Preliminary results of an exploratory study towards a general task and data model for telemedical visualizations

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Telemedical systems use broadband technology in order to provide healthcare at a distance. As a result, they can improve access to medical services in distant rural areas or developing countries, save lives in critical care or support the care of elderly. Medical training and health education at a distance are further relevant scenarios. Continuous vital data originating from sensors, labs and pharmacies, clinical as well as public health data have to be summarized into suitable overviews in order to provide valuable information for users of telemedical systems. Presenting health-related data equally comprehensible for all of them still remains a challenge which can be addressed by ergonomic and human factors approaches. Only if data visualizations are designed with the individual user in mind, they enable to intuitively and quickly browse general health functions, anomalies, discover details and catch predictable risks early. Generalizable results of ergonomic visualization evaluation profit from systematic task analysis. Therefore, current efforts aim at constructing a general task and data model for telemedical visualizations. A user-centred approach investigates the extent to which abstract visualization task and data models are applicable to the telemedical domain. Preliminary results based on a sample size of n=10 suggest that existing abstract visualization task are throughout relevant to telemedical systems, while time-dependent and quantitative data are most relevant for either consultation, diagnosis, mentoring and monitoring. Furthermore, Bashshur et al.’s, (2011) telemedicine taxonomy was confirmed by telemedical experts.

Keywords: Health care, visualization evaluation, taxonomy, human factors engineering

1 Introduction

The world health organization (WHO) defines a good health system as one delivering quality services to all people, independent from where and when they need it. Access, equity, quality, and cost-effectiveness of health services ensure that people can be active contributors to their social and economic environment. However, access to health care is difficult in some situations. People might live in a region with sparse medical supply network; just as well they might not be able to leave their home to visit physicians or hospitals. Those examples for unequal access to medical care can be found both in industrialized and in developing countries and appear to depend on type of service (Zhang et al., 2014). Using ICT and broadband technology for “healing at a distance” (Strehle and Shabde 2006) contains enormous potential for contemporary global health issues. Especially smartphones and wearables are expected to improve access to medical services in distant areas or developing countries (Zimic et al. 2009; Kaplan 2006; Chen et al. 2008). Medical training and health education over distance are further relevant scenarios for what is known as telemedicine. Originating from the greek prefix ‘tele’ (= at a distance), telemedicine as medicine at a distance encompasses medical activities such as diagnosis, treatment, prevention, education, research and evaluation (Strehle & Shabde 2006; Luanrattana et al. 2012). Making sense of vital and environmental data and creating a way to make abstract statistical concepts understandable for the patient and clinicians even if information is accessed by mobile and wearable devices is one of the challenges in the development of future telemedical systems.

Consider as an example for telemedicine, a cardiac patient who has been equipped with a 12-channel ECG. With this device he can always submit her/his cardiac parameters to the monitoring centre via internet at the same time he is able to access the sensor data via his smartphone or tablet. Then the signal will be promptly evaluated by specialists. The assessment is based on the basis of previous findings, which are regularly recorded by the physicist or the patient in an electronic patient record. In case of emergency, necessary therapeutic action, up to alert the rescue chain without delay is initiated. Additionally the patient and the physicist might see how daily routines influence vital parameters collected by activity sensors or by
manual input of his eating behaviour, medication or it might even give behaviour recommendations and motivate the user to life healthy by displaying how certain behaviour influences his cardiovascular parameters. Specific data as well as abstract statistical concepts become relevant here. Individual heart rate values are interesting if related to time intervals at different granularity. In almost the same manner, cardiological data appreciate in value if related to events, or correlated with vital sensor or behavioural data.

Another example of a future tele-medical system is given by Bartels et al. (2011). He describes the work of future anaesthesia teams supported by accurate data analysis systems using automated patient and real-time data analysis. Patient’s physiologic parameters initiate real-time reminders, optimal compliance with quality initiatives and benchmarks, such as timely administration of prophylactic administration of antibiotics (Nair et al. 2010). Furthermore, they enable the review and documentation of allergies into the anaesthetic record (Sandberg et al. 2008) and even environmental parameters like ventilator settings might be included into medical alerts. Smartphones might provide resuscitation algorithms so that physicists do not have to rely solely on their memory (Low et al. 2011) or smartphones may be used by patients to send wound pictures in order to have them post-operatively accessed by clinicians. Face-to-face visits could thereby be reduced while information becomes accessible relative to medication and treatment. Telemedical systems thus facilitate the work of physicists and give the patient a prominent role in medical processes.

