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Title: Streamlining patient consultations for sleep disorders with a knowledge-based CDSS

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Keywords: Sleep disorder; workflow; online clinical decision support; hi-trees; usability

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Abstract: Objectives: This paper examines the workflow of sleep physicians during a patient consultation and how an innovative clinical decision support system (CDSS) provides efficiency and effectiveness gains. Methods: The CDSS tools consisted of two input applications for patient data, with a knowledge based decision support system developed participatively with physicians and an international panel. An argument tree approach was used to produce diagnostic explanations and an evidence-based report for the physician using medically correct and shared terminology. A usability evaluation using a qualitative approach was carried out to ensure that the CDSS met the physicians' information needs, as well as the wider needs of a Sleep Investigation Unit. Results: The physicians found the CDSS both useful and usable with clear applications in triage and diagnostic decision-making, and in patient education. Conclusion: The CDSS both reduces the time and number of visits needed for consultations, and helps focus consultation on better individual patient care through informed explanation of diagnostic and treatment decisions.

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Information Systems Journal

Dear Editor

Re paper titled Streamlining patient consultations for sleep disorders with a knowledge-based CDSS

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This paper demonstrates the development and evaluation of online tools which fit into the workflow of physicians when diagnosing the chronic condition, sleep disorders. With age increasing the prevalence of Sleep disorders this is a growing issue in countries with aging populations. The aim of this research was to focus on the operational concerns of the sleep investigation units.

The summary table is shown below;

Summary Table
What was already known on the topic;
Reports from decision support systems need to be centred on physician information needs, not administration.
Patient history collection during a consultation can be a barrier to an effective and timely consultation.
What this study added to our knowledge;
A hi-tree formalism for argument mapping can be used to produce a clear evidence-based explanation of a clinical decision making process.
The design illustrates how a justified knowledge base and digital patient histories can be developed with scalability to wider practice and electronic health records

Use of a human-centred development approach aided technological acceptance
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The online tools helped physicians effectively to triage patients based on immediate needs, not previously possible in the traditional approach.
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Regards

Jacqueline Blake

Information Systems Revision Document

Authors:

Jacqueline Blake

Don Kerr

John Gammack

Title

Streamlining patient consultations for sleep disorders with a knowledge-based CDSS

We have undertaken the revisions as suggested. Thank-you for the suggestions, it has improved the paper, however if more is required, please don't hesitate to tell me and I will make every effort to comply with any additional requirements. The table below provides details of how each concern was addressed.

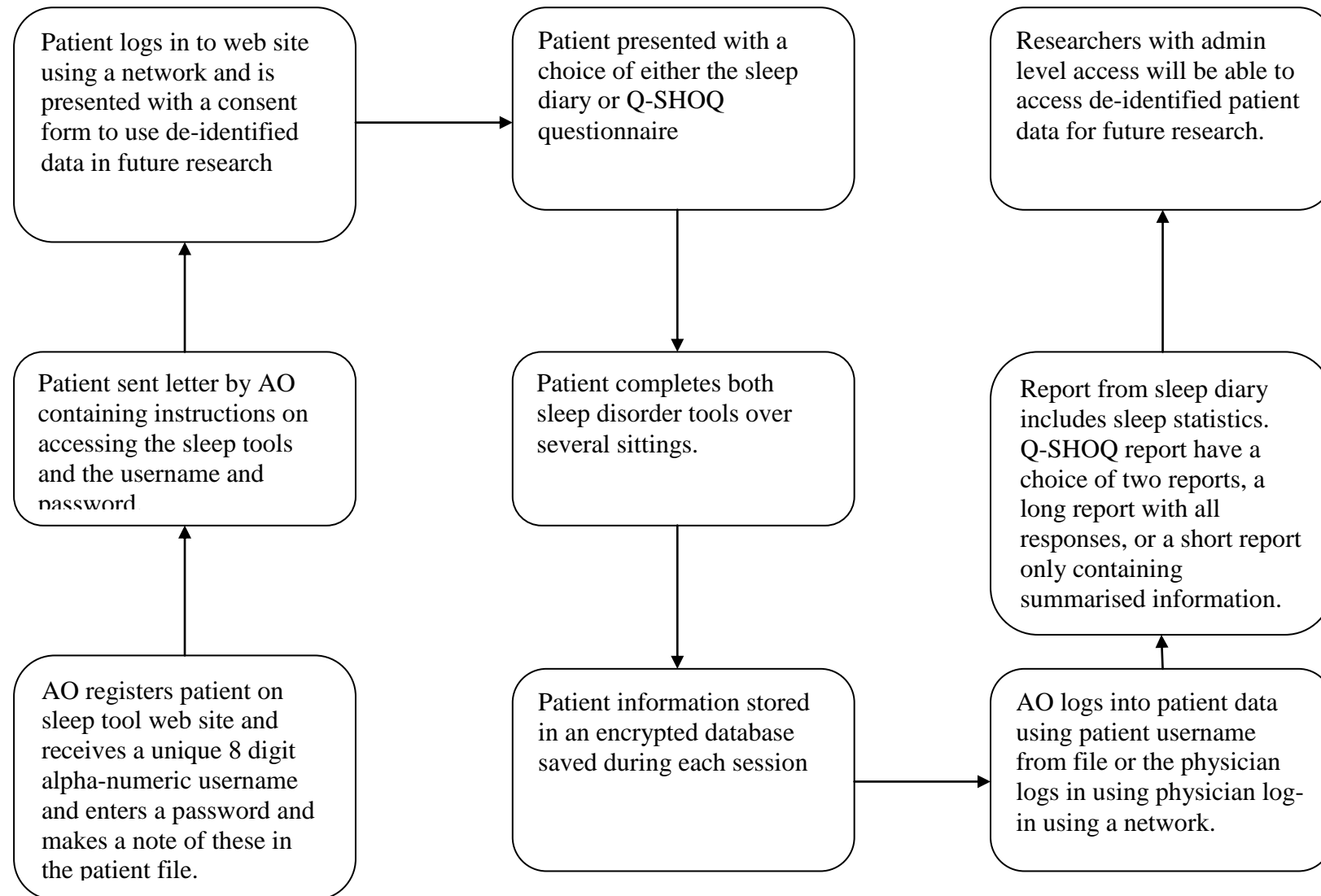
recommendations	How they were addressed
The experimental description should be more transparent. Show us the interface, put a typical run through in the appendix.	Two diagrams have been added to the appendix, one that shows the structure of the sleep tools application and a second diagram which shows the flow of how people will interact with the application. A user manual for the application showing screen shots of all interfaces and the code will be available in the research data DOI. The following text has been added under section 4.2 Development of the Sleep Tools Application. “The structure of the sleep tools application and the interactions of clinic staff and patients with the sleep tools application are available in the appendix. Research data from this project including the user manual of application, figures detailing outputs from the application (including a sample report) and raw data from interviews and quantitative data is available from the University of the Sunshine Coast Research Bank.”
There should be some before and after comparison to show that time is saved and diagnosis improved and that the docs accept the system.	The application has not been commercialised so wide scale before and after analysis cannot be undertaken at a level that would allow for effective statistical analysis. The doctors who helped develop the system have provided their estimates of the advantages and time savings associated with the system.
Raw (anonymized) data should be available on a website that will be maintained for at least 7 years.	I have completed a zip package which contains all the research data from this project. This contains the user manual for the application, sample outputs from the application, interview data and quantitative data.

