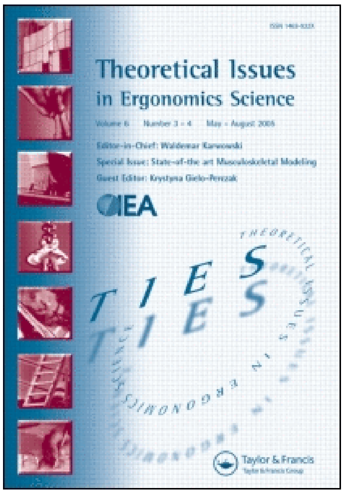

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Individual differences in human-technology interaction: incorporating variation in human characteristics into human factors and ergonomics research and design

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Theoretical Issues in Ergonomics Science
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Individual differences in human–technology interaction: incorporating variation in human characteristics into human factors and ergonomics research and design

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This paper argues for incorporation of an individual differences approach into human factors/ergonomics research and practice. Description of the systematic variation in the human portion (e.g. cognitive and personality traits; motivational and emotional states) of human–technology systems can complement the existing design methods (e.g. task analysis) to yield better models of system performance and improve system design and operation. Individual differences research should not and need not be atheoretical and opportunistic and applications should not and need not be restricted to selection. Instead, consideration of individual differences will lead to a more inclusive human factors/ergonomics in which the properties of the human are described in a level of detail commensurate with the properties of the displays and controls. Three theories are described and their implications for human factors/ergonomics are discussed. Key issues for future research and practice are identified, including a set of guidelines for implementing an individual differences approach.

Keywords: individual differences; human factors; ergonomics; personality; motivation; emotion; performance

1. Introduction: the problem of individual differences

Since the Second World War, research in perception and cognitive psychology has been successfully applied to the design of human–machine interfaces. Concepts from experimental psychology have been used to develop principles for display design (e.g. Wickens *et al.* 1998) and have more recently been applied to understanding the mechanisms that influence workload and stress (e.g. see Hancock and Desmond 2001). However, due in part to its origin in experimental psychology, human factors/ergonomics researchers and practitioners have adopted (sometimes implicitly) an approach to human information processing, decision making and response execution that focuses on universal mechanisms common to all without identifying the source of inter-individual variation (e.g. see Proctor and van Zandt 1994, their Figures 1-3 and 1-4; and see Wickens and Hollands 2000, especially their Figure 1.3). Although individual differences have been long recognised as an important topic within human factors (e.g. Wickens *et al.* 1998), manifested in a Technical Group of the Human Factors and Ergonomic Society, research in human factors and ergonomics has generally proceeded from the assumption of

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a motivated operator treated as a generic (i.e. average) person. That is, the psychological principles applied to human factors/ergonomics have been treated largely as universal in nature and within group variability has been treated either as error (Karwowski and Cuevas 2003) or as differences in ability/skill/experience. To be sure, there have been recent attempts to embrace the psychology of motivation and emotion and incorporate these phenomena into the design of artefacts and human technology interaction (Helander and Tham 2003, Norman 2004, Hancock *et al.* 2005). However, the general trend in human factors/ergonomics has been to represent the human as a 'black box' of general cognitive mechanisms, while affective traits and states have been relatively neglected (with the exception of stress, e.g. see Hancock and Desmond 2001). It is argued here that psychological theories of motivation, emotion and personality should be incorporated into human factors/ergonomics research and practice that parallels the successful application of theories of perception, cognition and psychomotor performance to ergonomic design issues.

The call for a synthesis of experimental and individual differences approaches in psychology is hardly new (Cronbach 1957, 1975, Vale and Vale 1969, Underwood 1975, Revelle and Oehlberg 2008), but if one is to have a truly 'human-centred' design approach the characteristics of the human certainly deserve the same level of detailed attention that the characteristics of displays and controls have received. Adequate description of the human operator characteristics, and their relation to system performance, is as important as the articulation of the characteristics of displays, controls and the tasks they support. To be clear, the purpose here is not to denigrate or in any way malign the accomplishments of a traditional human factors/ergonomics. Indeed there are more examples of successful applications of human factors/ergonomics to improving performance than could be summarised in even a moderately long text (e.g. application of Signal Detection Theory; Fitts Law; Wickens' 13 display principles) and nothing in this paper will, or could, attenuate the importance of these accomplishments. Rather, the purpose here is to define a fruitful next step in the evolution of the general approach to understand how humans interact with technology and how they perform tasks using that technology. A primary concern is the articulation of theories of motivation, emotion and personality that will serve as a foundation for both an individual differences approach to performance and for a broader, more inclusive human factors/ergonomics that incorporates a treatment of the human in a level of detail commensurate with the well-established principles and strategies for interface and training design.

1.1. *The human in human performance*

There has been a tradition dating back to the earliest days of psychology to apply the understanding of personality, motivation and emotion to human work and human performance (Boring 1950). However, these efforts have either been hampered by the emphasis on the technical (e.g. development of selection instruments) at the expense of the theoretical or they have not been well organised around a theoretical framework that would facilitate a systematic approach. What is needed is both a theoretical framework and an underlying paradigm that treats the human as more than a system component, but that incorporates theory and research on motivation, emotion, personality and cognition into 'human-centred design' in a manner specific enough to capture the individuality and the attendant unique needs of the human operators without losing the general principles common to most humans (e.g. 5th and 95th percentiles, principles of display and control design based on nomothetic human perceptual and motor characteristics) that are crucial for the design of effective technologies that facilitate performance as well as physical and psychological well-being. By analogy, one would not design an interface by ignoring the properties of a display crucial to the task or environmental variables that are crucial to performance (e.g. lighting), nor would one design a training programme that ignored skill sets fundamental to the task. Just as one would not neglect task or environmental characteristics in training and interface design, it is argued here that one should not ignore the differences across and within individual human operators in characteristics that may influence system performance.

