Ergonomists and Usability Engineers Encounter Test Method Dilemmas with Virtual Work Environments

Ari Putkonen and Ursula Hyrkkänen

Turku University of Applied Sciences, Sepänkatu 3, 20700 Turku, Finland
ari.putkonen@turkuamk.fi

Abstract. Today's ergonomists and usability engineers need a broad understanding of the characteristics and demands of complex sociotechnical systems in order to develop virtual work systems and mobile communication tools for workers. Familiarity with appropriate ergonomics tests and evaluation methods is a prerequisite of this understanding. The literature review about ergonomics methods was performed. Applicable, potential and inapplicable ergonomics test methods for virtual work systems have been identified, based on the validity analysis and case example. The large number of available methods is confusing for ergonomists and therefore a hierarchical top-down approach is needed for method selection. The issues highlighted in this paper may be useful for ergonomists and usability practitioners who are participating design processes in complex virtual work environments.

Keywords: ergonomics, work system design, human-centred design, virtual work, test methods.

1 Introduction

The capacity of workers to percept and process information is burdened with the complexity and high demands of working life. Knowledge of the complexity factors of the overall work system is essential for an in depth understanding of human working capabilities and limitations [17]. It is also essential for proper test methods selection during design process. The complexity of work is usually considered as a factor related to the task. At one end the task is creative and demanding and at the other end it is simple and routine-like [2].

Working environments are changing from the traditional model. An increasing amount of work takes place in networked and virtual environments which are not tied to one place and time. The work is defined 'mobile', if the employee works more than ten hours per week outside of the primary workplace and uses information and communication technology (ICT) for communication [9], [29]. The use of ICT tools generates the virtual work environment. The planning of working conditions becomes challenging, because there is a lack of proper tools for analysing and testing mobile working conditions.

Society is becoming more and more dynamic and complexity of work is increasing, this has several implications that cause new challenges to the ergonomists and usability engineers. Rapid develop in technologies along with economic demands

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have led to a noticeable increase in the complexity of engineering systems. Rasmussen [22] emphasises that ergonomic contributions should be rather proactive than only responding to identified problems, but especially, they should be based on overall models of complex socio-technical systems [6]. In complex socio-technical system the increasing number of operation levels requires also that broader circumstances are considered during the product design process.

This paper presents the ergonomic test method dilemmas related to complex virtual work environments from the perspective of the design process of ICT devices intend for use in such an environment. The questions to be studied are; (i) How the complex virtual work environment can be described as a hierarchical work system, in order to support human-centred design approach and ergonomics method selection? (ii) What are the applicable ergonomic methods to use in complex virtual environment?

This article is organised as follows. The first chapter introduces the principles of the complex system design, the complexity factors of virtual work, the known dilemmas of method selection and the abstraction hierarchy model applied in this study. Next the methodological and empirical context of this study is presented. Thereafter, the article describes the results of the empirical cases illustrating the complexity of mobile work done in virtual spaces. Finally, the results of the article and some suggestions for ergonomic methods selection are summarised and discussed.

2 Development Methods of Complex Systems

In the 1960s Christopher Alexander and Herbert Simon developed early theories about how to design complex systems [7]. Since then, several design frameworks have been presented in theoretical and applied literature. The fundamental conclusion of these studies is that the larger work systems have to consider when there is a need to understand human-technology interaction, capabilities and limitations better [17].

2.1 Design Principles

Human-centred design is a design method for complex systems that addresses such problems by focusing mainly on the user [21]. There are some principles how the human-centred design approach can be realised. Norman [21] defines it as a process which starts with a multidisciplinary team that includes members from marketing, technology and user of product. The first task is to determine the product. According to Norman this seems to be obvious, but it is the most commonly ignored or badly examined task. Based on a thorough task analysis, the design process continues with the human-centred activities, like usability engineering [20]. The human-centred design process for interactive systems is formally described in ISO standard 13407 [13]. It formulates that human-centred design as a multidisciplinary activity, which incorporates human factors and ergonomics knowledge and techniques to enhance effectiveness and productivity, while improving human working conditions.

Task analysis is the process of analysing the way humans perform their jobs: the things they do, the things they act on and the things they need to know. This process will identify and document the user's tasks and significant user attributes. Overall

analysis of the user's tasks is the foundation of a human-centred design method. Different task analysis techniques exist, e.g. Hierarchical Task Analysis [5], [23].

It has been emphasised by Ulrich and Eppinger [28] that system-level issues are critical when developing complex systems including many integrating subsystems and components. The architecture for the overall system has to be addressed at the system-level design phase. Ulrich and Eppinger [28] also remind that the experience of the environment of the product or the context in which the users work or live is essential. Otherwise irrelevant product features may be developed and solutions for users' real needs may never be discovered.

