Designing a Navigation Decision Support System for Bronchoscopy

Development of design guidelines

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ABSTRACT

Navigating through a three dimensional environment using a mental map constructed by two-dimensional images is a cognitively demanding task. This is a task physicians must perform while operating a bronchoscope during a bronchoscopy. Having a supporting system that presents a route to follow in a three dimensional virtual environment could reduce the mental workload of performing the navigation task. Suggesting that using a navigation decision support interface could increase the success rate of reaching the target, this article reviews theories about cognition, decision making and navigation to develop a list of guidelines for designing a navigation decision support interface. The review will be done using Oxford's framework of decision-centred design and the guidelines will be used as a theoretical model for designing a navigation decision support interface. Bronchoscopy is used as a case in this article because the procedure is cognitively challenging for the physician and the success rate of finding non-visible tumours in the lungs through bronchoscopy is only 15%. The article is written based on a design project collaboration with the physicians at St. Olavs hospital and engineers from SINTEF Medical Technology who have developed the Fraxinus project. Fraxinus is a research navigation platform for image guided therapy supporting physicians performing bronchoscopy. The findings from this case are transferrable to navigation interfaces for other medical equipment that examine the interior of a hollow organ or cavity, or goes through tiny incisions in the patient.

KEYWORDS: Bronchoscopy, human-factors, navigation, cognition, interaction design.

1. INTRODUCTION

The development of equipment and systems have traditionally been driven and based on the development of technology. This technology-centred design approach tends to overlook the user's interaction with the system. It often leads to systems that demand unnecessary mental processing from the human interacting with them [1, p.5][2, p.229-230]. Humans have certain information processing bottlenecks, which limits the ability to process and use information [1, p.10, 31-41] [4, p.293-330] [6, p.375-398]. Limited visuospatial abilities and working memory are examples of such bottlenecks. Often, the unnecessary mental workload also leads to errors [1, p.5-6][4, p. 293-330]. Across different industries and different systems "Human error" is the factor that constitute 60% to 85% of all accidents. In many of these cases "Human error" it is not the result of a faulty human, but a direct result of equipment and systems that are ill suited for supporting human performance[1, p.5-6].

The knowledge about, and study of, human needs, capabilities and behaviours are often referred to as human-factors [8]. Human-centred design integrates technology with human-factors to create systems that supports the users [3][5, p. 8-10]. The goal of this article is to develop a list of guidelines for designing a navigation decision support interface for bronchoscopy based on human-factors.

1.2 Cognitive science

Human cognition is one aspect of human-factors. Cognition can be defined as the neural processes concerned with the acquisition, retention, and use of information [9]. Cognitive science is an interdisciplinary study that embrace the fields of philosophy, psychology, artificial intelligence, neuroscience, linguistics, and anthropology [10]. Significant achievements have been accomplished in the field of cognition over the past few decades, e.g. the development of cognitive models for perception, memory and computation [2, p.3-7], and the findings of specialized brain areas and cells for perception, memory and navigation in neuroscience [28]. Cognitive engineering is an applied cognitive science domain that use the knowledge and technologies from other cognitive sciences to the design and construction of systems or workplaces [7].

Decision-centred design(DCD) is a cognitive engineering framework that examines what makes critical decisions difficult, and how they can be effectively supported [2, p. 261]. The DCD framework's focus on key decisions makes it appropriate to use in the case of designing a navigation decision-support interface. This article will present the framework of decision-centred design and use it in the review of cognition theories that are important to consider in the design of a navigation decision-support interface.

1.2 Bronchoscopy

With today's technologies, physicians do not have to do open surgery to diagnose several diseases on internal organs. Endoscopy is one of these technologies. Endoscopy enables physicians to examine the interior of the hollow organs and the cavities of the patient's body without cutting the flesh. Bronchoscopy is an endoscopic technique for examining the airway, the lungs, or the lymph nodes in the chest of the patient. The procedure is done by inserting the bronchoscope through the patient's mouth and steering it down the airways. The bronchoscope is an optical fibre instrument with real time video equipment, lighting and a pipe for operating equipment [22].

