The Interactive Ward Round Table: A Cognitive User Interface for Multi-Touch Tables to Support Clinical Diagnosis

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***Abstract*—With the *Interactive Ward Round Table*, we developed an advanced prototype of a patient record system for multi-touch tables that is aimed to support clinicians in making diagnoses. This is a complex task that requires clinicians to integrate critical information across multiple medical documents. The incorporated features of our user interface (UI) are thus based on research findings on how readers construct an integrated understanding from multiple documents. Specifically, previous psychological and human-computer interaction research suggests that readers' integrated understanding can be supported by facilitating comparison and corroboration of information across documents. Because the features of the UI are aimed to support these cognitive processes, we refer to it as a cognitive UI. In this paper, we motivate the core features of the UI, namely (1) a simultaneous presentation of multiple documents on screen, (2) relevance marking of full documents or text within a document (i.e., highlighting), (3) an interactive timeline enabling temporal filtering of documents, (4) a keyword search, (5) categorical filtering of documents, and (6) notifications of newly added documents. Further, we present a user study with $N = 11$ clinicians, which indicates a greater satisfaction with and better usability of the *Ward Round Table* compared to their system currently in use. Finally, we discuss additional qualitative results of the user study and possible implications for UIs used in hospitals. (*Abstract*)**

Keywords— patient record system, cognitive user interface, multi-touch table, user test (*key words****)***

I. Introduction

Electronic patient record systems are commonly used in hospitals nowadays to help diagnosing and monitoring patients. However, previous studies have shown that such systems can affect clinicians' medical reasoning [1], and that a poor usability of such systems can increase clinicians' mental workload [2], thereby jeopardizing their diagnostic success. Accordingly, Patel and Kushniruk [3] suggested developers of such systems should take into account not only design guidelines and factors of human-computer interaction, but also findings from psychological research investigating the underlying cognitive processes involved in the task at hand. In developing the *Ward Round Table*, we took this suggested approach for supporting clinicians in their ward-round preparations, in which they diagnose and monitor patients currently on the ward (see Section II). Because the features of the *Interactive Ward Round Table* (hereafter: *Ward Round Table*) are aimed to support clinicians' *cognitive* processes when diagnosing a patient, we refer to it as a cognitive user interface (UI). In the remainder of this section, we shortly describe the cognitive processes involved when clinicians make a diagnosis and review findings from psychological and human-computer interaction research that give suggestions on UI features that support these processes.

A. Related psychological and human-computer interaction research

When clinicians use a patient record in an attempt to find the correct diagnosis (or to determine missing information and order the respective tests), they are often required to read and browse a large number of documents from different medical disciplines [4] and to form an *integrated understanding* of these documents. That is, they need to extract relevant information, draw inferences between information provided and their prior knowledge [5], and *compare and corroborate* pieces of information within and across these documents (e.g., [6]–[8]) in order to decide whether they all support the same diagnosis or potential differential diagnoses (see also [9]). Importantly, previous research (outside the medical field) suggests that the time and effort required for accessing task-critical information can affect the likelihood to which a user will engage in information comparison and corroboration [10], [11]. Hence, a UI that aims to support clinicians in finding the correct diagnosis (which requires information comparison and corroboration across documents) might do so by facilitating the accessibility of information. As we will argue next, this might be achieved by incorporating the following features: a simultaneous presentation of multiple documents, the possibility to freely re-arrange documents on screen, the possibility for text-highlighting, categorical filtering of documents, keyword search, and temporal filtering of documents.

First, previous findings from text-comprehension research suggest that a *simultaneous* as compared to a sequential (i.e., only one document being visible at a time) presentation of multiple documents fosters readers' integrated understanding [12], and decreases their cognitive load [13], [14] in constructing an integrated understanding. This might be because in a simultaneous presentation of multiple documents, pieces of information (across documents) can be directly compared and corroborated rather than having to keep them in memory [15]–[17], thereby reducing readers' cognitive load compared to a sequential presentation [16].

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Second, observational studies have found that clinicians spatially organize paper records on tables [2] and readers [18]–[21] spontaneously *re-arrange* and re-order multiple paper documents during reading. It has been argued that this may happen in an attempt to compare and relate them to each other [18], [21]. In order to allow for a simultaneous presentation as well as for a flexible re-arrangement of multiple documents on screen, the *Ward Round Table* was developed for multi-touch tables (MTTs), i.e., large horizontally oriented displays that allow for a direct, touch-based interaction with objects displayed [22].