1.2. *Nomothetic vs idiographic approaches*

The traditional approach within experimental psychology and within human factors/ergonomics has been nomothetic, that is, the identification of general laws and universal mechanisms underlying human behaviour. Within personality psychology there has been a debate regarding the appropriateness of this approach, as opposed to a more 'idiographic' approach, in which each individual is treated as a unique personality to be studied (for early examples, see Allport 1937, Eysenck 1954). At conferences the present author has heard individual differences research described as an 'idiographic approach' that complements the nomothetic approach of applied cognitive psychology. However, the currently dominant trait approach to personality is not idiographic, but falls firmly in the region of nomothetic research. Trait models assume that the characteristics described in their taxonomies (e.g. extraversion, emotional stability) are universal dimensions of human personality and that individual differences emerge in the magnitude of each dimension and the profile of magnitudes along multiple traits (Eysenck 1954, but see also Lamiell 2003). Hence, the separation of the two disciplines addressed by Cronbach (1957) more than half a century ago is not the result of irreconcilable differences in approach to psychological science. Indeed, it has been argued that both group and individual differences, particularly their interactive effects, must be understood for a complete understanding of human behaviour to be achieved (Vale and Vale 1969, Szalma 2008). Such a perspective has also been adopted across diverse areas in psychology, including emotion (Lazarus and Folkman 1984, Lazarus 1991, 1999, Matthews 2001) and perception (Gibson 1966) and even in personality research itself (e.g. Mischel and Shoda 1995). Incorporation of individual differences into human factors/ergonomics does not therefore require a shift in paradigm or general approach, but rather the inclusion of person characteristics into the existing nomothetic perspective (cf. Vale and Vale 1969, Underwood 1975).

2. Incorporating individual differences into human factors/ergonomics

To envision a successful application of an individual differences approach to human factors/ergonomics, the history of the field itself may serve as a guide. Development of current principles for design (e.g. Wickens' 13 display principles) was built upon a foundation of research in experimental psychology and theories of perception, cognition and motor performance. Hence, if one is to unpack the 'black box' of the human to identify the underlying elements, relevant theories and taxonomies of motivation, emotion and personality should be brought to bear in a manner analogous to that previously done with cognitive theories. However, a problem immediately presents itself for the human factors/ergonomics researcher/practitioner: Which of the many theories of motivation, emotion and personality should one use? Which have the greatest validity and scope? It is not possible to satisfactorily answer these questions in a single paper and, ultimately, the answer will depend on the biases of the individual researcher. There are models, however, that are sufficiently broad in scope that they may serve useful as general frameworks for research and application. Three such models are examined here, with the caveat that 'reasonable minds can disagree' and that one could easily identify other potentially useful approaches. These theories are self-determination theory, appraisal theory and the cognitive adaptive framework, for motivation, emotion and personality, respectively.

2.1. *Motivation: self-determination theory*

Efforts to understand how motivation develops and how it influences knowledge acquisition are complicated by the vast array of theoretical perspectives on the construct itself (e.g. see Reeve 2005). However, most theories share three components that represent core themes defining motivation (Atkinson and Birch 1978). These are: (1) direction (goals); (2) effort/energy; (3) persistence. A particularly useful framework for human factors/ergonomics is self-determination theory (SD theory; Deci and Ryan 1985). (Self-determination theory researchers generally refer to the theory as 'SDT.' A different notation has been adopted herein, 'SD theory', to avoid confusion with signal detection theory, which experimental psychologists and human factors professionals also refer to as 'SDT.' That such confusion has not been an issue until now is a testament to how separated and isolated from one another the two research areas are.)

This perspective is based on the 'organismic' assumption that humans are innately active and growth oriented and 'it assumes that human beings act on their internal and external environments to be effective and to satisfy the full range of their needs' (Deci and Ryan 1985, p. 8). SD theory also assumes that humans self-regulate by setting goals, finding means toward those goals and engaging their cognitive capacities to meet them. A third fundamental principle is that there are three innate and universal psychological needs that affect motivation, performance and well-being. These are the needs for autonomy, competence and relatedness. One of the aspects of this theory that differentiates it from other models of motivation is that these needs are not viewed as a deficiency (e.g. Hull 1943) or as something varying in intensity (e.g. Murray 1938, Atkinson 1964), but rather as 'universal necessities, as the nutriments that are essential for optimal human development and integrity' (Gagne and Deci 2005, p. 337).