	<p>This is contains a readme file containing details and descriptions for the variables from the quantitative data. This will be given a DOI and will be available as a link from the publication landing page in the University of the Sunshine Coast's open access publication bank.</p>
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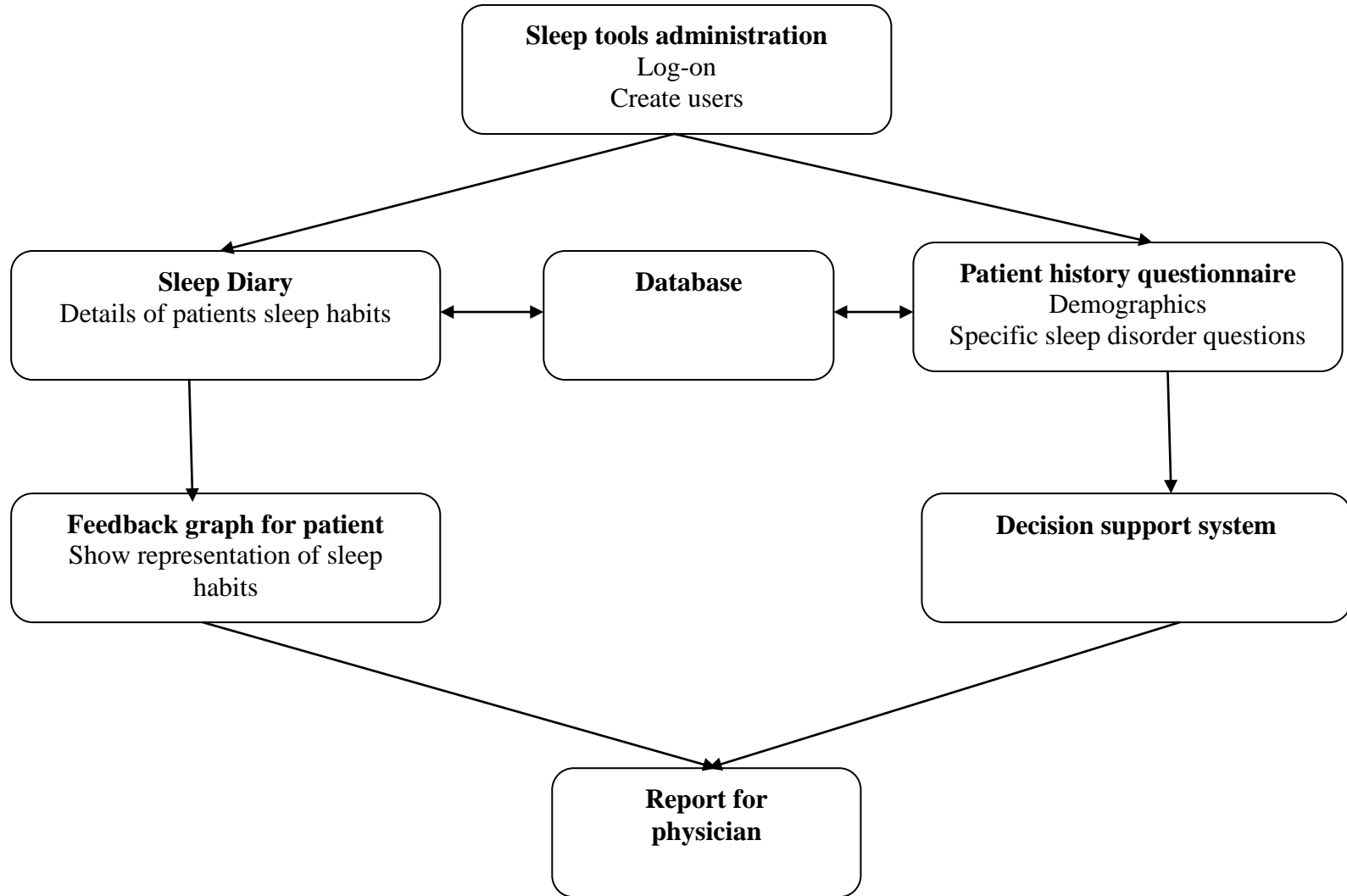
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Appendix

Interactions with sleep disorder tools



Sleep tools application



Streamlining patient consultations for sleep disorders with a knowledge-based CDSS

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Streamlining patient consultations for sleep disorders with a knowledge-based CDSS

Abstract

Objectives: *This paper examines the workflow of sleep physicians during a patient consultation and how an innovative clinical decision support system (CDSS) provides efficiency and effectiveness gains.* **Methods:** *The CDSS tools consisted of two input applications for patient data, with a knowledge based decision support system developed participatively with physicians and an international panel. An argument tree approach was used to produce diagnostic explanations and an evidence-based report for the physician using medically correct and shared terminology. A usability evaluation using a qualitative approach was carried out to ensure that the CDSS met the physicians' information needs, as well as the wider needs of a Sleep Investigation Unit.* **Results:** *The physicians found the CDSS both useful and usable with clear applications in triage and diagnostic decision-making, and in patient education.* **Conclusion:** *The CDSS both reduces the time and number of visits needed for consultations, and helps focus consultation on better individual patient care through informed explanation of diagnostic and treatment decisions.*

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1. INTRODUCTION

Diagnosing sleep disorders involves combining formal sleep studies with extensive questionnaire data. There is, however, a shortage of physicians trained in the sleep speciality, which Dement (2008) suggests will become exacerbated in countries with an aging population. Moreover effective diagnosis of sleep disorders takes time and requires consideration of a lot of data, so efficient interaction in the consultation is important not just for physician workflow, but also for patient wait times impacting the overall cost of treating the disorder. The sleep community is therefore interested in changing the traditional model of care for sleep disorders to one that leverages information systems to provide efficiencies and timely communication flows within the sleep disorder consultation (Colten & Alterogt 2006). Clinical decision support systems (CDSS) have meantime evolved from standalone

applications into ever more sophisticated integrations into clinical workflows (Wright and Sittig (2008)). These tools promise integration of patient data into useful reports for physicians, informing efficient and evidence-based diagnostic and triage decisions. To date however few studies have focussed on DSS for sleep disorders. Those that exist have mainly focussed on classifying events in polysomnograms (e.g. Alvarez-Estevéz and Moret-Bonillo (2008); Charbonier et al. (2011); d'Addio et al. (2013)) improving questionnaire based screening (Nettleton and Muniz, 2001) and implementing a sleep apnea diagnosis guideline in a smart home environment (Roy et al, 2014). In contrast, our study describes the development and evaluation of clinical decision support tools that increase efficiency in consultation by embedding them into the sleep physician's workflow.