Macroergonomics is a top-down approach to the design of work system, where the design characteristics of the overall work system are carried to the design of human interfaces. There are three criteria what are essential for an effective work system design: (i) joint design purpose of personnel subsystem and technological subsystem, which should be developed simultaneously and supported by employee participation thorough the entire design process; (ii) humanised task approach concerned with human functions and tasks in the work system, prior to the decision to allocate tasks to workers or devices; (iii) consideration of the organisation's sociotechnical characteristics, which should be evaluated and integrated into the design process of work system. When the selected development methodology fulfils the above mentioned three criteria design is human-centred and macroergonomic [10].

2.2 Virtual Work Environment and Its Complexity Factors

Working across organisational, geographical, cultural and temporal boundaries, increases the complexity of work systems [6], [12]. These demands are met especially in virtual work environments.

The concept 'virtual' is widely used in various frameworks. There is much discussion of virtual space, virtual groups and virtual organisation. Virtual space is used for communication and collaboration: it refers to electronic working environment where documents, messages and images and even avatars are stored, exchanged, retrieved and worked. Virtual group signifies a number of persons, who are to a certain extent dispersed in space and sometimes also in time, communicating through the media [3].

The complexity of work is usually considered as a factor related to the task [2]. The expanded complexity concept considers also the working environment that can be a different combination of physical, virtual, social and cultural spaces.

Vartiainen [29] has described the complexity of virtual team working contexts by applying the model of six complexity characteristics. The characteristics are mobility, geographical dispersion of the workplaces, diversity of actors, asynchronous working time, temporary structure of the working groups and mediated interaction. These six dimensions form in addition to task complexity a set of requirements that can also considered as ergonomic challenges for constructing virtual working space [19].

According to the previous studies the challenges of virtual work entails many novel questions for ergonomics discipline. For example working in virtual, geographically distributed manner has influence on working procedures, coordination and communication [8], [18]. It has also been proven that virtual, multi-seated work increases the physical distance of the workers of the main team and hinders face to face communication of the team. Non-verbal cues are absent in mediated communication

and this may easily lead to misunderstandings and lack of trust. Especially the global groups have members with different backgrounds, which may further create communication problems. The temporary nature of projects leads to loose social engagement due to the limited expectations of working together again. Asynchronous work time in relation to the main team makes further demands on communication. On account of this, the proper functioning of ICT technologies is compulsory.

2.3 Dilemma of Ergonomics Methods Selection

Ergonomics methods have been classified by various aspects by authors. They are, for instance, either evaluative or analytic [4], empirical or non-empirical [14], expert or non-expert performed, time consuming or fast, expensive or inexpensive and they can relate to different stages of the design process [24]. The one aim of classification has been to support the selection of applicable methods in design process.

Table 1. Summary of the ergonomics methods selected for consideration

Method	Overview/Objective	Type of approach	Work system context to consider
Checklists	Design evaluation and finding of improvements	evaluative	Human-Device interactions
Heuristics	Design evaluation and finding of improvements	evaluative	Human-Device interactions
Layout analysis	Examining of display and control layouts, device optimisation	evaluative	Human-Task interactions
Questionnaires	Predicts user satisfaction and perception	evaluative	Human-Task interactions
Hierarchical task analysis, HTA	Describes the task in terms of a hierarchy of operations	analytic	Human-Task interactions
Focus groups	Participates users and customers in discussion	evaluative	Work Process interactions
Observations	Expert observes users as they work in real work context	evaluative	Human-Task interactions
Error prediction methods	Systematic human error reduction and prediction	analytic	Human-Task interactions
Repertory grids	Predicts user satisfaction and perception	evaluative	Human-Device interactions
Link analysis	Examination of the way humans use displays, device optimisation	evaluative	Human-Task interactions
Keystroke level model, KLM	Measures speed of performance	analytic	Human-Task interactions
Interviews	Obtains in-depth data about a particular process or tasks	evaluative	Work Process interactions
Walkthrough	User do and explain demonstration of a task in realistic environment	evaluative	Work Process interactions
Macroergonomic analysis and design, MEAD	Framework for conducting work system improvements	analytic	Organisational interactions
Participatory ergonomics	Employee involvement in their own work activity design	evaluative	Organisational interactions

Some selection guidelines have been proposed in the literature as well. For instance, Kjeldskov and Skov [16] state that more realistic test environment and more experienced subjects discover more problems from the system. Stanton [26] states that the methods have to be selected by the required output of the test or analysis, choices are; errors, performance, usability or design characteristics. Hendrick and Kleiner [10] emphasise that early observation of the system's complexity is an increasingly important managerial task in order to design a work system where the well-being of workers and the overall system performance are in balance.