Within self-determination theory, Deci and Ryan (1985) presented cognitive evaluation theory, which they developed to account for differences between intrinsic and extrinsic motivation. Intrinsic motivation is defined as motivation in which the energy behind behaviour is within the organism and is based in organismic needs to be competent and self-determined. It is a tendency to seek novelty, challenge and opportunities to effectively interact with one's environment (cf. White 1959, Bandura 1997). It is essentially motivation that is based on interest and, given the proper environmental conditions, will spontaneously emerge (Ryan and Deci 2000). By contrast, extrinsic motivation is energy for behaviour that is determined by forces external to the person, including reinforcement and punishment contingencies. SD theory asserts that environmental events that facilitate development of competence will tend to facilitate intrinsic motivation for the activity. Further, these effects occur only if the individual also experiences autonomy (Ryan and Deci 2000). The result of intrinsic motivation is to energise and maintain behaviour because of the satisfaction inherent in the behaviour itself (Deci *et al.* 1999). Intrinsic motivational states characterise the experience of 'flow' states (Csikszentmihalyi 1990).

An important difference between this theory and other theories of motivation is the recognition that there are qualitatively different forms of motivation (Deci and Ryan 2000). SD theory emphasises a distinction between autonomous and controlled motivation. Autonomous motivation occurs when the individual experiences choice (cf. Dember and Earl 1957) and an internal locus of control. This distinction is incorporated into a continuum of autonomous motivation, which ranges from fully extrinsic motivation, in which the source of volition is entirely external to the person, to fully autonomous, intrinsic motivation. In SD theory, five categories of motivated behaviour are identified that vary in the degree to which the motivation is self-determined. At one end of this continuum is intrinsic motivation and the other four categories reflect extrinsic motivation that vary in the degree to which regulation of behaviour is internalised by the individual; behaviour that can therefore be considered more autonomous and self-determined (Ryan and Deci 2000). The process of internalisation involves transforming an external regulation or value into one that matches one's own values.

At the extreme, *external regulation*, there is no internalisation of task goals and the behaviour is entirely controlled by external reward and punishment contingencies. The second level is *introjected regulation*, in which the individual adopts a goal but does not fully accept it as his/her own. Thus, the person is motivated by a desire to avoid guilt or anxiety, or to increase self-esteem. The third level of extrinsic motivation is *identified regulation*, in which the person accepts the goal as important to them personally. The most autonomous form of extrinsic motivation is *integrated regulation*, in which the goal has been incorporated or 'integrated' into the person's self-concept and the goal or activity is congruent with the person's values. In integrated regulation the activity becomes an integral part of the person's identity. In autonomous extrinsic motivation the person experiences a greater internal locus of causality and choice in doing the activity (Gagne and Deci 2005). What distinguishes integrated regulation from intrinsic motivation is that the latter is doing activities that are inherently interesting and enjoyable for their own sake, while the former is doing an activity that, although not inherently enjoyable or interesting, serves to meet higher order goals related to the self. It is this 'integrated motivation' that would likely characterise many well-designed work activities (although in some cases intrinsically motivated work activity may be possible; see Csikszentmihalyi 1990). For instance, Gagne and Deci (2005) provide an example of nurses who may feel relatively autonomous in performing tasks such as bathing patients, even though it is not intrinsically motivated behaviour.

2.1.1. *Identifying motivational affordances*

Self-determination theory emphasises the importance of social environments in determining whether a person is intrinsically motivated, or the degree to which the extrinsic motivation is autonomous. It is likely, however, that this tendency, which from Deci and Ryan's perspective is the result of evolution (Ryan *et al.* 1997), would manifest not only in interpersonal interaction but in human–technology interactions. It is therefore possible, in principle, to specify what could be termed the motivational affordances of a task (and social) environment (cf. McArthur and Baron 1983). Drawing on an analogy to ecological perception (Gibson 1966, 1979), it is likely that individuals, in appraising their environments, are able to detect the motivational invariances and affordances in the structure of the environment. For instance, individuals learn very quickly to expect certain forms of feedback (which in motivation theory could be delineated as 'controlling' or 'informational'; see Deci *et al.* 1999), which determines the affordance structure in the environment for autonomous performance as well as for learning and improving competence that subsequently drives motivational states to be more or less autonomous motivation. Such an interpretation and transformation from perception to motivation psychology is more congruent than it might seem at first glance. Indeed, Gibson (1966) viewed the social and even cultural environments as a source of stimulation. For example, Gibson wrote: 'If the response of one animal to another is considered a "social response", then the stimulus from the other animal is a "social stimulus", and we therefore need to consider the nature of this stimulus' (Gibson 1966, p. 23). The motivational and emotional affordances of other animals also extend to human-made artefacts and human–technology interactions.

Further, the idea of the person–environment interaction as being the key unit of analysis is central to the dominant motivation and emotion theories (e.g. Lazarus and Folkman 1984, Bandura 1997), as well as to older but very influential models of behaviour such as field theory (Lewin 1936). From the ecological perspective there is an on-going perception–action cycle in which the person's actions are constrained by both his/her capabilities and the physical properties of the environment that permit or 'afford' the action. In ecological perception, affordances describe what an individual can do with objects or events in the physical environment and are viewed as properties of that environment. As such, they only have existence as a function of *both* the environment and the properties of the individual (Zaff 1995). An affordance only exists in the relationship between the person and the environment. Thus, a motivational affordance can be viewed as properties of the social, physical and task environment that support different forms of motivation (i.e. intrinsic, extrinsic), but that also depend on the person's interpretation (i.e. attribution and appraisal) of the environment (e.g. whether they perceive feedback as 'controlling').