Third, clinicians sometimes re-access previously sighted documents [23] in order to compare or corroborate information across documents [8]. However, finding specific information previously deemed relevant in a re-accessed document can be effortful when it requires skimming the text for specific keywords. In this regard, previous research has shown that highlighted text "pops out" [24], [25], thus making it easier for readers to re-access (i.e., find) information previously deemed relevant.

Fourth, it was shown that when dealing with large amounts of documents, a *categorical filtering* that fits a given criterion increases users' speed, accuracy, and satisfaction as compared to a UI without filtering [26]. Since a patient record contains documents from different medical disciplines (e.g., reports from radiology, from gastro-enterology, or from a microbiology laboratory), a filtering according to these disciplines might be helpful when attempting to find a specific document.

Fifth, in the same vein, a *keyword search* functionality might support clinicians in finding documents containing specific keywords faster and with less effort than when having to skim through all documents (of a specific discipline).

Sixth, in addition to filtering by category and relevance, an *interactive timeline* might support clinicians in diagnostic reasoning because it allows for *temporal filtering*, which reduces the number of documents presented and, thus, increases accessibility of specific documents. Furthermore, while the latest findings might be the most relevant for most cases, some complex medical histories might require clinicians to understand the temporal unfolding of a patient's illness. Here, timelines can be used as easily comprehensible visual tools (e.g., [27], [28]).

II. Current System in Use

The *Ward Round Table* was developed in cooperation with the University Clinic of Tübingen. There, clinicians of one ward gather together before the ward rounds in order to share information of the admitted patients, plan diagnostic algorithms, diagnose patients, and discuss their current state of health and medication. Typically, one clinician prepares these ward round meetings individually in order to explain the patients' states to the other clinicians. During these meetings the same clinician will also most likely be the one operating the available system. The current system which is used both to individually prepare and to jointly hold these meetings consists of three computer programs running on three different computer screens. Each shows different facets of patient-related information: 1) MEONA™ displays the medication, notes and a vital sign summary diagram of each day during the admission, 2) SAP i.s.h.med. allows clinicians to search and manually enter relevant information in different category-tabs (e.g., anamnesis, medication, diagnostic findings), and 3) Swisslab Lauris™ displays laboratory orders and results. Consequently, this setting does not allow to flexibly display multiple patient-related information simultaneously.

In a short questionnaire study conducted in December 2017, we asked $N = 14$ clinicians from the University Clinic of Tübingen to rate their satisfaction with the currently used system and how easy or cumbersome it was to find information in the system (2 items, 5-point Likert scales), as well as to give suggestions on possible modifications of their currently used system. Results showed that clinicians were only moderately satisfied with the currently used system ($M = 2.93$, $SD = 1.00$; on a scale from 1 = "not at all satisfied" to 5 = "very satisfied") and found it rather cumbersome to find information ($M = 2.46$, $SD = 0.50$; on a scale from 1 = "very cumbersome" to 5 = "not at all cumbersome"). Regarding the suggested improvements of their currently used system, seven participants stated they wished for an integration of all three systems into one in order to gain a cumulated overview, and one participant stated that the current system lacks a notification of documents newly added to a patient record. Furthermore, clinicians were asked to rate the relevance of potential new features for a new UI on 5-point Likert scales. Results are provided in Table 1. Overall, clinicians rated the suggested features as (rather) relevant for their task. We thus implemented these features as well as a notification of newly added documents in the *Ward Round Table*.

TABLE I. Means (and standard deviations) of $N = 14$ clinicians' relevance ratings (1 = not at all relevant, 5 = very relevant) for potential features of a new UI. The middle column indicates whether the respective feature is implemented in the system currently used for (preparations of) the ward round meetings at the University Clinic.

