

Improving Human Cognitive Processing by Applying Accessibility Standards for Information and Communication Technology

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Abstract. This article concerns with human-computer-interaction (HCI) from a neuroscientific perspective. The motivation for this perspective is the demographic transition, which shifts population structures of industrial nations. The authors will explain consequences of the demographic transition in terms of HCI and establish a hypothesis for these research activities. To evaluate this hypothesis the authors develop an approach, which combines different disciplines. This approach examines the effects of IT-accessibility on human cognitive processing. Therefore, required methodologies and instruments will be explained, discussed and selected. Possible effects of IT-accessibility on human cognitive processing will be illustrated with an acknowledged cognition model. The result of this article will be a concept, which enables the measurement of IT-accessibility impacts on human cognitive processing.

Keywords: Information systems, Accessibility, Neuroscience, Usability, Cognitive processing.

1 Introduction

Practically no enterprise relinquishes the application of information systems today. The major goal is to support business processes to increase efficiency and productivity. However, due to the commoditization of information technology, the pure deployment of these systems is no longer a competitive advantage (Carr, 2003). Productivity and efficiency are significantly determined by the capabilities of users to interact with applied information systems to achieve specific goals. The design and development of information systems therefore need to focus on human behavior and capabilities. Figure 1 depicts an ideal-typical goal attainment process that is supported by an information system.

Steps 1 to 4 in figure 1 will be normally reiterated. At the end of each iteration the processed data output (step 3) should inform the system user about the achieved progress. The user will interpret (step 4) this information to plan and execute the next activity. After a certain amount of iterations the system user should attain the goal in step 6. If the user is not able to attain the goal after a certain amount of iterations, the process will be aborted by the user. Depending on task complexity step 4 might be

skipped. The time, needed to achieve the goal, decreases with the amount of interferences during this process. Interferences can be for example, loading times, system failures, operating problems, perception problems or comprehension problems.

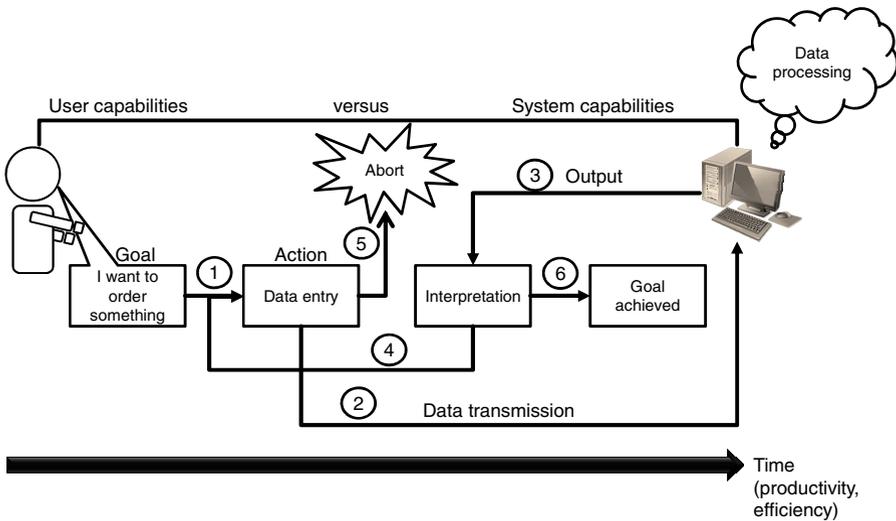


Fig. 1. Goal attainment process

2 Background

The demographic transition of industrialized nations leads to a declining and at the same time ageing population (Lutz et al., 2011). While the amount of young people aged 15-24 stagnates respectively declines, the amount of people aged 60 or over increases significantly (United Nations, 2010). In addition, increased life expectancies and the intergenerational contract demands employees to retire at a later date (Sanderson et al., 2010; Leon, 2011). Referring to these facts, the authors identified three consequences, which will affect the design and development of information systems.

Consequence 1: A higher susceptibility to disorders or injuries related to computer work has to be anticipated. A study conducted in 2001 revealed injuries and disabilities induced by computer work. The mean age of the study participants was 38.5 years (Pascarelli et al., 2001).