Beginning with a workflow analysis of sleep physicians we developed and evaluated a set of online tools aimed at reducing the time required for obtaining lifestyle and symptomatic information. Removal of data gathering and completing online forms from the consultation can improve communication (Patel et al. 2002), as well as obviating the history gathering format during consultation which can form a barrier to effective communication (Charavel et al. 2001; Collins et al. 2007). The online tool should therefore ensure the consultation becomes more targeted to providing solutions and discussing the lifestyle changes needed. The research used a mixed method approach to guarantee that the outputs met the physician's needs and were fully embedded in the diagnostic workflow during patient consultations. Our approach, using an online sleep log and generated patient history report is argued to be both more supportive for the patient and also to assist the physician's decision making. Because of the need for transparency in decision making, a best-practice requirement for auditable evidence and the general need to explain the logical and complete path followed in justifying the decision, we took a formal argument mapping approach (Marriot et al, 2010) to developing the knowledge base. The accompanying knowledge sharing using a controlled and agreed vocabulary developed within the DSS aimed also to avoid confusion and to improve treatment compliance by the patient, as well as supporting more general knowledge management initiatives. The rest of the paper proceeds as follows. The literature review outlines clinical DSS requirements and related work in healthcare, together with knowledge management issues for evidence based practice. We then describe the general method by which the application was developed, including the argument mapping process, followed in section 4 by a more detailed description of the application itself. Section 5 describes the

evaluation of the DSS tools, and we finish with some general conclusions and delimitations of the research.

2. Background LITERATURE REVIEW

“The ultimate objective of a health information system is to produce information for taking action in the health sector”, and this principle applies from patient care through to national and global levels (WHO, 2005, p9). The potential of health information technologies to inform decisions, however, remains “unmet” with electronic health records (EHRs) struggling to achieve basic data entry let alone the widespread coordination and interoperability needed for effective information exchange at all levels (Lum On, Bennett and Whitaker, 2010; O’Malley, 2011). Commenting on the lack of EHRs that provide any links to DSS O’Malley (2011:1090) argues that “for the development of adequate decision-support tools, the evidence base must be expanded and actively maintained”, noting “daunting” issues of practical data entry, efficiency, and usability, and the time impacts of these on quality patient care.

The requirements for a clinical decision support system success are discussed by Kawamoto et al. (2005). Possession of five specific features increased the success rate of the systems significantly. These requirements are for the support (a) to be provided to the user automatically, (b) to be incorporated as part of a charting or input system, (c) to employ a computer to generate the decision support, (d) to prompt clinicians to provide a reason when not following advised action and (e) to provide a recommendation, rather than an assessment, for the patient. Kawamoto et al. (2005) highlighted the importance of providing decision support at the time and location of the decision making process. Castillo and Kelemen(2013) also considered the requirements for successful clinical DSS, and cite evidence that CDSS that are “customized to a specific specialty area ... are more inclined to be utilized properly” and should be integrated into the workflow and avoid workflow interrupts. They also consider it “imperative” for good communication between the users and the development team and note various benefits of user involvement for acceptance and efficient utilization.

Other authors have found other features also to be important, Regan and Holtzman (1995, p.91) add that if no explanation for the outcome is given then the output from a decision support system is likely to be rejected, because explanations enhance user satisfaction and

trust. Haug, Rocha and Evans (2003) state that their requirement for a decision support system lies with accessible data that is timely and complete. In their experience, another requirement is regular evaluations of the quality of the decisions presented by the system in light of current practise. Yet another requisite is to produce quality, timely, relevant reports which are problem focused to aid in decision making (Guerlain et al. 2000; Haug et al. 2003).

Many information systems have been developed for clinical decision support, with mixed success. Indeed many early expert systems and DSS were developed in medical and diagnostic contexts, but despite many decision support systems being in current practical use, many more are not used clinically. Coiera (2015) attributes this failure to 1) depending on an electronic medical records (EMR) system for their data, 2) poor design of the human interface, 3) solving irrelevant problems, 4) imposing changes and failing to fit naturally into the routine workflow, and 5) resistance or computer illiteracy of some healthcare workers. Coiera qualifies this last point by suggesting that it may mask the real reason: if a system is not *perceived* as beneficial it will be rejected, regardless of its true value.

Reviewing healthcare information systems failures generally, Zhang (2005) notes that failure is rarely attributable to the technology, but rather to a lack of consideration of human issues in the design process, a point echoed by Abugabah and Alfarraj (forthcoming) and others who recommend a human-centred development process, in which the users are active participants throughout, ensuring relevance, ownership, trust and meaning. By following this design and development process, the uptake problems noted by Coiera (2015) can be obviated.

Human-centred (also known as user centred or participatory) approaches benefit from the design inputs of their target users: examples in healthcare include Rinkus et al's (2005) application of human-centred methodology in biomedical engineering and Pickering et al's (in press) clinician-designed EMR viewer. Zhang (2005) summarises the process as beginning with a work domain analysis to understand the nature of the work, followed by designing and implementing the product. Finally comes evaluation using human-centered criteria. This involves understanding the characteristics of the target users, the domain knowledge (as a functional ontology), the information display formats that support direct interaction, and the task goals and workflows involved.

The most critical aspect of evaluation is user acceptance, assuming the functional aspects work correctly. Many technically correct information systems have failed to gain traction due to a lack of acceptance by their intended users. Technology acceptance models such as TAM (Davis, 1989) and its successors are concerned with predicting how users will accept a new technology and suggest that perceived ease-of-use and perceived usefulness are key determinants of acceptance. Although less parsimonious, refinements such as TAM2 (Venkatesh and Davis, 2000) include specific aspects of usefulness such as job relevance and output quality (i.e. how well it serves relevant needs).

Despont-Gros et al (2005) examine evaluation of clinical information systems (CIS) and describe “IS acceptance” as an integrated construct for their human-centred evaluation that specifically considers the active situation of CIS use and goes beyond “intention to use”. Their acceptance model embraces other human-centred dimensions including user characteristics such as expectations and attitudes, as well as process characteristics (particularly participation by users). As well as efficiency and effectiveness, these user aspects are important in a human-centred evaluation, summarised by Zhang (2005b:) as “ease-of-use, ease of learning, reduction of medical error and user satisfaction”.

Chau and Hu (2002) state that physicians exhibit different technology acceptance behaviour than some other professions having a pragmatic approach with an emphasis on usefulness of the technology rather than its ease of use. However the usefulness of the technology is recognised when the technology is perceived to be compatible with their work patterns and not requiring major changes in their work habits. Viitanen et al. (2011) postulate that when evaluating health informatics systems the complete technological environment of the physician must be considered rather than a single application in isolation from where and how it will be used. It was therefore important that the environment that the CDSS would be used in was considered carefully.