Feature	Implemented in the currently used system	Mean (SD) of relevance ratings
Automated "new" marking of incoming documents	No	4.50 (0.76)
Simultaneous presentation of documents	No; only across computer applications, and without customized arrangement	4.43 (0.76)
Categorical filtering	Yes	4.43 (0.65)
Keyword search	No	4.36 (0.63)
Timeline	No	4.07 (0.73)
Free arrangement of documents	No	3.86 (0.95)
Text-highlighting	No	3.86 (0.95)

III. User Interface

We implemented the Ward Round Table for MTTs because they offer a large digital working space and, thus, allow to present multiple documents simultaneously as well as to re-arrange them freely (for a motivation see Section I.A.). Furthermore, previous studies suggest that users prefer touch-based over mouse-based interaction with MTTs (e.g., [29]). Consequently, icon size and gesture-detection were implemented in accordance with the requirements of touch-based interactions (see Table 2). In the following subsections, we describe the features of the *Ward Round Table* (from top to bottom, see Fig. 1).

A. Accessing a patient's record

A patient record can be accessed from the overview of the records of all patients currently on the ward. It contains the name of each patient as well as a miniature preview of the patient view in the state it was last exited (see Fig. 2). In case that new documents were added to a patient's record since the last visit, a red circle indicating the number of newly added documents is shown in this preview. Within the patient view, the patient's name, room number, and birth date are displayed prominently in the top left corner of the UI. The initial state of a patient view is the same as when it was last exited (i.e., the same that is captured in the miniature preview). This enables users to resume where they left the system instead of having to recreate the arrangement ([30], pp. 29-31).

B. Presentation of and interaction with documents

Multiple documents can be displayed simultaneously in the interface. When a document is opened (see also Section III.D.), it will be displayed either in a default size in a position where it creates the least overlap with already opened documents, or in its previously manipulated size and position. Documents can be freely re-arranged and scaled on screen.

TABLE II. DESCRIPTION OF THE GESTURES IMPLEMENTED AND HOW THEY ARE INTERPRETED BY THE UI DEPENDING ON THE LOCATION OF INTERACTION.

Gesture	Location	Interpretation
single tap	keyword-search button, document-icons	open / close
single tap	category-chips, document-relevance-button, page-miniature-view in document frame, highlighting-buttons (including the "back" and "forward" arrows as well as the highlighting-color-buttons)	(de-)activate / (de-)select
pinch	timeline, document frame	scale
touch (= hold down) + move	timeline, document frame (except for buttons), document text (when highlighting is de-activated)	re-arrange
touch (= hold down) + move	document text (when highlighting is activated)	text-highlighting
touch (= hold down) + move	page-miniature-view in document frame (if number of pages exceeds the preview)	scroll