Consequence 2: Enterprises will need additional human capital sources to compensate the lack of young personnel. To date, enterprises do not sufficiently concern with the integration of people with impairments or disabilities. In 2003 approximately 45 Mio people of the declared working age population either had a disability or an enduring health problem (Eurostat, 2003). According to the demographic alterations, this figure is likely to increase within the next decades, as elderly people are more susceptible to impairments and disabilities (WHO, 2011).

Consequence 3: Susceptibility to mental disorders induced by computer-related stress factors will increase. Kessler et al. examined that 26.2% of the US population

have mental disorders, including anxiety, mood etc. (Kessler et al., 2005). Also in Europe, Wittchen et al. investigated in an extensive study that almost 165 Mio Europeans suffer from brain disorders e.g. depression, anxiety, insomnia or dementia every year (Wittchen et al., 2010). The World Health Organization anticipates an increase of mental and neuropsychiatric disorders of 15% per year (WHO, 2001).

These alterations will affect the capabilities of system users and therefore change the requirements of employees and customers. As elderly and disabled people will constitute a bigger proportion of the overall population, enterprises need to adapt their ICT to different user capabilities to ensure productivity and profit. This adaptation requires developers to apply new methodologies and instruments to derive more detailed user requirements.

3 Hypotheses

The authors assume a correlation between the accessible design of ICT and human cognitive processing. For their research activities they establish following hypotheses in table 1:

Table 1. Hypotheses

Hypothesis	Description
H1	<i>Accessible ICT does not affect the time a user requires to achieve a specific goal.</i>
H2	<i>Accessible ICT does not increase the satisfaction of a user.</i>
H3	<i>The user's cognitive strain does not increase with the time required to achieve a specific goal.</i>
H4	<i>The user's cognitive strain is not dependent on the user's satisfaction.</i>
H5	<i>There is no correlation between accessible ICT and human cognitive processing</i>

Within this article the authors will elaborate an appropriate approach to reject H1-H5. In the context of this research in progress paper, the approach will mainly focus on required methodologies and instruments.

4 Neuro-Accessibility Design

Neuro-Accessibility Design (NAD) embodies the authors attempt to integrate methodologies and instruments of IT-accessibility design and brain research. It provides the opportunity to measure the influence of IT-accessibility criteria on human cognitive processing. The next sections will concern with information on cognitive processing and IT-accessibility.

4.1 Insights of Neuroscience on Cognitive Processing

Cognitive psychology deals with the mental processes which occur when knowledge and experience are gained from an individual's senses. This can be for example the processing of visual or auditory senses (Esgate et al., 2005) when working with an information system. Figure 2 depicts a simplified model of how the human brain handles cognitive processing (Persad et al., 2007).

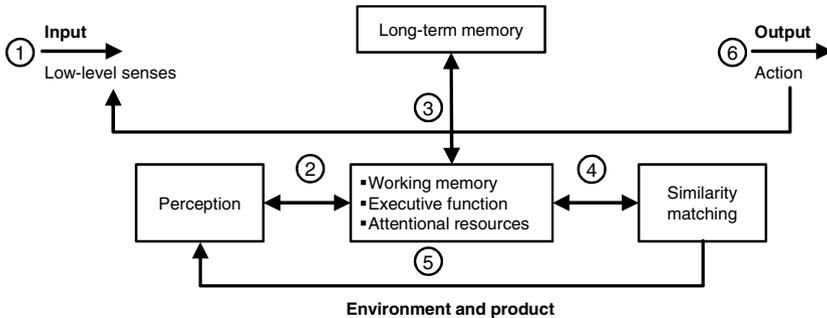


Fig. 2. Simplified model of cognitive processing

As the process of cognition is important for the NAD approach, the authors will briefly explain Persad's cognition model in the following paragraph.

Step 1: The user gets in contact with external stimuli.

Step 2: The perception component analyses and processes the incoming sensory information.

Step 3: The working memory retrieves long-term memories and decides to act on the selected stimuli. The attention resources are directed to focus on the most informative parts of the stimuli and initiate actions and reasoning (Mieczakowski et al., 2010).