As elucidated, patient and environmental data originate from various sources, they are huge, unstructured, and raw and they seldom match a standard format. Automation may support the analysis to some extent, but given the dynamics, flexibility and the creativity of the human brain it can hardly be substituted by machines. In order to analyse medical data and make it understandable to non-analysts or medical experts an interface between data, algorithms and human cognition is needed. Data visualizations have proven to be highly efficient here (Keim 2002; Keim and Thomas 2008). Detecting life threatening events in large amounts of unstructured healthcare data is strongly influenced by humans' cognitive abilities, so that decisions concerning the information and data representations as natural interface between automated algorithms and human cognition require ergonomic research, especially if the representations address live critical decisions in time critical contexts such as telemedicine.

2 Related work

The importance of ergonomic data visualization for telemedical systems becomes clear in the light of age-related changes. Many visual functions deteriorate slightly with age such as acuity (Elliot et al. 1995) and contrast sensitivity (Sekuler et al. 1982; Zhang and Sturr 1995). Higher level functions such as those needed for visual search (Madden et al. 1996; Plude and Hoyer 1986), visual attention (Folk and Hoyer 1992; Madden 1992), visual word identification (Madden 1992; Madden et al. 1993), and visuomotor tracking (Moschner and Baloh 1994; Wickens et al. 1987) are also impaired in healthy aging. Additionally, visuospatial functions change with age such as processes required for spatial integration (Salthouse 1987), localization (Sekuler and Ball 1986), and mental rotation of visual stimuli (Puglisi and Morrell 1986). Age-related changes have also been observed in tasks involving perception (Ball and Sekuler 1986) as well as encoding and recognition of visual stimuli (Cherry and St Pierre 1998; Smith et al. 1990). This age-related slowing of visual function has been interpreted as reduced processing efficiency or effectiveness (Salthouse 1987). Data visualizations thus need to consider age-related changes in order to be usable for the elderly.

So far, the human factor has mainly been involved at an a posteriori stage of novel visualizations techniques or tools (Rogers et al. 2011; Nielsen 1992). As tasks strongly influence a certain evaluation their analysis needs to precede the visualization development and its evaluation.

Taxonomies are able to support task descriptions and hence the measurement during an evaluation. As classification of tasks and data, they perfectly provide conceptual clarity and categorize information for an increased theoretical understanding and predictive accuracy in empirical research. Taxonomies have been widely applied and discussed regarding information visualizations (Shneiderman 1996; Tory and Moller 2004; Paul and Whitley 2013; Ward 2002; Valiati et al. 2006; Jae-wook Ahn et al.; Ellis and Dix 2007; Chi). In the telemedical domain taxonomies were applied to make concepts and their relation clear in order to differentiate ambiguous terms representing the concept of IT supported medical processes (Tulu et al. 2005; Bashshur et al. 2011; Ingenerf 1999; Chan et al. 2009; Starren and Johnson 2000) but it remains unclear to which extend visualization tasks are relevant and eligible for the telemedical domain. Using them as basis for ergonomic evaluation bears the risk of findings with minor practical relevance. On the other hand, domain specific telemedical taxonomies only serve a differentiation of ambiguous terms representing the concept of
IT supported medical processes. Using them as basis for ergonomic visualization studies bears the risk of disregarding a visualization oriented perspective. So, in order to construct a general telemedical task and data model it is relevant to know to which extend visualization tasks are applicable to the telemedical domain. Bashshur et al. (2011) provide the telemedical taxonomy necessary to that end. He differentiates among other telemedicine dimensions, user tasks when describing the functionality dimensions consultation, diagnosis, monitoring and mentoring. Unfortunately, his research remains vague when it comes to the origin of his classification. So current study takes them as starting point for a user oriented perspective on telemedical task and data analysis by having it verified from a domain expert’s perspective and extend it if needed.