The fifteen ergonomics methods selected for consideration in this study are listed in Table 1. For each method the following information is given: an overview with an indication of objective, type of approach and typical context to use in the work system. The methods were selected based upon the patterns of usage [27], methods for macroergonomics applications [11] and our analysis, so that these are a representative variety of ergonomics methods to cover the analyses and evaluation needs of complex work system. Besides of above mentioned sources the details of these methods are presented in a number of ergonomics text books [15], [26].

2.4 The Abstraction Hierarchy as a Framework

The Abstraction Hierarchy (AH) is one of the best known representation frameworks describing complex work environments and adaptive sociotechnical systems [22]. The AH describes a system at different levels of abstraction using how and why relationships. Moving down the model levels answers how certain elements in the system are achieved, whereas moving up reveals why certain elements exist. Elements at highest level of the model define the purposes, goals and constrains of the system. Elements at the lowest levels of the model indicate and describe the physical forms (e.g. ICT device) of the system.

3 Method and Data Collection

The aim of this article is to depict how the well-known methods of ergonomic assessment function in virtual work sets. The question can be placed in the field of validity research. Validity refers to the degree to which a study accurately reflects or assesses the specific concept that the researcher is attempting to measure. While reliability is concerned with the accuracy of the actual instrument of measurement or procedure, validity is concerned with the study's success at measuring what the researchers set out to measure. Especially this study was directed to first steps of building an assessment framework for exploring construct and content validity of the ergonomic evaluation methods [1], [25].

First the assessment tool was constructed by defining the hierarchical model for complex, virtual work. This was done by using the AH as a theoretical framework for creating a model of the virtual work structure. Articles concerning the definition of virtual work environment, ergonomics methods and complex systems were extracted from databases. After that, expert proceeding was used to analyse articles and to construct a frame of reference applicable for describing the hierarchical system of virtual work and it's environment.

A single case study was used for testing the developed framework. The case was selected in cooperation with a company, operating some 800 service centres in more than

40 countries, the company's call centres are linked with the service offices and 13,000 employees. The selected group was one of their mobile maintenance groups (N=8). Information of this case was gathered by observing the work of theirs and by individual interviews. The data was coded with the assistance of the developed framework and classification. After the framework and classification tool was acceptable the existing and commonly known ergonomic evaluation methods were set against it.

4 Results of the Study

The studied virtual work organisation is described as a hierarchical work structure in Table 2. The abstraction hierarchy levels from the physical form to the functional

Table 2. Abstraction hierarchy of the virtual work system of the mobile workers

Whole/Part Means/Ends	Individual, mobile worker	Functional unit, service team	Sub-system, service centre	Total system, corporation
Functional purpose	Keeps up the machine	Accomplish customer service and maintenance on particular geographical region	Customer service and maintenance of products world wide	Worldwide business operations with industrial products
Abstract function	Service and maintenance of specific machines	Service and maintenance of the products	Plan and sustain availability, performance, efficiency and safety of the products	Manufacturing, marketing and service
Generalised functions	Planning of the service operations and travel logistics	Allocation of work force, job scheduling, improving of efficiency and quality	Worldwide service execution, customer management, control of safety requirements and legislation	Conducting strategy, running business, planning operations, coordination of units
Physical function, process and activity	Performs service tasks, utilises information and communication tools, travels	Data transfer between domains, decision making, customer contact management	Proactive service planning, negotiations and agreements with customers, invoicing	Customer relation management, financing planning, target setting, capacity planning
Physical form	Service in domain context, machines, tools, computers, documents, reports	Joint meetings in various places, shared calendar and tasks, work orders, reports	Office facilities, technical documentation, data network, servers, databases	Office facilities, data network, mainframes, databases

purpose interrelate with different sub-systems of organisation (whole/part), i.e. individual, functional unit, sub-system and total system. The smallest work system is individual as a mobile worker in this case. The functional unit represents a service team, which consist of some individuals. The service centre of the corporation is such a sub-system. Corporation level stands for the total system of the case organisation.

Vertically moving on the work system levels (means/ends) shows the how and why relationships between levels. Upper element answers why lower element exists and lower element tells how upper element is achieved. At the bottom mobile workers service machines in the domain context. At the next level, managers are planning operations and supplying resources to the mobile workers. Variety of managerial plans and functions are needed to maintain operations of sub-systems and, finally, the purpose of corporation is setting priorities through strategies and company policy.