Effective knowledge management however remains a challenge, and particularly when not only different data formats or record taking and management protocols are involved, but even when the provenance of a knowledge base is not fully known. Considerations including those with legal consequences discussed by Berner and La Lande (2007) extend to the very vocabulary of the system and whether this matches other systems such as EHRs, or the local

thresholds for alerts. Apart from the accuracy physicians naturally demand, the knowledge should be kept up to date, and the physician should know how the system was tested before implementation (Berner and La Lande, 2007) There is also a professional requirement that knowledge relied upon is justifiable, and that nothing is hidden from the user. As Berner and La Lande (2007) note: “evidence-based medical practice (can only occur) if the knowledge base contains high-quality information”

Knowledge management systems in healthcare have however, been shown to improve physician adherence to evidence-based guidelines for treatment and to reduce error (Chaudhry 2008; Jamal et al. 2009; Leape 2009) while assisting physicians in processing new research findings and guidelines (Chaudhry 2008). In addition, (Feied et al. 2004) describe how “fast, ubiquitous, and unified access” to data is needed to reduce error and improve patient outcomes. Garg et al. (2005) reviewed studies that investigated physician performance; showing that when diagnostic clinical decision support systems were in place, improvements in performance were realised. Graber and Mathew (2008) found that newer clinical decision support systems have been designed to require less physician time for information input and were better embedded into physician’s work flow.

Our research therefore aims to embed the CDSS into the physician’s workflow while also ensuring that the output of the system (report to the physician) met their patient history and diagnostic needs in a trustworthy and easily assimilated format when and where they desired that information

The next section looks at our method for developing a Clinical Decision Support System that meets these requirements.

3. METHODOLOGY

A participatory approach to data collection and application development was adopted. The participatory approach can produce “knowledge used in action” (Cornwall & Jewkes 1995, p. 1667), which meant in practice that physicians had input into the form they wished the decision support to take and to provide feedback as to when the support was needed. The artefact was developed using the design science guidelines from Hevner et al. (2004). Since the development concerned the production of an IT artefact which “changes an environment

to better reflect current aims” (Boland 2002), the Klein and Myers’ (1999) hermeneutic framework was used to inform the design science research guidelines, to ensure that the knowledge base was coded in terms meaningful to sleep professionals.

Before developing the application software however, it was important to understand the physician’s workflow within the decision-making context, the inputs and knowledge base required for diagnostic tasks and explanation, and the requisite outputs and reports considered useful. It was also important to ensure that target users meaningfully understood the professional terminology of the application. This was achieved using a combination of convergent interviews, observations, document analysis and questionnaires, using triangulation to establish and verify understanding. Similar techniques were also used in subsequent evaluation of the IT artefact, with the whole process being participatory throughout. We now briefly describe how these applied in this study, before detailing the application development itself.

3.1 Participatory research

In this project the community affected comprised sleep specialists who worked within the public system, and who showed concern about the problem by approaching the university with the research concept.

The researchers formed a team with two sleep physicians and a psychologist. The collaborative approach was taken with the medical staff to gain their shared knowledge and experience in the sleep disorder domain, to facilitate the acquisition of knowledge for the knowledge base of the Decision Support System (DSS), and to integrate the resultant application within a physician’s work flow. Gaining these stakeholders’ approval of the reports generated as output from the DSS and the data gathering instruments was essential for two reasons: first, it allowed access to the sleep investigation clinic’s patients on which to test the instrument; second, it gave the team members a vested interest in the success of the project (Cornwall & Jewkes 1995).

3.2 Convergent interviews

Convergent interviews are a practical but well defined, rigorous method of data collection.

Prior knowledge about sleep disorders is needed to appreciate the medical terms and jargon to explain concepts so extant literature and SIU documents were reviewed first to gain prior knowledge as recommended by Riege and Nair (2004).

The study was carried out in a publicly funded Sleep Investigation Unit (SIU) in Queensland, Australia. The “exploratory” attribute of convergent interviewing was used in early interviews with the director of the sleep investigation unit to narrow down the broad problem domain and to direct the scope of work. This follows WHO guidelines (WHO, 2000) that identify the appropriate interviewees and protocols for Health Information Systems needs assessments at each level of a (national) health structure. The “spiral” aspect of convergent interviewing was used to refine the requirements for the sleep tools and depict the context of the diagnostic interaction with a patient. This process ensured the application development would fit the needs of the SIU as well as individual physicians.

3.3 Observations

As well as interviews and follow-up interviews, this study used observations of the processes in the SIU as well as of staff and patient interactions and communications. Observations are important, as they reveal what people actually do, rather than just what they say they do (Green and Thorogood, 2004, p. 132). Observations were made during diagnostic interviews that physicians conducted with patients, aiming to provide information on the current practice of patient–physician interactions and to indicate how this process could be supported by information technology.

These observations were used to confirm the information that the physicians acquired during the consultations and the elicitation processes used. In these consultations the focus was on the questions asked by the physician and any extra information such as test results. These sessions served to check that inputs into the diagnostic process had not been excluded and ensured that in the interview process the researcher and participants would be able to share meanings about the processes at the SIU.

The lead researcher observed two types of patient consultations: those that focused on the questions that the physician asked the patient, and those that depended on tests; for instance, the depression index test. The first set of observations were of two separate 45-minute initial interviews with middle aged males with complaints of snoring. The focus was on the type of questions asked; in both interviews most of the interview was taken up with information

gathering questions such as “What are your work hours?”, “How long is your commute to work?” and “When do you finish the last can of coke?”.

The second set of observations comprised five twenty minute consultations during which the patients were told of the diagnosis, or offered a follow-up visit to a sleep study. The sleep physician brought the patient’s files into the office with him. He showed patients the results from the polysomnography sleep study, focusing on oxygen levels and the presence of sleep stages. He compared their sleep study with the results of a normal sleep study to show for example a diagnosis of obstructive sleep apnoea, where the respiratory disturbance index (a measure of sleep disturbance events) from the sleep study determined the recommendation of CPAP. Even when he had made a firm diagnosis he remained very intent on information gathering. For example, he continued to ask questions, some of them about depression and sleep wake times. This observation changed the researchers’ view of this second interview: it had originally been described as a confirmatory consultation where the physician would only discuss the diagnosis with the patients; however, it became clear that information was still being gathered at this point.

These observations helped to uncover more of the diagnostic process, and were important for understanding the inputs that went into the decision making process, the extended duration of information gathering, and the context of how a diagnosis was made. These investigations confirmed that the physicians spend a large portion of the available consultation time on routine questions such as capturing details on smoking habits and caffeine consumption.

The data gained from interviews, observations and document analysis were transcribed into electronic documents and data reduction was achieved using a content analysis to draw out themes or clusters of ideas, which were then stored as an annotated document.