![Figure 1: Bashshur et al.'s (2011) taxonomy of telemedicine.](image)

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![Figure 2: Brehmer & Munzner's (2013) model represents the 'why', 'how' and 'what' dimensions of visualization tasks.](image)

Figure 2: Brehmer & Munzner's (2013) model represents the 'why', 'how' and 'what' dimensions of visualization tasks. Present work investigates their applicability for the telemedical domain.
Instead of Bashshur et al.’s (2011) telemedical taxonomy, Brehmer & Munzner (2013) provide a visualization oriented multi-level typology of visualization tasks incorporating the ‘why’, ‘how’, and ‘what’ perspective, so that task descriptions contain nodes from high-level to mid-level to low-level. The data level is addressed within in the ‘what’-dimension which in parts overlap with Shneiderman’s (1996) task by data type taxonomy. Regarding the identification of important teledmedica data types relevant for teledmedical systems we consider Brehmer & Munzner’s (2013) ‘what’-dimension items values, extreme values, distributions, anomalies, clusters, correlations, graphs together with Shneiderman’s (1996) data types (quantitative data, qualitative data, ordinal data, nominal data, 1-, 2-, 3- dimensional data, time dependent data, multidimensional data, tree data, net data). Based on described teledmedical and visualization classifications current research aims at constructing a general task and data model for data visualizations in the teledmedical domain in order to provide a framework for future ergonomic evaluations. As a starting point, this paper addresses the following research questions:

RQ1: To which extent are abstract visualization tasks and data models relevant for teledmedical tasks?
RQ2: To which extent do teledmedical experts support Bashshur et al.’s (2011) teledmedical taxonomy?

3 Method

Regarding an answer to the previously mentioned research question we set up a questionnaire consisting of twelve questions. In the first question, participants should list medical tasks that profit from teledmedical applications. A query based on an existing categorization was deliberately omitted here in order to not restrict expert’s view. On the contrary, the next question requires participants to subdivide Bashshush et al.’s (2011) functionality dimensions into subtasks. Forerunning, we created a matrix where participants had to choose which of Shneiderman’s (1996) data types (quantitative data, qualitative data, ordinal data, nominal data, 1-, 2-, 3- dimensional data, time dependent data, multidimensional data, tree data, net data) and Brehmer and Munzner’s (2013) ‘what’-dimension items (values, extreme values, distributions, anomalies, clusters, correlations, graphs) are important for each of Bashshush et al.’s (2011) functionality dimension (consultation, diagnosis, mentoring and monitoring). In the next question, teledmedical experts had to indicate which abstract visualization tasks (‘why’-dimension, see fig. 2) can be assigned Bashshush et al.’s (2011) functionality dimensions. Additionally, five questions served to analyse to which extent experts support Bashshush et al.’s (2011) teledmedical taxonomy by asking participants to assess the benefits of telemedicine applications for all dimensions (see fig. 1) by means of a five point Likert scale.

In order to acquire participants, we approached experts from our existing network and automatically extracted expert contacts from the e-health-com.eu webpage, where experts are indicated by readers. Propositions of an expert are edited and reviewed by the editors of the website and can be made by everybody. The website lists them all alphabetically and provides one profile page per expert containing the name and position together with a short description, contact information and affiliation description. We initially sent the link to the online questionnaire to 70 experts by e-mail, 24 of them came from e-health industry companies either as CEO of a company selling e-health products or consultants which are active in the domain, 40 came from research institutes occupied with IT in the health sector and the remainder were medical experts from various domains or politics. The answers were fully anonymous, participants rated their familiarity with medical domains as high only one out of ten participants indicates to be not familiar with the teledmedical domain. As the study is currently running we only present preliminary results of n=10 complete expert responses.