2.1.2. *Implications for human factors/ergonomics*

One implication of SD theory is that environmental structures and processes that facilitate fulfilment of the basic needs will promote intrinsic motivation, while those environments that thwart or neglect these needs undermine intrinsic motivation. The latter is unfortunately more characteristic of many work (and educational) environments than the former. Although SD theory has been applied to understanding the factors that influence work motivation (Gagne and Deci 2005), it has not been applied to human factors/ergonomics. A central question for human factors/ergonomics is the role that technology can play in promoting autonomy and competence and thereby facilitating intrinsically motivated operators. Gagne and Deci (2005) argued that creating environments that promote satisfaction of the three needs will increase intrinsic motivation and integrated regulation and will result in more effective performance on complex tasks, such as those requiring creativity, as well as increased well-being and job satisfaction. They also indicated that internalisation of task goals is facilitated by three factors: (1) providing a meaningful rationale for doing the task; (2) acknowledging that the activity may not be interesting to the person; (3) emphasising choice rather than control by an external authority. They propose that autonomous extrinsic motivation will be effective in improving allocation of effort to persist on uninteresting tasks and that intrinsic motivation will predict persistence on interesting tasks. Although they presented their analysis in the context of applications of motivation theory to industrial/organisational psychology, these factors are also relevant for human factors/ergonomics. There are many instances in which human–technology interfaces are designed for complex systems that include tasks that are not particularly interesting (e.g. fault monitoring in automation). In principle, SD theory could be applied to the design of triggering criteria and the dynamic allocation of function between human and machine to be done in a way that does not undermine autonomy and competence (Wiener 1988). By contrast, systems that impair or inhibit autonomy and relatedness, and either fail to support or actually damage development of competence, will impair motivation, self-regulatory processes (and the associated effort regulation), adaptation and, very likely, performance. To underscore the importance of choice, there is evidence that providing even a small degree of personal control over a monitoring task can have facilitative performance effects (Dember *et al.* 1992) and reduce operator stress (Gunn *et al.* 2005). Further, there is evidence that the use of feedback, a common approach to training for task performance, can impact the motivational state of the individual. Hence, Deci *et al.* (1999) reported that feedback that is experienced as controlling will undermine autonomous motivation, while feedback that is informational but promotes autonomy and competence does not undermine such motivation.

The notion that promoting autonomy and competence is important for motivation and performance may seem like an obvious truism that provides no new insights into human–technology interaction. Indeed, an implicit assumption in much of the work in human factors of the past half century has been that the tasks are performed by 'motivated operators'. However, the level of motivation has been *assumed* but not thoroughly addressed theoretically or measured empirically, and little research has examined the complex interaction of specific elements of a task, the characteristics of the environment that are motivationally relevant, and the characteristics of the person to influence autonomous work motivation (Gagne and Deci 2005). Human factors/ergonomics, as a field, is well equipped to examine such interactions and only needs the intrinsic motivation to do so.

2.2. *Emotion: appraisal theories*

Although appraisal theories date back to the late 1950s/early 1960s (e.g. Arnold 1960; for a recent discussion see Ellsworth and Scherer 2003), one of the most influential models has been the cognitive–motivational-relational theory (Lazarus and Folkman 1984, Lazarus 1991, 1999). There are two concepts central to this theory that are particularly relevant for human factors/ergonomics: person–environment transactions and the concept of appraisal itself.

The concept of person–environment transaction is not, at its core, a completely new idea, as Lazarus himself noted (Lazarus 1999). What Lazarus did was to take this idea and place it within the context of a theory of stress and emotion, identifying the transaction as the fundamental unit of analysis and appraisals as a central mechanism in controlling this on-going process.

The idea of appraisal has at its core: (1) the cognitive evaluation of events that are perceived; (2) the meaning of these events for a person's psychological or physical well-being. Note that the term 'meaning' does not necessarily imply a purely conscious mechanism. Like other cognitive processes, appraisal of meaning can be automatic and outside of awareness. Lazarus identified two fundamental mechanisms, primary and secondary appraisals. Primary appraisals occur when objects and events are evaluated for their relevance to the person's physical or psychological well-being (Lazarus and Folkman 1984, Lazarus 1991). Secondary appraisals are evaluations of coping options regarding the event; how to respond to the event (whether positive or negative). Secondary appraisals are characterised by evaluations of blame or credit for the event (which would include attributions of causality), coping potential, and future expectations (positive or negative expectancies; Lazarus 1991). Further, these appraisal processes are continuous and on-going, such that secondary appraisals lead to decisions and execution of response, which impacts the environment, which, in turn, is appraised (Lazarus referred to this as 'reappraisal', but such a term seems unnecessary as appraisals occur continuously throughout an individual's interaction with the environment).

The centrality of the human–environment transaction as the fundamental unit of analysis is reflected in the identification of core relational themes of emotions, which are the patterns of appraisal of harm or benefit associated with each emotion (Lazarus 1991). Core relational themes are, by definition, a product of a person's appraisal of environmental events (thus, 'relational') and they are viewed in this framework as universal themes. Recently, there have been efforts to specify the details of appraisal processes via computational or neural network models (e.g. Sander *et al.* 2005). The component process model described by Sander *et al.* (2005) specifies the underlying mechanisms, both cognitive and physiological, of the appraisal process and the generation of emotions.