The participatory research design incorporated the physicians and a sleep psychologist throughout the development process. This ensured that their involvement went beyond a data-source role as subject matter experts in the knowledge acquisition process. The next section describes the development of the DSS application itself.

4.THE SLEEP TOOL APPLICATION

4.1.1 NON-FUNCTIONAL REQUIREMENTS

The general requirements for the system had emerged from interviews with the director of the SIU, and from the medical staff on the team, as well as being familiar from the literature of medical informatics. These may be summarised as follows. The CDSS must be useful, easy to use, transparent in its logic and have fast learnability. The CDSS and data it relies on must be accessible and available, and fit within a time-constrained workflow. The terminology of input and output reports must be readable, trustable and understandable to all stakeholders as well as being medically correct. The knowledge base must be maintainable, scalable (can add extra diagnostic instruments) updatable (as new diagnostic criteria emerge these can be added) and flexible to be useful both to an individual physician and at a more general level. It must also be accurate and verifiable to reduce diagnostic error. The data recorded should also be portable to other practitioners as well as in principle to other future systems and be interoperable with future electronic health records. Finally the confidential patient data held should be secure. The chief requirement is general usability and user-acceptance which encompasses several of these specific features.

4.1.2 FUNCTIONAL REQUIREMENTS

To address the general concerns of O'Malley (2011), for a DSS to become a useful clinical tool its data must be relevant, readily producible, and fit within the physician's time-constrained workflow. The starting point of the development was to establish the functional goals of the CDSS for the main users, the sleep physicians and its role within the diagnostic process. The most common use for a CDSS during the diagnostic process is for alerts to be issued when certain conditions have been met (Horsky et al. 2012). Our interviews established that currently the sleep specialists use a pen and paper patient history file, with no immediate plans to move to electronic health records (EHR). The close coupling of an EHR and CDSS as suggested by Horsky et al (2012) is therefore not immediately possible, however, our CDSS solution was designed readily to migrate to an environment with an electronic health record.

Table 1 shows the current diagnostic process for sleep disorders. Prior to the diagnostic consultation it embodies patient classification, data gathering questionnaires and forms, and, at

the physician's discretion, a 14 day sleep diary¹, supplementary questionnaires and an overnight study.

The physicians wanted access to a patient's history before a consultation so that they could improve their current system of prioritising, i.e. determining which patients to see first. The current system was considered too subjective with a lack of consistency across sleep physicians. The physicians also considered the existing paper based sleep diary to be a good tool but it was not used effectively because of the length of time required to extract information from it during a consultation. Lack of time within a consultation can form a barrier to the patient playing an active role in the consultation (Gravel et al. 2006; Shepherd et al. 2008) and can also cause the patient to make treatment decisions which disagree with the physicians recommendations (Breslin et al. 2008).

The physicians were therefore also interested in any efficiencies which could be driven by information systems during a consultation. Hence it was agreed that an electronic version of the sleep diary and patient history questionnaire would provide current, contextually relevant information at the time of the consultation.

Table 1 Current sleep disorder diagnosis process

Step	Description
1	A General Practitioner (GP) completes a referral to the SIU if a sleep disorder is suspected.
2	The patients are divided into two categories: local and remote. The patients are then further divided into three medical priorities – urgent, semi-urgent or routine. The physicians prioritise these based on the information in the referral, using a set of heuristics that each physician has developed individually.
3	A patient record is created and a patient number is assigned.
4	The first consultation is a three-quarter of an hour appointment, which consists of completing a questionnaire, other questions necessary for the consultation and a physical examination. If the sleep physician deems it necessary, a paper-based sleep

¹ A sleep diary is used to record sleep patterns, usually for fourteen nights. Each day the patient notes details of the night's sleep, along with intakes of caffeine, alcohol etc, to build up a picture of sleep habits (known as *sleep hygiene*). Poor sleep hygiene, or insufficient time made available for sleep, may be a cause of excessive daytime sleepiness, the main symptom of a sleep disorder. Sleep diaries are used by various health professionals, including psychologists, physicians and sleep specialists and is the primary diagnostic tool for identifying insomnia. It is a very useful aid in the diagnosis of other sleep disorders, as relatively short periods of time taken to fall asleep or frequent awakenings are indicators of poor quality sleep, and of sleep disorders generally.

	diary is given to the patient with the instruction to complete it over a two-week period.
5	An overnight sleep study (polysomnography) is carried out if needed. The patient returns the sleep diary during a quarter hour appointment before the sleep study.
6	A half-hour consultation is held with the sleep physician, during which the results from the sleep study, sleep diary and tests such as thyroid are discussed.

One of the most important factors in the design of the sleep tool web application was the significant role that patient history played during a consultation. Physicians have very clear expectations about what they want and need from patient history and consider access to a comprehensive sleep history as being best practice during a consultation. This meant that gaining a patient history that fulfilled all the physician's needs was a critical component in the sleep tool application.

The application was developed in consultation with two sleep specialists and a psychologist. For the initial convergent interviews, descriptive codes were applied to the field notes in conjunction with the director of the sleep investigation unit. This was to highlight the important themes in the physician's dialogue. Three main themes in the early interviews were apparent. These were:

- A concern for the patient's treatment.
- A concern for consistency of treatment across the clinic and
- Operational clinic implications (maximising the number and quality of consultations).

These initial interviews informed the process to develop the structure of the sleep web tools. In later meetings, the discussion was solely operational; for instance, which specific pieces of information were required to be gathered in the questionnaire. In early interviews the sleep physician stated that he "was unsure what the project could offer the clinic". However, by the third interview the sleep physician had a clear view of what the CDSS should offer, which was to act as "a web-based triage process" by "identifying or predicting a significant sleep disorder". This statement set a clear objective for the expectations the clinic had about what it would achieve from the system.

In the new system, the capturing of patient information (using either online tools or a paper-based questionnaire) transfers the form filling responsibility to the patient. Due to the reduction in time given for data collection, the physician could spend time with the patients discussing patient-specific symptoms and lifestyle. This would enable them to see more

patients or to perform a more in-depth consultation with each patient. This meets the objective of the system acting as a web-based triage system as well as meeting operational concerns. The components of the sleep tools application are shown in Table 2. The next section outlines development of these components of the sleep tool.

Table 2 Sleep tools application main areas of functionality

Functionality	Output
An online sleep diary, which records 14 days of a person's sleep habits and mood.	Patient: a graphical representation of their sleep habits. Physician: A graphical representation of a patient's sleep habits and a report containing sleep statistics showing the averages of sleep data.
An online patient history questionnaire	Data stored in a database.
A knowledge-based decision support system	Data retrieved from a database, manipulated according to logic embedded in the decision support system and presented as a report to the physician detailing if the person's patient history meets the criteria for the main sleep disorders.