By using a bronchoscope e.g. to do a biopsy, instead of open surgery the physician loses his three dimensional (3D) overview of the workspace. The physician's navigation towards the target is based on their mental model of the lungs and its airways and the video imaging from the bronchoscope.

Today's procedure of bronchoscopy often starts with the physician finding a target on the computerized tomography (CT) scan images of the patient's lungs. The CT scan pictures gives the physician two-dimensional (2D) images of the branching of the airways of the lungs from different angles and in different layers. Using the 2D CT images the physician creates a mental map for navigating through the different branches to reach the target position to take a cell sample for diagnosing. The process of mentally flipping images and create an understanding of the lung system (the environment) and construct a procedure plan, then remembering it while operating the bronchoscope, is cognitively demanding for the physician.

The success rate for managing to hit the biopsy target area for non-visible tumours in the lungs is 15% and 80% for visible tumours. Success is also dependent on tumour size, the physician's experience and the method used for sampling

[17][18][19]. Using a navigation decision-support system either before or during bronchoscopy is a possibility to reduce these challenges and thus increase the biopsy success rate. This article is limited to focus on finding design guidelines for a system that helps the physician before the bronchoscopy and not during the procedure.

2. METHOD

1.0 Literature review

The basis of this article is a literature review presenting literature and publications that the author finds relevant for the development of guidelines for designing a navigation decision support interface for bronchoscopy. The relevant fields identified are clinical decision-support and navigation. These fields are extensive. The author used the cognitive engineering framework of decision-centred design (DCD) [2, p.261-270] to limit and focus the literature review. Complementary to the literature review a design project of designing a navigation decision support interface where executed using the DCD framework. The literature review in the article is complemented by the insights from observations and interviews that were performed in the design project. The information acquired in both the literature review and the project is used to develop the design guidelines for a navigation decision support interface for bronchoscopy.

2.0 Decision-Centred Design

Decision-centred design (DCD) is a cognitive engineering framework that focuses on designing solutions that support decision making during challenging situations. DCD is similar to other design frameworks like; **Cognitive work analysis** by Jens Rasmussen; developed in the nuclear power industry, **Situation Awareness oriented design**; which emerged from the piloting community, and **Work centred design**; which was developed for the U.S. air Force Air Mobility command. The DCD framework differs from other cognitive engineering frameworks by its focus on identifying key decisions rather than exhaustively documenting all possible cognitive requirements [2, p.261-270]. This focus is the motivation for choosing the DCD framework for the guideline development rather than other frameworks. The DCD framework acknowledges that individual differences in expertise play an important role in decision-making. It focuses on designing for context specific performance, and uses cognitive performance indicators to assess how well the solution supports cognitive performance.

At first the framework was developed for addressing time-pressured and high risk situations, now it is used in a broader sense in situations that involves expertise and tactic knowledge [2, p. 261-270]. The author finds the DCD framework appropriate to address decisions regarding navigation in an environment known by experience and mental models.

The DCD framework consist of five stages; preparation, knowledge elicitation, analysis and representation, application of design and evaluation. Following is a short description of each stage.

1- Preparation
The preparation stage is a phase for gathering insights. Background material about the domain, tasks and the user group is reviewed during the preparation stage. The goal is to identify cognitively demanding tasks. The term “task” could be considered as the discrete activities in which people engage or the sequences of activities aimed at achieving a particular goal. This information gathering stage is common among most cognitive engineering and design frameworks [2, p. 267].

2- Knowledge elicitation
The second stage of DCD framework is the election of critical incidents and key components of the decision making. Cognitive task analysis is an umbrella term for methods that are used to map and analyse the tasks components from a cognitive perspective. There are several different methods for cognitive task analysis. Observation

and interviews are methods that are often used [2,p. 229-233]. The think aloud method is a technique for understanding the users reasoning while performing an exercise. The users are asked to say aloud what they are thinking while solving tasks. It provides verbal data about the users reasoning during the task. The think aloud method identifies the information that is concentrated on during problem solving and how that information is used to facilitate problem resolution [30].