2.2.1. *Implications for human factors/ergonomics*

This perspective has already been incorporated into human factors/ergonomics as part of efforts to understand and mitigate the effects of stress on performance (e.g. Matthews 2001), but should now be extended to *hedonomics* to permit further application to a 'positive psychology' of design (for a definition of hedonomics, see Helander and Tham (2003), Hancock *et al.* (2005)). Appraisal theories have been applied to human factors and ergonomics research in the context of the effects of workload and stress on performance (e.g. see Proctor and van Zandt 1994, Wickens *et al.* 1998). However, the individual differences within and between persons that influence these appraisals, and the effects of particular aspects of appraisal on information processing and cognitive state, are less well researched (Scherer 1999, Szalma and Hancock 2005). In addition, there has been little research regarding the role of appraisals in individual differences in human–technology interaction, information processing (Szalma and Hancock 2005) or in affective design (e.g. Jordan 2000, Norman 2004, but for an exception see Desmet 2004). Similarly, the role of cognitive and affective traits and states on appraisal processes, while examined extensively in clinical, health and social psychological research, has not been thoroughly examined in the context of human–technology interaction or interface design. Given that appraisals are an important step in information processing and decision making, the identification of factors that influence appraisal mechanisms is a crucial topic for future research.

2.3. *Personality: the cognitive-adaptive framework*

There has emerged a perspective in personality psychology that has integrated the 'two disciplines' identified by Cronbach (1957). Matthews (1997, 2008, Matthews and Zeidner 2004) has applied a cognitive science perspective to personality, emotion and self-regulation. This framework has at its core an 'adaptive triangle' consisting of (primarily cognitive) skills, knowledge structures and (adaptive) behaviour itself (see Figure 1).

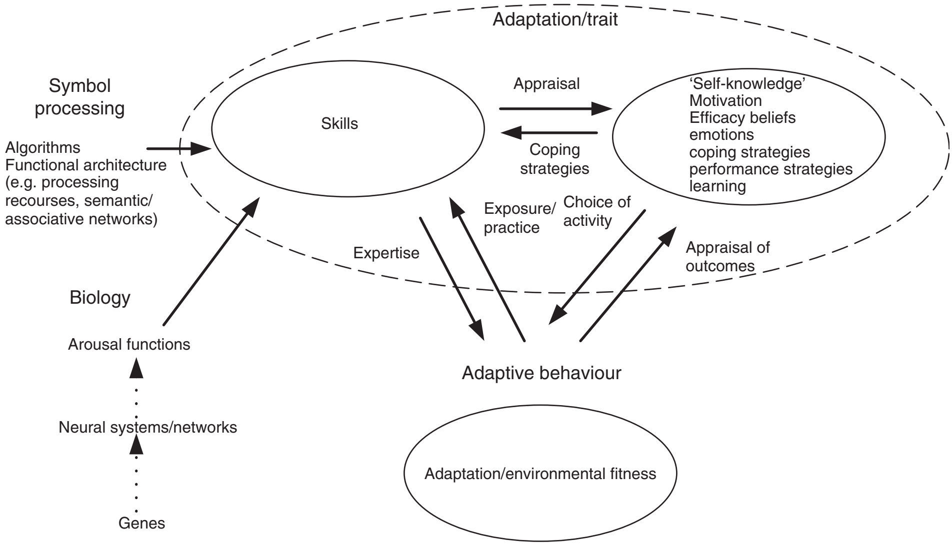

Figure 1. The cognitive-adaptive framework, illustrating the 'adaptive triangle' of skill, knowledge and action and the multiple levels of analysis. Adapted from Matthews and Zeidner (2004).

Skill is delineated into its components considered at multiple levels, including cognitive (symbol manipulation, algorithms), neurological (e.g. arousal mechanisms) and genetic. The knowledge structures are decomposed into motivation, coping strategies and self-efficacy. These processes influence appraisals, which, in turn, determine cognitive state.

A key assertion of this perspective is that differences in levels on a trait are not directly related to adaptive behaviour. Thus, one cannot reasonably argue (from this perspective) that high or low extraversion, or even high neuroticism, is 'bad' or 'maladaptive' in general. Rather, different traits are better suited to different environments (Matthews *et al.* 2003). For instance, extraversion is associated with better adaptation to time-pressured environments requiring divided attention, while introverts are better suited to under-load situations such as vigilance. Individuals high in trait anxiety are ill-suited to time-pressured environments, but they are more sensitive to potentially threatening stimuli than individuals low on that trait. Indeed, a potentially fruitful area for future research is to examine how such individuals respond to threat detection tasks inherent in many complex human–machine systems. The adaptation of individuals with a particular pattern or 'syndrome' of characteristics that constitute a trait cannot be determined independent of the environmental context. What is needed is a framework within which these different topics (motivation, emotion and personality) can be integrated both structurally and in terms of mechanisms of operation. The cognitive-adaptive framework provides such a general structure and the relations among the structural components. As a practical matter, one could implement the synthesis of task and person characteristics and their effects on performance by identifying, via existing taxonomy or by task analysis, the relevant features of an interface and then the relevant characteristics (physical, psychological, traits, states of the person) and empirically evaluate the effect on outcome variables of systematically varying combinations of person and environment characteristics. Such data could then be used to fit a mathematical function of the person–interface interaction.