4.2 DEVELOPMENT OF THE SLEEP TOOLS APPLICATION

The structure of the sleep tools application and the interactions of clinic staff and patients with the sleep tools application are available in the appendix. Research data from this project including the user manual of application, figures detailing outputs from the application (including a sample report) and raw data from interviews and quantitative data is available from the University of the Sunshine Coast Research Bank.

4.2.1 ONLINE SLEEP DIARIES

The online sleep diary requirements were developed by using semi-structured interviews with the director of the Sleep Investigation Unit together with a review of existing sleep diaries. The information gathered by the online sleep diary follows closely the pen-and-paper sleep

diary previously used in the sleep disorder clinic. This document is similar in structure to the Pittsburgh Sleep Diary (Monk et al. 1994; Smith & Wegener 2003).

With an on-line system, the physician gains earlier access to patient sleep hygiene information and can therefore prioritise those patients who need to be seen first, ensuring that those in most need of the service will have the shortest wait times. It is also forecast by the experts that patient satisfaction with the service will increase as during the wait time for an appointment they are able to self-monitor their condition. Therefore, the online sleep diary has a number of benefits, namely:

1. The data contained within the diary is presented in a summarised, readily accessible format for both physicians and patients.
2. The diary contents are available online and in real time (subject to security precautions) and therefore fits in the physician workflow.
3. The diary facilitates the development of a database of sleep patterns and this can be used for historical data analysis.
4. The online diary has all the advantages of digital data such as reuse (e.g. as part of an EHR), multiple storage locations, easier transferability of data to other medical professionals and availability for statistical analysis.

4.2.2 PATIENT HISTORY QUESTIONNAIRES

There are a number of questionnaires that are designed to diagnose specific sleep disorders, such as the Sleep Disorder Questionnaire (SDQ) and the Pittsburgh questionnaire. However, these questionnaires are neither designed to act as a complete information gathering point for a physician consultation about sleep nor designed for future automated data collection.

There were two objectives to the questionnaire tool; the first was to gather standard patient history information and the second was to gather patient information that would be used as input into the decision support system and would be used to support the physician's diagnosis of a sleep disorder. Questions which met the first objective were drawn from the current pen and paper patient history questionnaire. Questions to meet the second objective were drawn from a bank of questions previously developed by one sleep physician and the sleep psychologist. These questions had been generated from a large pool of questions based on an extensive review of existing sleep questionnaires and structured diagnostic interviews by a

psychologist. An expert panel, comprised of experienced, board registered, sleep medicine clinicians from the Stanford School of Medicine, and the Stanford Medical Center's Sleep Disorder Unit reviewed the initial set. The item pool was modified based upon this review, redundant and irrelevant items were removed, as were items that made no significant diagnostic discrimination. The initial pre-test of the questionnaire was carried out by asking colleagues to fill in the questionnaire; to write comments on the grammar, readability and length; and to provide a general response. There were twelve responses, coming from psychologists, information system lecturers and other sleep physicians, errors were corrected and technical questions referred to the development team.

4.2.3 KNOWLEDGE BASED REPORTING

The need to provide an explanation of the process of decision making was paramount in this project, as one of the critical factors for physicians to accept a clinical decision support system is openness and transparency of how the decision was derived. An explanation of the pathway to a decision by an application leads to increased satisfaction and increased trust in the outcome by both patients and users. The provision of an explanation module and the diagnostic environment of heterogeneous sleep disorder sufferers drove the decision to adopt a small, rule-based decision support system. This approach allowed an argument to be made at every decision point in the diagnosis. In addition a rule-based decision support system made it possible to simplify each decision point to a yes/no response. Each disorder in the International Classification of Sleep Disorder (ICSD), followed by its individual criteria, made twenty-eight natural decision points. The simplicity of the multiple DSS ensures that the system is flexible and easy to change in the event of alterations in the diagnostic criteria.

The process of a medical diagnosis is logically described by Seising (2006, p. 238) as:

The doctor notes the patient's signs and symptoms, combines these with the patient's medical history, physical examination and laboratory findings and then diagnoses the disease (Seising 2006, p. 240).

Hence, as no two clinical presentations are identical and the medical environment dynamic, physicians use a set of heuristics and their own intuition to diagnose a health disorder (Breslin et al. 2008; Seising 2006); consequently, experts in the sleep disorder domain often skip steps in the reasoning process (Patel et al. 2001).

To justify a diagnosis, the physician might construct a logical argument to support the diagnosis. Using Toulmin (1958) we can treat a diagnosis as an assertion that is a statement

which is intended to be taken seriously and, if challenged, can be defended with the foundation for the assertion. An argument is then built using the information upon which the assertion was built. This argument will be presented in a series of stages or steps; however, these steps do not necessarily reflect the process originally used to arrive at the assertion, but rather reflect the best argument that can be put forward in its support (Toulmin 1958, p. 17). As it is clearly important that the CDSS could provide consistent, evidence-based reasons for its recommendations, an explicit argument mapping approach was adopted. Recent developments from Toulmin's theory have produced the formal computational structure of hi-trees (Marriott et al, 2010), which represent conceptual structures and multi-premise reasoning applicable to argument mapping (and decision mapping more generally). Hi-trees visually represent the logic followed to reach a decision, and can be supported with software implementations both to avoid cognitive biases and to ensure complete and warranted consideration of the relevant components. As well as formally describing the evidential relationships between propositions the visual explanation helps ensure shared understanding and provides a recorded justification of a diagnostic recommendation. This is important since the hi-tree formalism accommodates arguments relying on conjunctions of propositions, which better represents the clinical decision making context.

In practice our method of using rule-based logic at each decision point meant that an explanation of the decision process in the decision support system could be communicated to the physician in the form of a report. This report aims to provide the accuracy and transparency of the decision making process which physicians require if they are to trust the patient recommendations delivered by the decision support system's output. The report summarises demographic and patient history information contained in the questionnaire as well as the output from the decision support system itself. This means that the report integrates into the physician's consultation workflow by containing a near complete patient history; this has the potential to increase physicians' acceptance of the decision support system by lowering the difficulty threshold of its use. By including background patient data in the report, the physician is presented with a comprehensive overview of the patient, while preserving the patient's individuality (Morris 2002). In line with the literature (Guerlain et al. 2000) recommendations are then given for treatment, such as if an overnight sleep study (polysomnography) is required.

Standard accepted tests in the sleep disorder community – such as the Epworth sleepiness scale (Johns 1991) and the Insomnia severity scale (Morin 1993) – were also included. This means that the results from these tests can be taken from the report and communicated throughout the medical community; that is, from the patient's primary care physician to other specialists, such as psychologists. Clearly, this will increase the utility of the report for the physician.