3- Analysis and representation
During the third stage of the DCD framework qualitative data are organized and examined for themes, decision requirements, and other elements that will support project goals. Decision requirements are then articulated.

4- Application of design
In the fourth phase of the DCD framework design concept prototypes are developed using the requirements identified in phase 3.

5- Evaluation
The final stage of the DCD framework addresses whether the purposed design solutions support decision making in the context or not. The evaluation is a part of an iterative design cycle, it uncovers info about the impact of the current design and how it can be improved.

This paper will use the first three stages of the DCD framework to develop a set of guidelines for designing an interface that will support navigation decision making.

3. PREPARATION

In the case of designing a navigation decision -support interface for bronchoscopy the author finds the domains of clinical decision support systems and virtual environments relevant. In the following is an introduction to these domains. Interviews and observation will be used to gather insights regarding the user group and the environment in which the decisions are made. Navigation is considered as the key task in the case, and literature about this field will be presented.

3.1 Clinical decision support systems (CDSS)

Clinical decision support systems (CDSS) are tools that use patient data to generate case-specific advice to support physicians in making clinical decisions [12]. Even though several of today's CDSS have the technology to improve quality and safety of healthcare, there have only been a few successful CDSS implementations [13]. There are several reasons why the implementation of a CDSS fail. One reason is the challenges regarding the technical complexity of delivering CDSS. Another reason is the lack of focus on the social aspects of incorporating changes into clinical care. Some of the reasons are due to the complexity within the nature of decision-making. There are also intellectual challenges for the users when creating knowledge based on the system data. In the article "Grand challenges in clinical decision support"[14] several researchers and physicians identified and ranked challenges in the development and implementation of CDSS. The human–computer interface(HCI) of the CDSS was the challenge that was ranked the highest. The authors stated that there is a need for a new or a greatly improved HCI paradigm for the presentation of clinical decision support recommendations. The new HCI paradigm should focus on support and not interrupt the clinical workflow, this means presenting data in a seamless process in the context of the decision-making process. Clear and intuitive displays, that make it easy for the physician to take action based on the information provided, was requested by the authors in the article. These insights supports the hypothesis that an improvement of the interface of the support system could increase the success of the CDSS, this might be the case for bronchoscopy as well.

3.2 Virtual environments

Virtual environments (VE) are interactive, head-referenced computer displays that give users the illusion of presence in a simulated location [15]. During the past thirty years VEs have evolved in line with the advancement of computer graphics. Within multiple fields different VEs have been created to support research and training activities. Spatial orientation and navigation have been some of the biggest usability challenges in the creation of VE [15]. The spatial layout of the VE often demand unnecessarily attention from the users in expense of their focus on the objectives of the task to be performed. Even though VEs are used in multiple fields, the issue of navigation within VEs has limited research attention [15]. Several researchers has suggested that there are few differences between the navigational experiences gained from simulated environments and those from actual environments. Navigation research of real environments could therefore be used to gain understanding for the development of guidelines for designing a navigation decision support interface that present a VE of the insides of a patients lung system.

3.3 The user group

Physicians are a user group that have knowledge about the lung system from studies and experience. Within the field of bronchoscopy the user group's expertise can be divided into novice and expert. Expert physicians do often perform the procedure on their own. Novice physicians are often accompanied by more experienced physicians while performing the bronchoscopy [16]. The number of bronchoscopies that a novel physician need to do before they becomes skilled varies. Some only need 30 procedures while others never get the hang of it, because the task is highly dependent on spatial abilities [16]. Experienced physicians have established knowledge about the different parts of the lungs and how to reach them with a bronchoscope. The physicians interviewed had a clear understanding of the airways branches up to the fourth or fifth division. Even though they have solid knowledge about the environment (the lung system), every patient has small variations or different branch structures in the lungs, this means that the physician operates in a slightly different environment from patient to patient.