Step 4: For matching the selected stimuli with objects of similar physical properties and functional attributes and for grouping them into categories in memory, working memory frequently has to refer to long-term memory (Miller, 1994).

Step 5: If the user has experienced the stimuli before, information about them will probably affect the speed and efficiency of cognitive processing.

Step 6: The user executes an action based upon the previous cognitive processing.

Studies investigated that ageing and certain impairments or disabilities can have significant effects on the elements of cognition. Therefore it is important to understand human cognitive processing and identify methods and instruments which might improve cognitive processing (Rabbitt 1993; Freundenthal, 1999).

Neuroscience, as it is the study of multidisciplinary sciences which analyze the nervous system and its functionalities (Squire et al., 2013), can help to comprehend cognitive processing (Esgate et al., 2005). Studies in the interdisciplinary field of cognitive

neuroscience examine the underlying neural mechanisms, which are involved with input, perception, attention, working and long-term memory as well as the transformation of information in correspondent action (McBride and Schmorrow, 2005).

Particularly the brain measurement technique of electroencephalography (EEG) is likely to be of great importance for comprehending the neural processes with regard to cognition (Niedermeyer, 2005). An EEG records the electrical activities in the cerebral cortex. When neurons transfer information, small electrical signals are generated, which can be measured by electrodes (Davidson et al., 2000; Dowling, 2001). These electrical signals represent the neuron’s activity and speed which allow the identification of mental states (Sharma et al., 2010). The activities are then further divided into several frequency bands which can be interpreted as shown in table 2 (Sherlin, 2009):

Table 2. Interpretation of EEG frequencies

Frequency	Interpretation
Delta (0.5-4 Hz)	Delta waves primarily occur in states of deep sleep. In addition they may also show slowed cognitive processing, learning difficulties or attention deficits.
Theta (4-8 Hz)	Theta waves can be seen most commonly in states of creativity and spontaneity. This is shown in an increase of theta waves when an individual passes on to drowsiness.
Alpha 1 (8-10 Hz)	Low alpha waves report an unaware state of relaxation with decreased cortical activation. They occur in states where an individual does not focus on surroundings of the environment.
Alpha 2 (10-13 Hz)	High alpha waves appear in a state of vigilance and alertness. They represent awareness of the surroundings but without focusing anything specific.
Beta 1 (13-21 Hz)	Low beta waves are primarily associated with cognitive processing. The cognitive requirements to fulfil a task become obvious by the activation of the cortex.
Beta 2 (21-35 Hz)	High beta waves represent higher states of concentration and cognitive processing and might be a result of cognitive challenges.

These insights provide the opportunity to examine the effects of IT-accessibility on human cognitive processing and therefore will be discussed in Chapter 5.

4.2 IT-Accessibility for Information and Communication Technology

The term “IT-accessibility” stands for the development of systems for users with diverse capabilities. The International Organization for Standardization (ISO) defines IT-accessibility as follows:

“The usability of a product, service, environment or facility by people with the widest range of capabilities.” (ISO, 2008).

This definition implies that usability is an essential goal to achieve IT-accessibility not for specific user groups, but all possible user groups, including young, healthy, disabled and elderly people.

For the successful implementation of this goal theory provides detailed guidelines on how to develop accessible IT-systems. The following paragraph will briefly introduce the reader to important accessibility-development principles.

Principle 1: Perception

All content presented within an application must be perceivable for any user. This includes e. g. color contrasts, font sizes and screen reader compatibility.

Principles 2: Operability

The content and its functionalities must be operable by different devices. For example, a visually impaired user is able to navigate through the content by keyboard commands.

Principle 3: Understandability

The structure of the application as well as the content must be easy to understand for the user. For example, abbreviations and foreign words are explained if the user demands it.

Principle 4: Technical openness

An application must be compatible to diverse devices. For example, the content and operation of a website adapts to the accessing device. This device can be e.g. a computer, a smartphone or a tablet.

The aforementioned principles of accessibility are part of the Web Content Accessibility Guidelines 2.0 (WCAG 2.0) published by the World Wide Web Consortium (W3C, 2008). The international organization for standardization approved this guideline as an international standard in the year 2012.

