure indicating a significant temporal influence on the system and strong inertial effects due to stressful exposures.

7. Human-systems integration

Our brief discussion can, of course, only serve to illustrate a few of the numerous known interactions that occur between and within the subsystems we have identified as our present focus. However, if we are to truly consider the human within an environment, we must certainly take an even broader systems view in context. Most of the work in HF/E has accumulated in silos that have necessarily focused on some small component of the larger system. Perhaps this is an inevitable byproduct of a young and evolving discipline such as ours. If we now endeavor to comprehend and embrace the larger systems context we must understand how the task environment influences both the cognitive and physical human subsystem components in combination. Research is still needed to further understand the cognitive-physical interaction among the subsystems that define the elusive mind–body interaction (and see e.g., Perry et al., 2008). As nominal materialists, our science should then have diminishing issues integrating other physical components of interacting environments subsystems but then also proportionately greater challenges in integrating the higher social dimensions of interaction. An understanding of these respective interactions within and between the subsystems is needed for us to derive a full systems appreciation. Ultimately, the goal of such endeavors could be to model the entire system in a quantitative fashion so that we can predict the overall-system performance, with respect to risk, safety, and the probability assessment of incipient response degradation and failure.

8. Conclusions

Our very brief review has suggested that as human factors and ergonomics professionals we should be considering the total context within which the person must operate when performing a task or using a product. If "man is the measure of all things" then truly the human is already a system of systems within themselves. We have traditionally thought of the person as having a cognitive system and a physical system and our scientific literature has primarily been focused on one or the other of these systems while, in general, totally ignoring the other. Within each of these systems we have begun to recognize the many interactions that occurring between them (e.g., biochemical subsystems influence on biomechanical subsystems) that can have a profound influence performance and dictate overall response capacity. Although these systems have appeared separate and distinct in the past, our science can now no longer afford to sustain such artificial distinctions. We must take our next steps toward a holistic maturity.

Similarly, environmental context sets the stage or the initial conditions for human physical and cognitive systems. One should consider all aspects of the environmental context that can influence either the physical systems and subsystems coincidentally with the cognitive system and subsystems and any potential interactions within and between them. It is probably safe to say that very few ergonomics or human factors professionals view their professional responsibilities through this particular lens at this time. However, if we are going to truly live up to our distinctions as HF/E professionals we must expand our scope to include the consideration of all the human and environmental systems and subsystems. After all, there is little logic to separating the human at the neck or considering them outside of their environment. Our expectation is that as the utility of this emerging systems-based perspective is appreciated, the artificial divisions which have divided our science will fall away.

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