3.4 Navigation

Navigation is identified as the key task that need decision support in the case addressed in this article. Wayfinding and navigation are related concepts. Wayfinding is a broad term which refers to the process of following a route between an origin and a destination. Navigation refers to the specific means of locating position and plotting a course [11, p.6, 125-127]. There are several theories about how people perform navigation tasks. Most of them contains the hypothesis that people construct mental models of the environment. This construction is referred to as Cognitive mapping [11, p.6]. Cognitive mapping is performed using Visuospatial abilities mediated and supported by Working Memory (WM). A Cognitive Map (CM) is the product of cognitive mapping. The following sections contains short descriptions of the cognitive abilities that are used during cognitive mapping and some findings from navigation research that the author finds relevant.

3.4.1 Visuospatial abilities

Visuospatial ability is the capacity of understanding, reason and remembering spatial relations [23]. Spatial perception, mental rotation, spatial orientation and spatial visualization are examples of visuospatial abilities used in navigation.

Spatial perception is the ability to perceive objects and spatial relationships such as features, properties, measurement, shapes, position and motion. Some visual features such as shapes and motion are perceived faster than other features because of the processing functions of the human sense organs and brain [6, p. 2-22 and 154].

People's spatial perception is affected by the orientation in which the environment is observed. Spatial information can either be presented in an egocentric frame of reference or in an exocentric frame of reference. The egocentric frame is the subjective view of the environment, while the exocentric frame is an external view [6, p.362-366].

Mental rotation is the ability to mentally rotate observed objects or environments. It is a cognitively demanding procedure and it might lead to flaws within the mental model that is constructed.

Spatial orientation is the ability to maintain orientation with respect to objects in space. People with good capacity for spatial orientation do not lose their overview and understanding of the environment by variations in the orientation in which a pattern is perceived.

Spatial visualization is the ability to mentally represent spatial relations between objects, parts or locations. Research has shown that people generally tend to distort space when constructing CMs [4 , p.158-186]. CM tends to be laid out on more orthogonal (right angle) grid lines than the actual environment. This tendency is referred to as rectilinear normalization. Curved roads are mentally straightened and strange angles are adjusted to be right angles. Rectilinear normalization result in CMs that have a schematic quality. Henry Beck took advantage of this when designing the London Underground Tube map in 1931 [27]. The key to the design was the formation of the important and less important information and the extreme simplification, using straight lines and angles, nodes and symbols. This information visualization strategy resulted in a design that made it easy for the users to construct CM based on the map.

Good environmental learners differ from poor learners by their successful information encoding strategies, their evaluative abilities regarding the learning process, and their skill of focusing their attention on the unlearned information [15].

3.4.2 Memory

Memory is one of the information processing bottlenecks of human mental capacity. Only a small part of the information perceived by the human is stored and used. In 1956 George A. Miller suggested that the human processing capacity was limited to five to nine items [26]. The concept of bounded rationality in decision making was introduced in 1958. The concept explains that departure from optimal behaviour is due to the brain’s limited processing capacity to process information to compute optimal solutions.

In 1968 Atkinson and Shiffrin introduced the Modal Memory model. Atkinson’s theory suggested that human memory consist of one limited temporary memory part and one Long Term memory part. Within this model Short Term Memory (STM) was the temporary part that could contain five to nine items for a short period of time. In 1974 Baddeley and Hitch introduced the concept of Working Memory (WM) as a replacement of STM. WM was described as a more complex system than STM with separated information processing channels. WM consist of four components, namely the Visuospatial Sketchpad, the Phonological Loop, the Central Executive and the Episodic Buffer. The Visuospatial Sketchpad is the system who maintain and manipulate visual and spatial information. Verbal information is temporary stored and processed in the Phonological Loop. The Central Executive includes the capacity of focusing, dividing and switching attention, which means that it coordinates the Visuospatial Sketchpad and the Phonological Loop. The Episodic Buffer integrates information coming from Long Term memory with information present in WM. Baddeley and Hitch’s WM model suggests that people can process different kinds of information at ones. Even though WM can process more information if it is distributed to the phonological loop and the visuospatial sketchpad the capacity is still limited. The way humans cope with this limitation is the fact that most new concepts that are learned are built on existing knowledge [6,p.386]. In addition to its natural limitations the capacity of WM is also affected by several internal and external factors e.g. attention, situation awareness, cognitive load, stress, experience and individual abilities [1,p.15].