4 Results

For consultation, diagnosis, mentoring and monitoring together, experts indicated that time-dependent data (n=39) are most relevant. Concentrating on each task, we learn that time-oriented data (n=10), quantitative data (n=8), ordinal data (n=8), 1 dimensional data (n=8), single values (n=8) and groups (n=8) are relevant for consultation. Quantitative (n=9), time-dependent (n=10), 2-dimensional data (n=8) as well as data organized in a net structure (n=8), single values (n=8) and outliers (n=8) were considered as most important for diagnosis. Regarding mentoring experts considered time-dependent (n=9), ordinal (n=9), 3-dimensional data (n=8) together with anomalies (n=8) as the most important ones. For monitoring tasks they considered clearly time-oriented data (n=10) as the most important data type, followed by quantitative data (n=9), ordinal
data (n=8), single values (n=8) and groups (n=8). Regarding relevant visualization tasks for telemedical applications, Brehmer et al.’s (2013) abstract visualization tasks were related to functionality dimensions. Regarding the relevance of visualization tasks for telemedical tasks it can be stated that nearly all experts considered all visualization tasks as relevant for consultation, diagnosis mentoring and monitoring. Importing, searching and generating information is relevant for all functionality dimensions. At the current status of the study results they mark the most important visualization tasks. As nearly every visualization/ information task was considered as relevant by eight to nine experts less interesting visualization tasks are more interesting. Experts consider manipulation of information less often (n=7) as relevant for consultation while enjoying information (n=7) is classified as the least relevant visualization task to diagnosis and mentoring.

Concerning the verification of Bashshur’s taxonomy, it can be stated that functionality dimensions (telemedical tasks) can be fully considered for our telemedical task and data model. On the given Likert scale a value one corresponds to a high importance a given task for telemedical systems, while the value five corresponds to a very low relevance. For total importance for telemedical systems (n=10) averaged a Likert value of 1.60 (SD = 0.80) in consultation, of 2.00 (SD = 0.63) in diagnosis, of 1.60 (SD = 0.49) in mentoring and of 1.40 (SD = 0.49) in monitoring. Bashshur’s technological dimensions were supported as well. For the total importance for telemedical systems (n=10) averaged a Likert value of 1.50 (SD = 0.50) in synchronicity, of 1.75 (SD = 0.83) in network and of 1.50 (SD = 0.50) in connectivity. However, participants did not consider the technological dimensions as so distinctive that they require their own telemedical system. A value of one corresponds to total acceptance of the claim, while a value of five corresponds to the total rejection of the same. On average (n=10) supported the statement that every medical speciality 4.00 (SD=0.71), every disease 3.75 (SD = 0.85), site of treatment 3.00 (SD=0.71) and treatment modality 3.00 (SD=0.71) require a separate telemedical system. In correspondence to Bashshur’s model we also asked participants to state own tasks which profit from telemedical applications and to subdivide the given functionality dimensions (tasks) in order to see to which extent we could refine his model. Redundant tasks were removed for each participant and the frequency of a term nomination was counted. This led us to the following ranking list, starting with the most frequent mentioned task/s: (1) monitoring; (2) consultation; (3) expert cooperation; (4) care at a distance; (5) tele-cardiology, diagnosis; (6) therapy, after care, prevention, home care, pharmaceutical treatment; (7) data transfer, self-management (patient), patient information, urban safety, data management, anamnesis, care, medical round, date coordination, evaluation, treatment recommendations.

5 Conclusion

Present study adopts a user-centred approach to investigate the extent to which abstract visualization task and data models are applicable to the telemedical domain. Preliminary results based on a sample size of n=10 suggest that existing abstract visualization tasks are throughout relevant for telemedicine. Experts solely considered ‘enjoy’ (visualization/information) and ‘manipulate’ (visualization/information) less often as important. Referring to expert’s relevance estimation of data types for consultation, diagnosis mentoring and monitoring, results reveal time-dependent and quantitative data as most relevant. Experts furthermore confirmed and complemented Bashshur et al.’s, (2011) telemedicine taxonomy. The final results of this study will not only be restricted to the perspective of national telemedical experts and thereby lead to a comprehensive and general basis for an empirical visualization evaluation. It will be exciting to see whether given results replicate with a larger sample size.

Acknowledgements

This publication is part of the research project “TECH4AGE”, which is funded by the German Federal Ministry of Education and Research (BMBF, Grant No. 16SV7111) supervised by the VDI/VDE Innovation + Technik GmbH.
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