3. Application of individual differences to interface design: moving beyond selection

To date, when an individual differences approach to human factors/ergonomics is adopted, it is justified by pointing towards application to selection. Another often discussed application of motivation and emotion, and of individual differences generally, is that such an approach permits the design of interfaces and training procedures that can be customised to the needs of the user. However, there are many cases in human factors/ergonomics where operator selection is not possible or desirable (e.g. consumer products, mass-produced military equipment). Similarly, customisable interfaces or training procedures may be desirable in some domains (e.g. consumer products), in many environments (e.g. military, aviation) there is a need for standardisation. These concerns may lead some to conclude that individual differences are not applicable to many domains. However, improved selection and customisation are not the only benefits of an individual differences approach. Indeed, it may be that it is in the design of standard interfaces and training procedures that such an approach can make its most powerful impact. Specifically, consideration of individual differences can improve the understanding of human–technology interaction by accounting for more variability in behaviour between operators/users (and within operators/users over time) and by increasing the accuracy and precision of theoretical models of human and system performance. Further, knowledge of how variability within and across individuals affects human–technology interaction can improve interface and training design by making such designs more inclusive. That is, by considering human variation in the design process, it is more likely that interfaces and training procedures will be created that account for that variability. It is therefore time for the science of human factors/ergonomics to move beyond selection to fully realise the potential of including individual differences analyses in both research and practice.

3.1. *The challenge of principles*

A key element missing from existing theories, such as those described previously, is an explicit set of principles (or a paradigm for approaching problems) for application of the frameworks to interface design. The case has been made regarding the importance of individual differences in human factors/ergonomics, but specific principles and methods are needed if this approach is to be adopted. In other words, what would be desirable is a person analogue of the 13 principles of display design described by Wickens, and methods of 'person analysis' analogous to task analysis methodologies. This is clearly a matter for future research, which will need to determine how the measures of motivation, emotion and personality can be transformed into metrics that can be incorporated into the interface design process. Perhaps this may be accomplished by including the person in a task analysis or by conducting a parallel 'person analysis' to be integrated with the task analysis. This would likely result in a complex set of vectors that combine to predict system state at a given point in time and how that state may fluctuate as its component vectors (e.g. environmental conditions, operator mood, motivational state) change. Fortunately, current theories and methods in human factors/ergonomics can be modified to include individual differences.

3.1.1. *An example: symvatology*

One way to quantify and integrate the person and the environment is to adopt the approach of symvatology (science of compatibility), which is concerned with the identification of quantitative laws that govern human–artefact compatibility (Karwowski 2006). As is often the case in the behavioural sciences, it can be difficult to establish valid quantitative measures in cases where the unit of analysis is an interaction between the person and his/her environment. In symvatology, this problem is addressed by using entropy as a measure of human–artefact compatibility. The entropy of each component of the overall system (the human, H, the artefact, A, the environment, N, and time, T) are combined to yield an overall estimate of total system (S) compatibility (for a more detailed description, see Karwowski 2000).

Individual differences can be incorporated into symvatology by inclusion of affective and cognitive traits and states, as well as physical characteristics, to the human (H-subsystem) component of the model. If these variables could be represented in the H-system entropy function, this would, in principle, improve the accuracy and precision of the estimate of the entropy of the human component. An important issue for future research will therefore be to determine how measures of personality, motivation and emotion may be mathematically transformed to be represented in entropy models of symvatology.

3.1.2. *Task analysis and person analysis*

Task analysis involves breaking a task down into its sub-components, elements consisting of an action verb and a noun (Ainsworth 2006). The question is whether the same approach can be taken to 'person analysis', whereby the individual is analysed into cognitive and affective traits and states. The knowledge base is currently too sparse to implement such an approach immediately to a complete description of the individual, but it does support directions for research and application. To conduct a person analysis would require knowing:

(1) the states and traits relevant to a particular human–artefact system;
(2) how variation along each of these person dimensions relates to variation in task and environmental dimensions;
(3) how the different components combine and interact to determine system behaviour.

To obtain this information requires a theoretical model that describes and explains the multivariate relations. This could take the form of adding person characteristics to existing nomothetic models of human performance, or it could mean a transformation to a new person–environment unit of analysis function (e.g. entropy functions in symvatology).

When the demands of the task have been articulated via cognitive task analysis (e.g. Crandall *et al*. 2006), the relationship between each demand (e.g. working memory, time pressure, spatial rotation) could be linked to the traits/states known to affect the cognitive capacities required for task performance and these could then be used to identify learning objectives for training as well as modification of interfaces to support performance across a broad range of trait/state profiles. A particular challenge will be to incorporate design features that serve the needs of individuals with a particular characteristic (e.g. high in trait anxiety) while not interfering with the use of the interface by individuals who do not show that characteristic (e.g. individuals low in trait anxiety). That is, it will be important to meet the needs of the individual while maintaining the standardisation and general usability of the interface. To the extent that this can be accomplished, the interface design will be more inclusive and reduce performance variability across users. In a sense, an individual differences approach can potentially reduce individual differences in human–technology interaction, thereby improving both performance and operator/user well-being.