Individuals uses different strategies when storing information into their CMs. There are primarily two types of environmental strategies. One of them focus on perceptual information and visual details, the individuals who use this strategy are visualizers. Verbalizers are the individuals that focus on labels and guides, namely verbal information [15].

3.4.3 Navigation research

In 1960 the urban planner Kevin A.Lynch stated that CMs of cities function primarily as orientation aids. He claimed that people generally orient themselves by using five features of the environment to compose CMs [15]. These features was: paths, path intersections (nodes), landmarks, districts and boundaries(edges). Several urban planners have confirmed Lynch's findings in navigation research, and used it as a base for their own research [15].

In 1973 Downs and Sted classified spatial information in two classes, namely locational information and attribute information. When constructing CMs attribute information is added as markers of meaning to the spatial information. Attribute information can be descriptive or evaluative.

In 1975 Siegel and White presented a three level division of spatial information that result in CMs [21]. They divided spatial information into landmark knowledge, route knowledge and survey knowledge. Landmark knowledge is knowledge about single objects. It is the fundamental component of both route knowledge and survey knowledge. Route knowledge, also known as procedure knowledge, is the information about sequence of actions required to follow a particular route. Landmark- and Route knowledge is perceived from an egocentric frame of reference [24]. Survey knowledge is the knowledge about configuration relations among locations and routes in an environment. Survey knowledge can be acquired directly from maps or through the study of other media.

In 1984 Garling stated that CM contains travel plans to facilitate wayfinding performance in addition the spatial knowledge. A travel plan is a predetermined course of action used to reach a desired destination with minimal effort. Research from the environmental psychologist Romedi Passini supported Garling's extension of CMs. Passini defined the process of reaching a destination as a problem-solving procedure that can be divided into three main processes[15] namely: cognitive mapping, decision-making and decision-execution. In 1994 Kitchin reviewed CMs as mental devices and stores that helps simplify and code information from external environments. He stated that CM are used to solve spatial problems, and that wayfinding and navigation are the most essential spatial problems [20].

3.4.4 Navigational tools

Navigation support tools can be divided into five categories: current position displays, current orientation displays, movement logging displays, surrounding environment displays and guided navigation displays. Displays that shows an individual's current position and current orientation are developed to assist individuals in performing spatial-orientation tasks. They are especially helpful when landmarks or reference points are not readily available.

Movement logging displays are tools that can log an individual's movements. They supports individuals that have limitations in their CM due to lack of experience or limited spatial abilities. Surrounding environment displays are tools that expand the user's view to collect more spatial information. Guided navigational systems provide navigational plans. The users can generally reach their destination with minimal mental effort using guided navigational systems. The minimum mental effort in cognitive mapping and decision making is at the expense of spatial-knowledge acquisition, this is an critical restriction in utilizing these guided navigational tools in wayfinding tasks that require retrieving spatial knowledge from the VE [15].

4. KNOWLEDGE ELICITATION – KEY DECISIONS

4.1 Cognitive task analysis

Case interviews were executed to gather insights for a cognitive task analysis. The focus of the case interview was the cognitive tasks of evaluating CT images and preparing for a bronchoscopy. Five experienced physicians participated. They were presented CT images of a case patient. Their task was to evaluate the images and plan a bronchoscopy. They were asked to think aloud and explain their reasoning. Which CT images that were used and how the physicians went through the CT images were observed. The time spent looking through the images and reaching a decision was measured.

After going through the CT images the physicians were interviewed. In the interview they were asked about the procedure. At the end they where asked to recall their plan for the bronchoscopy in the case. Following is a short summary of the findings from the cognitive task analysis.

4.1 Findings

The goals of the physicians was to take a biopsy in the target position. Their assessments during the period between receiving CT images and taking a biopsy can be divided into two main categories, namely assessments done before the procedure and assessment during the procedure. The assessments done before includes choosing what to do and how to do it. Evaluating which methods to use is an important part, some wanted a second opinion of their decision before they would have performed the procedure. They found the target position and which airways that led to it.