4.3. EVALUATION OF SLEEP TOOLS APPLICATION

In order to aid the sleep physicians' evaluation, real time data needed to be obtained. Ten randomly chosen sleep patients filled in 14 days of sleep diary data and completed the patient history questionnaire. These sets of data were used to populate the sleep software application and the output was presented to the physicians. These outputs included (a) the sleep diary graph, (b) sleep diary statistics and (c) the physicians report, generated from the diary graph and the statistics. These reports were then sent to the physicians by email. This is equivalent to the second stage in the consultation process, where the physician categorises patients into the three levels of appointment urgency. The physicians who were involved in the development of the sleep tool web application were asked to comment on the results. They then considered the difference that having this information would make when they were consulting a patient.

One physician made comments focusing on the operational aspects of the reports – that is, the output of the sleep tools web application – rather than on how the application might affect the consultation process. The other physician focused on how the use of the application would affect a consultation, so that both points of view were discussed. Access to the online application was offered to both physicians, but both declined the offer as they felt that this could inadvertently affect their evaluation.

For the purpose of checking acceptance of the technology, evaluation focused firstly on the ease-of-use aspects, particularly addressing readability and layout, and secondly on the usefulness of the reports themselves for supporting professional decisions. The comments made by the physicians were grouped under these themes, as described below.

4.2.1 Ease of Use

A major non-functional requirement was that reports be readable, and this is a prerequisite for trustability and understandability. Both physicians agreed that the legibility of the current questionnaires was not an issue. Indeed the legibility of the printed report was noted as an advantage by one physician, who stated: "Everything is readable, which is a big advantage over the pen and paper questionnaire".

For effective decision support the information in the patient reports must also be accessible (Haug et al. 2003). Here the involvement of physicians in the development and layout of the reports played a major part in physicians finding the information in the report accessible and useful. The report focused on the physician's immediate information needs in a patient consultation without a focus on administration requirements. This meant that the relevant information was available and accessible within the workflow, in an easy to use layout directly specified by physician users. Due to shifting the burden of form filling to the patient this separation of the clinical information needs from administration does not incur an administrative overhead but rather assists in physician acceptance of the system, through timely, relevant and problem-focussed reports, in line with the recommendations of (Guerlain et al. 2000).

In addition Haux (2010) has described the role of medical informatics as a driver for change to more cost-efficient and effective care. The physician who evaluated the instruments of this study considered that the use of the sleep tool web application could reduce the number of diagnostic sleep disorder consultations required. This addresses the call by Colten and Alterogt (2006) who describe the need to gain efficiencies through improved technology for sleep disorder diagnosis, particularly "reliable portable diagnostic technologies".

4.2.2 Usefulness of the reports

In discussing usability of the reports generated from the patient history, the physician used various terms indicating that the software-generated reports were professionally relevant and useful within a consultation. He stated: "In terms of coming to the summary, the person's demographics are quite handy", and "Hypoventilation that says it is indicated. Insomnia it is saying here that criteria A & B have been met and it says what questions caused those conditions to be met. Which is handy", "Insomnia severity scale is helpful", "Circadian

Rhythm is useful", and "The preparedness to change is quite good and the Epworth is good as well".

Similarly, the other physician thought that the tool would be useful for indicating if a referral to a sleep clinic would be necessary, and how urgent the referral to the sleep clinic should be. He suggested that the existing referrals from general practitioners were often "lacking in patient information", and might omit pertinent information such as the patient "being a professional driver". However, he thought that if the application were to be used in this role, it would need a tailored summary report for this purpose due to the time pressures that a general practitioner experiences. He saw the application being used as a triage method, recalling his desire for a better way to triage patients for appointments than that currently used at their facilities. He stated that:

"I see the tool as a screening tool to be used prior to referral. It would work either as a tool for GPs and other referring practitioners to use as something to indicate who should be referred and the urgency of that referral. I would see that the GP would get the patient, maybe with the assistance of the practice nurse, to complete the questionnaires, and then if sleep disordered breathing was indicated, use the report generated as the body of the referral. If it were to be used in this role, however, the report would need to have a summary at the end, perhaps of the significant positives, so that a reader without sleep experience and limited time could cut to the chase."

He also commented:

I would see that patients are requested to complete the questionnaire before their referral is processed to use to assign clinical priority.

He further stated that he:

...thought that the introduction of the sleep tools web application in their sleep practise would change workflow, as they would be better able to prioritise which patients to see first. If Sleep Disordered Breathing was indicated in the reports then the patient would be offered a sleep study prior to the initial appointment with a sleep physician.

These comments offered a clear acknowledgment of the benefit of this information gathering approach in terms of the health budget and best use of sleep physicians' time. They also believed that this consultation protocol would change the current information gathering consultation to one favouring shared decision making and patient adherence to treatment plans. This physician also thought that the administration of a tool such as the sleep tools

web application acted to educate the patient and improved the consultation. This was demonstrated in statements such as :

Basically, less time on collecting routine data, ... It will allow better focused discussion on where to go from here

and

One benefit of a tool like this is unconscious education of the patients. It can make them think about the influence of factors that they had not been aware of and the influence they may have on their disease. This precognition can improve the clinic visit and I have noticed in other situations that the questions asked by patients and relatives/carers are more insightful and they seem to understand more about their illness and retain more from the interview in this situation.

The sleep diary graph was also a way to target treatment discussions on patients' lifestyle choices. This is shown in the comments:

I like the graphical representation and find that it helps with patient's understanding when trying to explain sleep hygiene and sleep phase disturbances in particular, and to a lesser degree sleep restriction

and

It may also be something that we could give to patients as reminder of their sleep issues whereas the current sleep diaries are less visually appealing. The statistics are useful in that it quantifies the visual data – most useful I think are the mean sleep time and range. An additional item might be the mean and range sleep onset and waking, or some measure of variability.

The report was seen as another avenue for gaining information to assess patients before a consultation. This function had been part of the objectives that the physicians outlined in the initial meetings. This is shown in the comment:

Overall, I think that the sleep diary will have most benefit in those with symptoms without sleep apnoea or those who have an incomplete response to therapy where other issues often need to be addressed. That being said, I would see it as part of the initial assessment as it quickly helps determine the triage group (i.e. somnolence with normal sleep hygiene needing sleep study, somnolence with disordered sleep pattern requiring this to be addressed and maybe a sleep study, and those with nothing wrong).

The main outcomes from the physicians' assessment may be summarised as follows:

- All the information was readable.

- The information was useful within a consultation.
- The application had potential as a screening device for primary care physicians.
- The application was useful as a web based triage system.
- The application could change consultation flow by bringing forward physical tests and reducing the number of consultations by one.
- The application could reduce time spent collecting routine data during the consultation, thus allowing for better focused discussions.
- Exposure to questions before the consultation facilitates shared decision making by the patient.
- The sleep diary graph was a useful education tool.
- The ease of being able to quickly scan a report and gather information was important to physicians.

The physicians found that the sleep tools application would be useful in their practice, potentially decreasing patient visits by at least one. They also claimed that completing the questionnaire performed a role in educating the patient in sleep disorders, and having access to this patient information meant that more time would be spent on patient-centric discussions of treatment plans, with the patient being a more active participant.