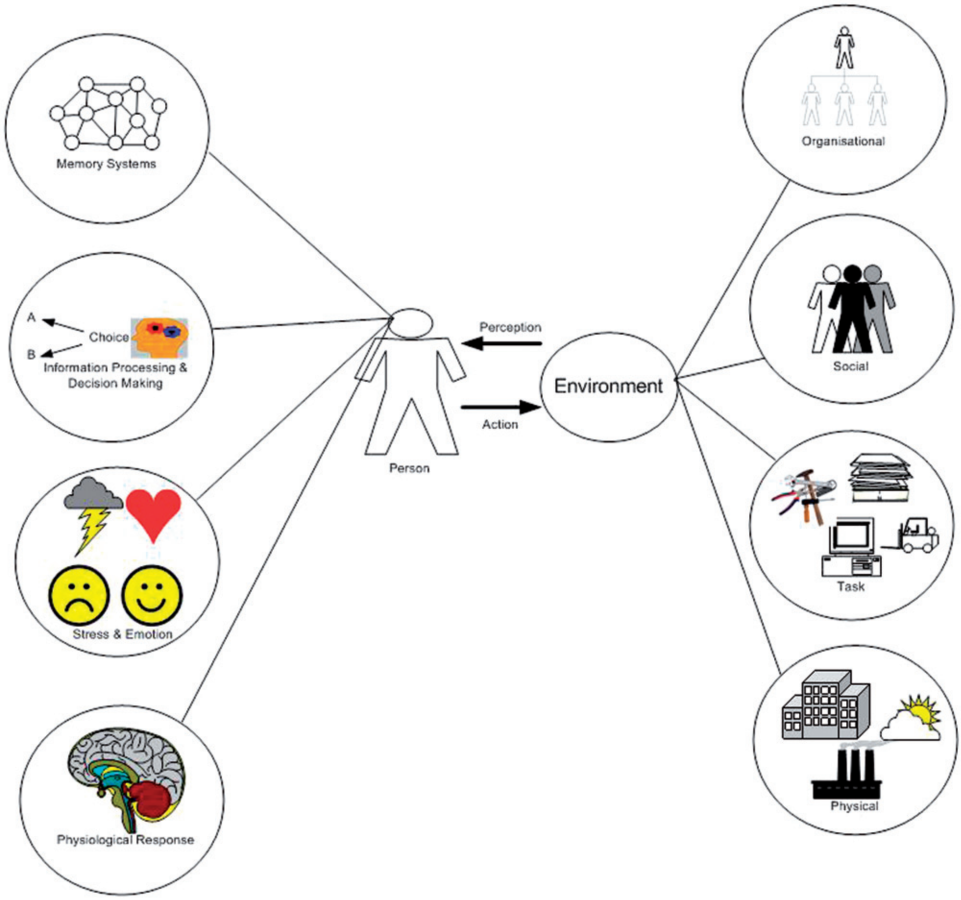

Figure 2. A 'universal' model of human–machine interaction. The human characteristics are treated as universal, such that variations across individuals are considered either error variance or trivial variance. The focus of this approach is to determine how changes in the environment impact psychological processes of operators and how changes in those processes impact operator response.

4. Summary and conclusions: incorporating motivation, emotion and personality human factors/ergonomics

Human factors textbooks (e.g. Sanders and McCormick 1993, Proctor and van Zandt 1994, Wickens *et al*. 1998) present a representation of systems as consisting of the combination of the physical interface (displays and controls) and one or more humans that perform functions directed towards a common goal. System function is influenced by variables external to the system that include both the physical and social environments. The relationship between the demands of the task, the characteristics of the interface that support performance and the cognitive, perceptual and psychomotor processes of the operator are often represented in models such as the one shown in Figure 2. Two aspects of such models are relevant here. First, human factors/ergonomics emphasises the relationship between (general) human characteristics and machine characteristics. Second, the human characteristics are treated as 'the' psychological processes within 'the' human. Such an approach implicitly treats the human component of the system as a component with universal properties. Incorporation of an individual differences perspective would result in