The strategies the physicians used to construct a CM was scrolling through the axial photos and the frontal photos, looking for the airway branches that lead to the target position. They remembered where to steer the equipment by the name of the area and the name of the first four or five branches. Some looked at images of the different branch points in the construction of a mental overview of the route to follow.

The assessments done during the procedure was said to mainly be based on their understanding and CMs. This means that the assessments of where to steer the bronchoscope and where to take a biopsy are dependent on the quality of information stored in the physician’s mind.

5. ANALYSIS AND REPRESENTATION – LEVERAGE POINTS

The decision requirements during the procedure are based on the physician’s CM and situation awareness. Situation awareness is knowledge about where they are, what they have done, what is about to happen and where to go [1, p.13-29]. Today, the physician’s situation awareness during the bronchoscopy is dependent on having constructed a solid CM in beforehand of the procedure and on the real time video images during the procedure. The physician’s limitation in working memory makes it difficult to maintain situation awareness especially at the distant branch points. Here it is hard to remember which turns to take and which branches to follow. It is also hard to maintain situation awareness when there are obstacles that limits the view, e.g. mucus covering the camera.

When physicians evaluate the CT images they often have limited time. The physicians interviewed stated that the time slot for evaluating the images lasts somewhere between five and fifteen minutes. Limited time makes it difficult for the physician to develop precise CMs of the environment. The fact that they have to perform mental rotations to construct the CM might lead to uncertainty when rushed. The CT images are also sometimes unclear and it is difficult to see the smaller branches and channels.

In addition to the challenges due to limited overview of the environment, the physicians also have to cope with the fact that the environment is dynamic. When the patient breaths the environment changes slightly. Some channels change position between inhale and exhale, this makes it difficult to choose the right exit point. Spatial orientation skills are therefore an important prerequisite for the physician to maintain situation awareness.

For the physician to maintain situation awareness throughout the bronchoscopy the most critical factor is to have created a flawless CM before entering the procedure. Today experts construct their CMs by looking at 2D CT images and remember the parts by name. The procedure is highly dependent on spatial abilities and experience.

6. DISCUSSION

6.1 Design guidelines

Cognitive offloading can be defined as a tradeoff between internal processing to external processing [29]. This means manipulating or storing information externally instead of mentally. The interface must be a cognitive offloading tool, that present information in a way that it can be efficiently stored with limited errors. Following is a set of guidelines that should be considered when designing the navigation decision support tool that provide cognitive offloading for physicians while they construct CMs for a bronchoscopy.

1 - Prevent mistakes due to mental rotation
Mental rotation and spatial orientation claim processing capacity and time. Presenting the environment in the same view as the real environment is a cognitive offloading measure for environmental learning. This can be done by presenting a simulated VE in a 3D egocentric frame of reference. With an egocentric frame of reference the user do not have to preform mental rotations to understand the environment. Enabling the user to get to know the environment by looking at a simulated environment can provide a foundation for the construction of a CM without flaws due to the "human errors" that might occur when performing mental rotation.

2 - Support the construction of a CM
Even though an egocentric view prevent the workload of mental rotation, it is limited. It do not provide the user with a complete overview. Tasks that involves understanding of the structure of the environment are best supported by the overview an exocentric frame of reference can provide [4, p.158-186]. Constructing a CM is such a task.

A co-planar display is a display that contains both an egocentric frame of reference and an exocentric frame of reference. The co-planar display is often well suited for precision tasks [4, p. 158-186]. A co-planar display can provide an overview for orientation and an egocentric frame for cognitive offloading. The author finds that a co-planar display is well suited for a navigation decision- support interface.

3 - Provide a route to follow
To save time and cognitive resources of constructing a route, the system can present route to follow. This means providing clear signals of which way to choose at each branch node. Eliminating the mental effort of constructing a route can as mentioned be at the expense of spatial-knowledge acquisition. The user group have already knowledge about the

environment based on their education and experience. This guideline is therefor based on the assumption that the guided route is perceived and stored building on the physician's already existing CM of the lung branches and support precision, rather than be at the expense of spatial-knowledge acquisition.