5. CONCLUSION

This study has aimed to provide clinical decision support (CDSS) tools that are useful to practicing sleep physicians during diagnostic consultations, and that are also of wider value to sleep units where efficient use of time and expertise is crucial. To achieve this, a participatory approach was followed which helped ensure both technological acceptance and medical correctness and which was verified by an international expert panel.

An online diary, recorded patient history mechanism and a justified knowledge base were developed, using a rule based argument formalism that records and visualises justification of a diagnosis by combining and logically reasoning with evidence, and using terminology that is understandable to all of its stakeholders. It was important that the tool fitted physicians' workflows and practice without adding extra administrative burden, and produced readable and accurate reports for use during the consultation session. The CDSS was then evaluated for ease of use and wider usability.

The CDSS was evaluated by physicians who agreed that it was easy to read, information was accessibly laid out and most importantly was practically useful and relevant to their improved practice. Triage decisions were aided by the tool, it had practical uses in screening and educating patients, as well as focussing consultation discussion and informed decision making involving the patient. The generated reports were accessible, informative and fitted seamlessly within workflow, which was streamlined through use of the CDSS.

The evidence from the study is that the patient's use of the sleep tool web application can free time from data gathering in the consultation process, further enriching the interaction between physician and patient, and ensuring efficiency gains for the physician and sleep unit. This addresses the issues regarding both lack of, and inefficient use of consultation time noted by Colten and Alterogt (2006).

The output from the sleep tools web application was also evaluated as useful in allowing an efficient, consistent triage process before seeing a patient for the first time. One operational implication of this is that a patient with a high risk of sleep apnoea can be sent to have a polysomnography before a consultation with a sleep physician. This acts to shorten the diagnostic interaction by at least one consultation freeing the physician to see more new patients and reducing the cost of treating each of these patients. For publicly funded sleep disorder clinics this offers a direct saving to the government health budget and helps to alleviate wait times to be seen for patients, with analogous benefits for private enterprises.

The patient is also saved the burden of having to travel to one consultation, and also benefits by improved effectiveness achieved through more time for focussed consultation. This represents better patient care by increased quality time, transparency of explanation and justification of the relevance of an individual treatment plan, potentially increasing better adherence.

Another operational benefit of the removal of patient history taking from the consultation also raises the possibility of the physician being able to shorten the length of the consultation time. This means the physician is then free to carry out other tasks or to see more patients in the same length of time. This process can improve communication (Patel et al. 2002), (Charavel et al. 2001; Collins et al. 2007), and allow time for the patient to play a more active role in understanding the consultation diagnosis and their recommended treatment (Gravel et al. 2006; Shepherd et al. 2008) (Breslin et al. 2008). Evaluation of the CDSS suggested that it

improved patient education regarding their disorder, allowing them to see lifestyle factors and with implications for better treatment compliance.

The patient history data gathered is in digital form, allowing for ready export to future health records and transfer between practitioners. At the same time the knowledge base is scalable and updatable with other diagnostic instruments or categories as these become discovered. Integration with other data sources and electronic health records is planned in our future work.

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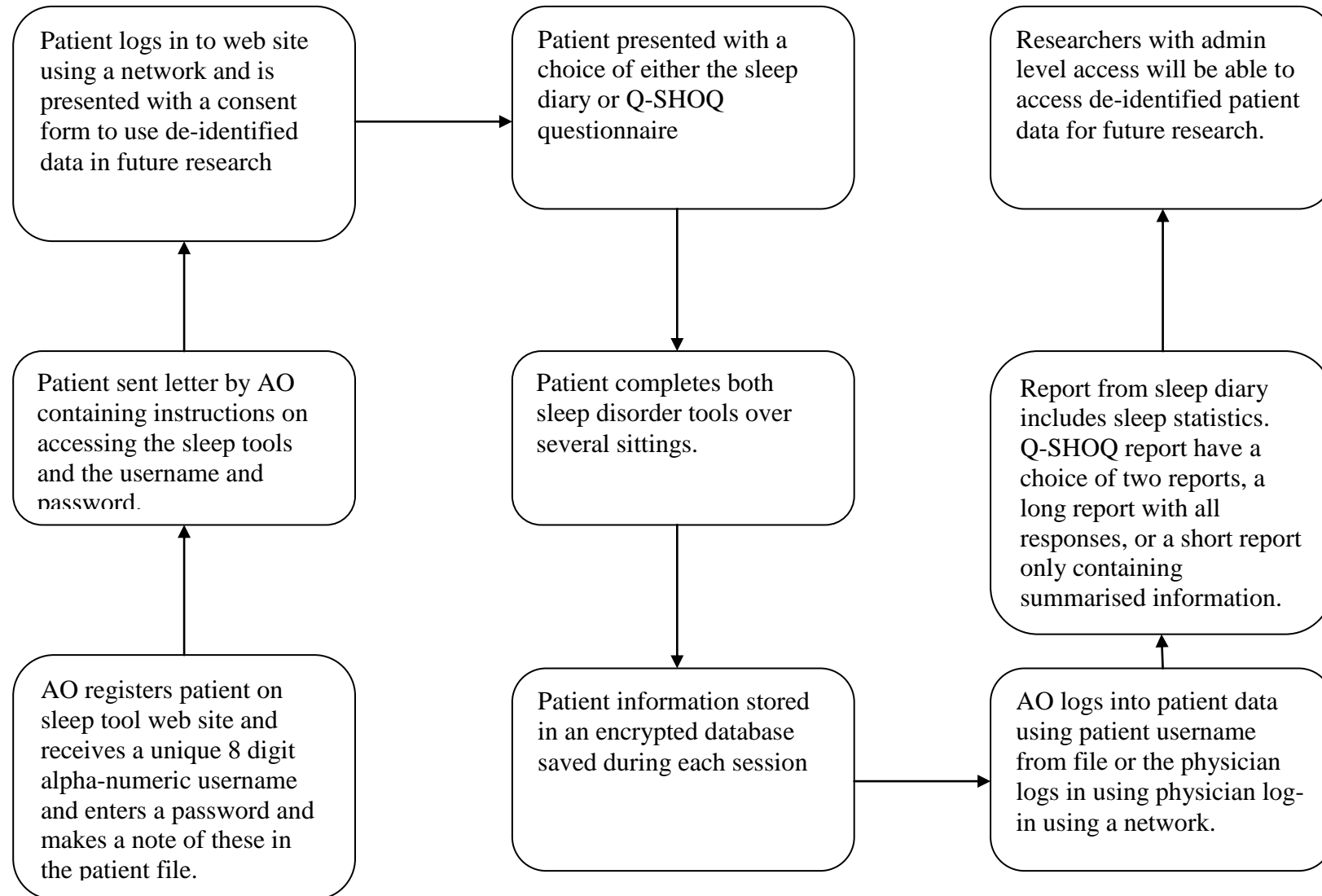
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Appendix

Interactions with sleep disorder tools



Sleep tools application