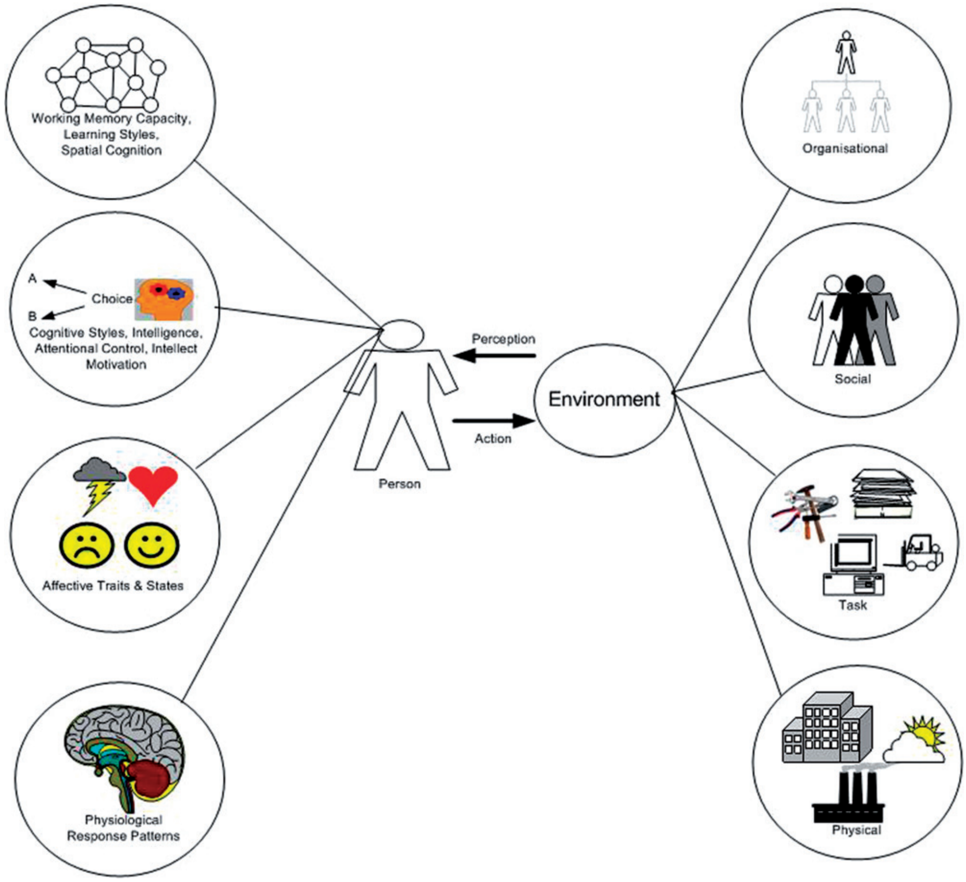

Figure 3. An individual differences model of human–machine interaction. Human characteristics are universal (i.e. nomothetic), but variation across individuals is considered systematic, relevant and measurable. The focus of this approach is to determine how variation in both the environment and the individual interact to influence overall system performance. Note that the focus is still on the human–environment transaction, but that variation in characteristics of the human are incorporated.

a modified model, as shown in Figure 3, in which the machine/task elements and the environmental factors are retained but the 'human component' is replaced by a more detailed description of stable traits and transient states that reflect both universal psychological processes and differences in the characteristics of the human that influence the operation of these processes. By specifying the human characteristics that contribute to system performance and, ultimately, how they interact with task and interface characteristics (a major issue for future research), a more complete model of system performance can be developed, thereby improving the application of design principles to interfaces as well as to training regimens.

5. Specific recommendations/guidelines

A primary purpose for this paper was to call attention to the relatively neglected issue of how individual differences in person characteristics affect human–machine interaction.

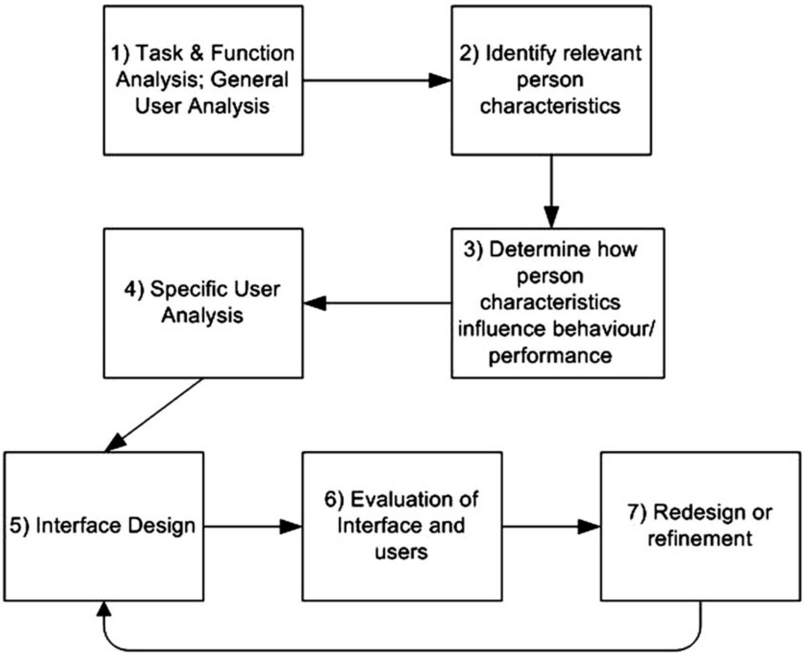

Figure 4. General guidelines for incorporating individual differences into design.

However, there have been many 'calls to arms' to combine the traditional experimental psychology approaches and individual differences approaches to understanding human behaviour (Vale and Vale 1969, Cronbach 1957, 1975) and human–technology interaction (Karwowski and Cuevas 2003). As indicated previously, what is needed is a set of methods and procedures for incorporating individual differences into existing human factors/ergonomics methodologies. This will require further research and articulation of a complete methodology is beyond the scope of this paper. However, it is possible to identify steps that can be based on current research and methodology. Concrete recommendations for the steps in such application are delineated below (also see Figure 4). These are intended as initial, general guidelines. Future research should seek to modify these steps and to specify details within each step.

(1) Conduct user analyses to identify interface requirements. Identify task characteristics and cognitive/perceptual/motor functions that underlie them using established techniques of task analysis and cognitive task analysis.
(2) Based on the task and user analyses, identify the person characteristics and what variables are most likely to influence the person–task interaction.
(3) Determine, through review of literature or empirical research, how the person variables separately and jointly influence the cognitive/perceptual/motor capacities identified by the task analysis.
(4) Using methods of usability engineering (e.g. Leventhal and Barnes 2008), identify user needs. Two categories of needs should be evaluated:

    (a) General needs that any user, regardless of their individual characteristics, would need (based on analyses in step 1).

(b) Specific needs for subgroups fitting a particular state/trait profile. The design features that serve the sub-groups (e.g. individuals high in trait anxiety) should not interfere with others not in the sub-group (e.g. individuals low in anxiety).

(5) Design the prototype interface (or training procedures) based on the evidence gathered in the previous steps.
(6) Evaluate the effect of the interface on behaviour, incorporating the person variables into the evaluation.
(7) Iteratively modify/refine the interface/training design based on results of the evaluation.

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