4 - Enabling the user to reach the information that is requested

The interface should provide fast, easy and responsive navigation possibilities. It should be possible to effectively reach the branch point that the user want to evaluate, and go back and forward in a seamless process. One way of doing this is using Shneiderman's mantra. The rules of this mantra is to present an overview at first, than provide the possibility to zoom and filter information that is interesting and make details reachable on demand [31].

5 - Presenting important and less important information

The HCI should be clear and intuitive. The goal is to reduce visual clutter to a minimum. Visual clarity makes it easier to perceive the situation and take rapid decisions. This is important in the environment of CDSS where limited time often is the case. Relevant information should be visually distinct and less relevant information should be less visible or excluded. This means that important information should be presented with qualities that are perceived faster than the qualities of less important information.

6 - Simplify information

The route should be presented in such a way that it can easily be acquired and kept in working memory. Taking advantage of rectilinear normalization and present information schematically with straight lines and right angles might make it easier for the user to remember the information.

7 - Consider environmental learning theory

Presenting branch nodes in a way that make them distinct from each other like landmarks can support the physician's construction of CM. This can be done by giving the nodes presenting the nodes with individual attribute information.

8 - Chunking information

Breaking up the route into manageable areas is a way of chunking information [6, p.388]. Presenting distinct units of chunked information might make the information easier to perceive and store, thereby facilitate a more effective cognitive mapping process.

9 - Information placement

The cost of visual search should be minimized by making the HCI as compact as possible, compatible with visual clarity. It is important to consider the gestalt principles when placing related and unrelated information for clear, rapid and effective understanding [6, p.181-237].

10 - Using both visual and verbal information

Different visual channels should be used to present different data entities to make them visually distinct. Exploiting different visual channels might reduce the risk of overloading the cognitive system. Spreading information over different modalities, e.g. text, picture, sound, might also make the information easier to keep in working memory since it is distributed to both the visuospatial Sketchpad and the Phonological Loop.

11 - Consider different environmental learning strategies

The interface can provide information for both visualizers and verbalizers. This can be valuable both for storing the information in different kinds of working memory stocks and for supporting different strategies for environmental learning.

12 - Supporting situation awareness

The interface could present an overview with the location of the user and where to go future. This will provide a general overview for the experienced physicians and supports novice physicians in their overall understanding. This can be done by presenting movement logging.

6.2 The DCD framework

The uncovered guidelines are based on the assumption that navigation research of real environments could be used to gain understanding for the development of an interface with a VE that support decision-making. Transferring knowledge about navigation an cognition into the framework of decision centred design combining it with context specific information from interviews, observation and case interviews have provided a starting point for the forth stage of the DCD framework, namely prototype development.

Using the DCD framework to uncover the key decisions to develop guidelines for designing a decision support interface has proven to be a useful method. The methods focus on the context specific performance and individual differences in expertise have clarified the task, circumstances that make the task difficult and how it should be supported.

The author recognizes that there might be some aspects, in addition to those presented in the article, that have importance while designing a navigation decision support interface for bronchoscopy that have not been considered.

The decision centred design framework is an iterative design cycle. The iterative method does not only include the prototype itself it also includes the design guidelines. Prototypes should be designed based on the design guidelines, tested and evaluated. Information and evaluation from user testing will uncover change requirements for both the prototypes and for the design guidelines.

7. CONCLUSION

Designing an interface for navigation decision support for an environment such as the lung branches is a complex process that should consider technology, human-factors and the context in which the system are operated.
In the case of bronchoscopy creating a solid CM is identified as the foundation of decision execution in the procedure. The interface should be a cognitive offloading tool that support the construction of a CM. The way an interface could support the construction of a CM is by presenting environmental information in such a way that it is effectively perceived and stored. With a solid CM the decision execution during the procedure might be easier for the physician to perform. If the cognitive workload of remembering the environment and the route to follow is reduced, the success rate of reaching the target might increase. The design guidelines uncovered can be a starting point for designing such a navigation decision support interface.

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