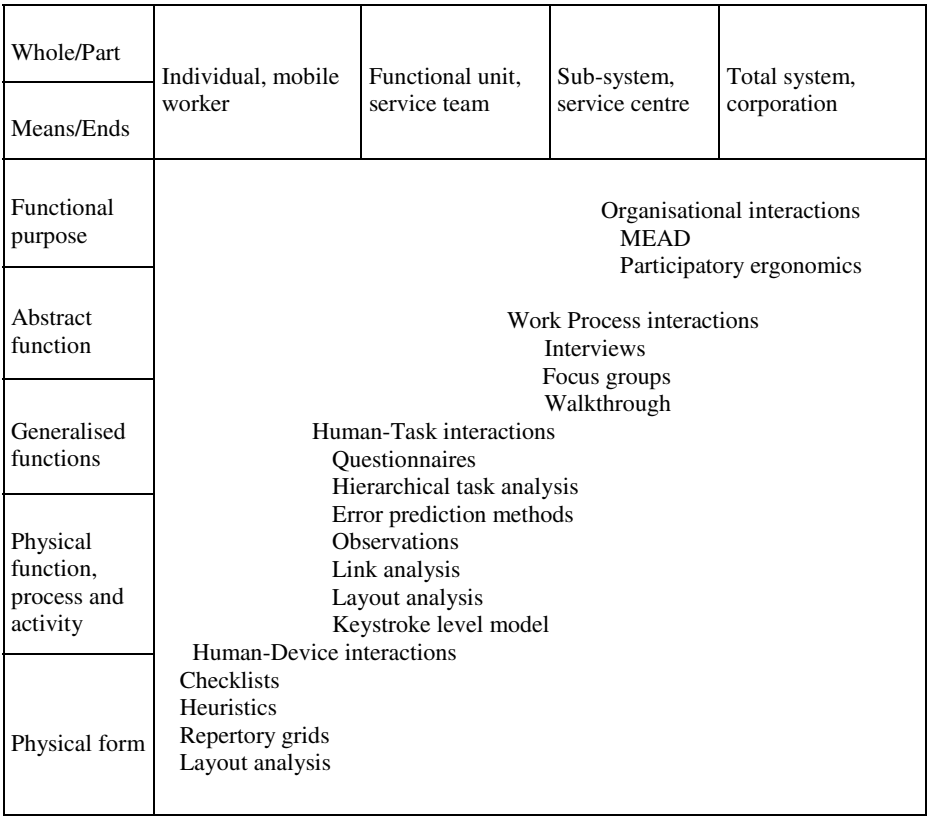

Fig. 1. Applicability of known ergonomics methods related to the work system's abstraction and organisational levels

Figure 1 depicts the abstraction hierarchy of the virtual work system as described above completed with the classified ergonomics methods. The upper the hierarchy level and the larger the system the more complex is the environment. The methods are

classified to four categories: human-device, human-task, work process and organisational interaction. The methods are not in certain order inside the category. The figure emphasises the hierarchy level between categories as indicating applicability to cover ergonomic development challenges in virtual work environment. Methods related the human-device and human-task interactions do not cover the development needs of the total system nor the ergonomic situation of the corporation. The methods in the work process and organisational categories are more potential and appropriate in virtual work environment.

5 Discussion

This paper aimed to answer for two questions about ergonomics methods and their use in complex virtual work environment. First the complex virtual work environment was analysed as a work system with the reference the case organisation. A frame of reference applicable to describing the hierarchical work system in virtual work was constructed with help of the AH –model. This new model supports the human-centred design approach and ergonomics method selection by the comprehensive approach.

The applicable ergonomic methods for complex virtual work environment assessment were identified by classifying them according to the extent of work complexity. They were classified to categories of human-device, human-task, work process and organisational interaction. The methods in work process and organisational categories are more applicable in virtual work environment than the methods considering human-device or human-task interactions. Methods related the human-device and human-task sub-systems only do not clarify the ergonomic situation of the total system nor the ergonomic situation of the corporation. Anyhow, human-device and human-task type of methods may also be valid in virtual work environment. It requires that the ergonomic analysis is first performed at upper functional levels and the obtained consequences are further derived to the specific sub-system as source data.

As organisations emerge towards virtual work environments, the need for advanced design methods will increase. However, analysing, measuring and developing the ergonomics of virtual environments is a difficult assignment. Identifying complexity factors of these environments and recognising limitations of existing design methods is a good start. The existing selection recommendations of ergonomics methods are mainly based on the concept of traditional organisational work. This study contributes to the discussion by offering one approach for selecting the ergonomics methods for virtual work environment.

When the functioning of the entire virtual working environment is under development, a human-system interaction and the entire work organization and socio-technical system have to be taken jointly into consideration. Macroergonomics is an approach of work systems design which attempts to achieve a fully harmonised work system. In the future, macroergonomics should be more common knowledge among ergonomists and usability engineers in order to meet the design and development challenges of complex work environments. This means, for example, that workers should be more involved in the design and implementation of technology and new information and communication systems in organisations. Our paper can hopefully highlight this significantly important issue in the future and encourage researchers for further studies.

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