4.3 Influence on Cognitive Processing

In theory there is only little work about individual cognitive aspects of IT-accessibility. Most of the articles and books focus on IT-accessibility criteria that promote people with cognitive disabilities. But none of these examined the influence of IT-accessibility standards on the cognitive processing capability. To evaluate this, the authors imply that a long interval between steps one to six of Persad's model in figure 2 indicates the presence of at least one interfering factor. Interfering factors can be defined as any event that prevents or impedes the user from achieving a goal. For instance, this can be a system failure, distracting elements on the graphical user interface (GUI), low system performance or poor menu structure. These factors induce stress perception by the user and thereby affect human cognitive processing (Shu et al. 2011). In 1984 Craig Brod denoted this kind of stress as "technostress" (Brod, 1984). Technostress can be defined as "any negative impact on attitudes, thoughts, behaviors, or body physiology that is caused either directly or indirectly by technology" (Weil and Rosen, 1997). Figure 3 provides an illustration.

The next section will discuss several instruments to analyze correlations between the utilization of ICT and effects on cognitive processing. These instruments will provide opportunities to measure effects of accessible IT on human cognitive processing. The authors will justify their selection of instruments for future research activities.

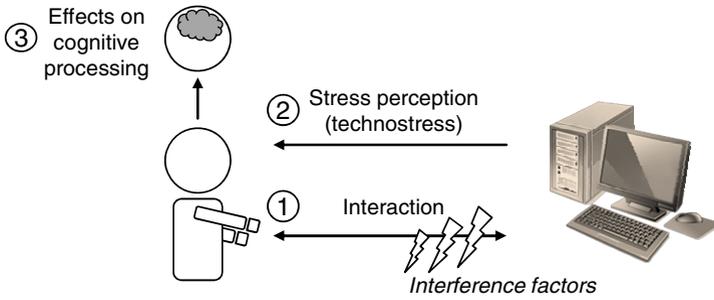


Fig. 3. Interfering factors influence cognitive processing

5 Selection of Methodologies and Instruments

The study of cognitive neuroscience concerns with how cognition and emotion are implemented in the brain. By using EEG, mental events, including all forms of “thinking” or “reasoning”, become visible (Penn, 2010).

The electrodes of an EEG record the activities from the cortex and upper layers of the brain where most of the cognitive processes occur. The benefit of using an EEG, compared to e.g. brain imaging techniques, is the real-time recording of brain activities which enables the monitoring of interactions in specific evoked situations. Nevertheless, EEG data only represents one source of data about the cognitive processing. This source is highly dependent on the situation and behavior of the user. Specific factors, which influence the measurement, cannot be clearly identified, such as eye blinking, head movements or muscle movements. This can lead to distorted measurements. Therefore the EEG data should be validated with other sources of information, which help to analyze and interpret the EEG measurement more accurately.

According to this, the attempt to measure the negative effects of technostress on cognitive processing solely with an EEG is insufficient. It is still unclear to which extent stress can be reliably evaluated from the EEG (Seo and Lee, 2010). EEG data can only provide indications for technostress, which have to be validated with additional methods.

As Riedl, Kindermann, Auinger and Javor found in their literature review most studies use questionnaires to investigate origins and impacts of technostress (Riedl et al., 2012). Participants are asked for experienced difficulties when interacting with an information system. The authors doubt that this method can provide reliable data, which can be used to validate EEG measures. Nevertheless, the gathered information about the interaction difficulties could be useful to identify weak spots of the system that refer to specific elements of Persad’s cognition model.

Therefore, the investigation of biochemical responses should be taken into consideration to measure technostress. Stress situations induce the secretion of hormones by the human body that includes cortisol, corticosterone, and adrenal catecholamines (Van der Kar et al., 1999). This secretion of cortisol correlates with the repeated exposure to stressful situations. Severe stress leads to a greater increase of cortisol than mild stress (Sherwood, 2010). Typically an increase of cortisol can be expected when

(1) the achievement of significant goals is endangered, (2) a situation is out of control, (3) the performance for executing a task is negatively judged by a third party (Dickerson et al., 2004). Riedl et al. successfully conducted a study where they investigated the impact of information system breakdowns on the secretion of cortisol. They found that the cortisol level was significantly higher after a test subject experienced a random system breakdown in comparison to the control subjects (Riedl et al., 2012). An elevated cortisol level can lead to e.g. chronically burnout, depression, obesity, suppressed immune function, chronically increased blood pressure and atherosclerosis (Melamed et al., 1999; De Kloet et al., 2005; McEwen, 2006; Walker, 2007). Therefore the authors consider this study as evidence that cortisol is an appropriate measurement unit to measure stress. EEG data that indicates stress through a high beta power measurement could be validated, if the corresponding cortisol level is significantly high as well (Seo and Lee, 2010). Numerous body fluids like blood serum, urine, and saliva are suitable to measure cortisol levels (Seo and Lee, 2010). Blood samples for measuring the level of cortisol are associated with greater inter-individual differences than saliva samples (Park et al., 2007). Therefore the authors will prefer saliva samples over blood samples. The comfortable measurement of salivary cortisol suggests that this method could be applied to further studies with justifiable expenditures.

Furthermore, the heart rate variability (HRV) can also be taken into consideration to validate EEG data. HRV represents the variation over time of the period between heartbeats and depends on the heart rate. It describes the ability of the heart to detect and quickly respond to external stimuli and in turn to adapt to new and changing circumstances (Malik, 1996; Acharya et al., 2006). HRV is often combined with other measurement methods like blood pressure, skin temperature etc. to testify certain interpretations in the context of stress measurement (Zhong et al., 2005; Lupien et al., 2006) and emotions (Lupien and Brière, 2000). The consolidation of HRV and EEG data showed that high beta EEG power correlates with increased HRV significantly (Seo and Lee, 2010).

Figure 4 illustrates the authors' selection of instruments that fit the NAD requirements and enable the evaluation of IT-accessibility impacts on cognitive processing.

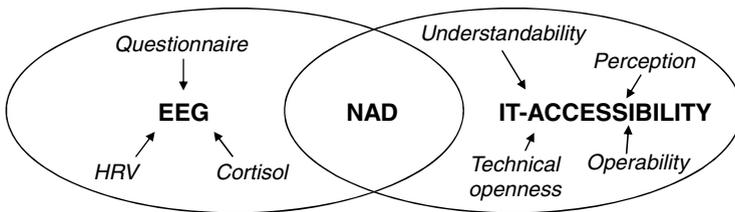


Fig. 4. Selection of instruments

To summarize, the selected instruments for the NAD approach are the principles of accessibility combined with results from EEG records, questionnaires, salivary cortisol measurements and heart rate variability. The latter three instruments are required to validate EEG records that indicate stress. The combination of the instruments,

shown in figure 4, provides data on technostress induced by the utilization of information systems and allows the authors to evaluate H3 and H4. To measure the effect of IT-accessibility on cognitive processing, different users and applications have to be tested with these instruments. The comparison of accessible and inaccessible applications will enable the authors to evaluate H1 and H2. The integration and interpretation of all results finally will allow an evaluation of H5 as shown in table 3.

Table 3. Evaluation of H1-H5

Hypotheses	Instruments
H1 / H2	questionnaire, principles of accessibility
H3 / H4	EEG records, salivary cortisol measurements and heart rate variability
H5	questionnaire, principles of accessibility, EEG records, salivary cortisol measurements and heart rate variability

6 Conclusion

This article concerned with consequences for the design of information systems, induced by demographic alterations. The authors hypothesised that there exists a correlation between accessible ICT and human cognitive processing. They established five null hypotheses that need to be evaluated in future research projects. The NAD approach was defined, including instruments and methodologies required for the evaluation of the null hypotheses. In chapter 4.1 and 4.2 the reader was introduced to the basics of human cognitive processing and IT-accessibility. Afterwards this article discussed several instruments needed to evaluate H1-H5. Finally the authors illustrated a bundle of instruments that will be applied in future research projects.

The next step will be the definition of detailed test procedures that will enable an appropriate evaluation of H1-H5. After that the authors will conduct studies and publish the results, to enrich current theory on information systems and neuroscience.

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