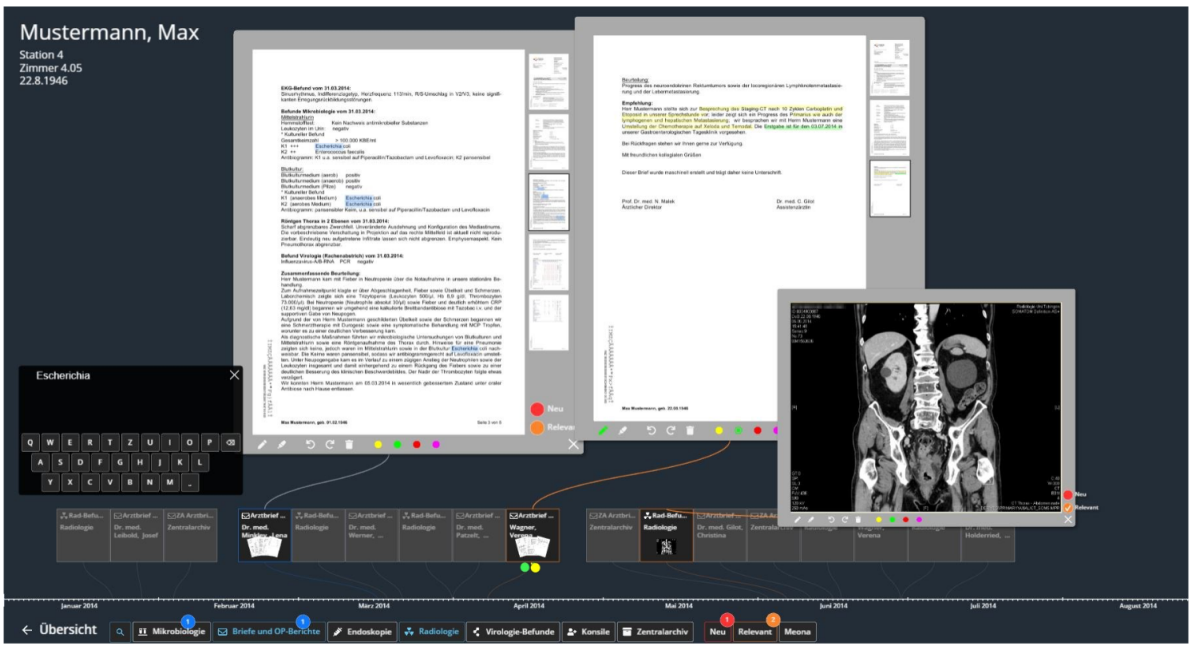

Fig. 1: Screenshot of the *Ward Round Table* UI. Features include (from top to bottom): (1) Documents manipulation area showing all opened documents in a document frame containing miniature views of all of the document's pages and options for relevance marking (full document and text-highlighting). (2) Interactive timeline containing icons of documents according to their category, whereas the surrounding of icons is orange (marked as relevant), red (new document), blue (contains word(s) matching a keyword search), or grey (no marking). Text-highlights in a document are indicated by small dots below the icon in the respective color(s). (3) Filtering chips (from left to right): keyword search (magnifying glass icon), document categories, newly added documents (red surrounding), and documents marked as relevant (orange surrounding). Activated document categories are indicated by blue font in the category chip(s). The blue, red, and orange circles on the category chip(s) indicate the number of documents with keyword-search matches, the number of new documents, and the number of documents marked as relevant. Blue highlighting in the documents (text and miniature views) highlight the keyword-search match.

Fig. 2: Overview of patients currently on the ward. Each preview of the patient view represents the state (i.e., manipulations of, for instance, documents and the timeline) as it was when last exited. The red circle indicates the number of newly added documents to the patient record.

Fig. 3: The interactive timeline: Zooming in (left) by moving the fingers further away from each other in order to diminish the time period; zooming out (right) by moving the fingers closer to each other in order to expand the time period.

C. *Relevance-marking*

Text-highlighting can be activated individually for each document in the document frame. A choice of four colors enables color-coding several pieces of information with regard to different diagnoses they support, thus further supporting comparison and corroboration of clinical findings. Single or all highlights can be deleted via the "undo" and "delete" button in the document's frame, respectively. Furthermore, full documents can be marked as relevant by a button in the respective document frame (see Fig. 1).

D. *Interactive timeline: Temporal filtering*

The timeline presents patient-related documents as icons indicating the respective medical discipline and their creation date by a connection to the timeline with a thin line. Whenever there is sufficient space on the timeline (see Subsection E.), additional information is displayed on the timeline: For text documents, the number of pages, and for image documents, a miniature view of the document is displayed (see Fig. 1 and 3). The time period of the timeline can be freely manipulated (i.e., documents represented on the timeline can be filtered; see Fig. 3). Opened documents are always connected to the timeline with a thin line, i.e., indicating their creation date. This visual indication of an opened document's creation date might additionally support clinicians in understanding the temporal relations between findings (i.e., which one was conducted first / latest).In order to enable a quick access of relevant documents even when they are closed, relevance markings are propagated down to the respective document icons: If the full document is marked relevant, the icon will have an orange surrounding. In case text was highlighted in a document, a dot of the respective color is displayed below the icon (see Fig. 1).

E. *Filtering by document category, relevance, and recency*

All documents available for a patient are categorized according to their medical disciplines. Document categories can be (de-)activated via the category chips, whereas only documents of the activated categories are represented on the interactive timeline. Irrespective of the document categories activated, all documents marked as relevant and all documents newly added to the patient's record can be displayed on the timeline via the filter chips "Relevant" and "New", respectively. The circles on these filter chips indicate the number of documents newly added to the patient record (i.e., documents that have not been sighted yet; red) and the number of documents marked as relevant (orange).

F. *Keyword search*

In the *Ward Round Table*, all digitally generated documents available for a patient are automatically indexed (please note that some documents are scans of handwritten documents generated before digitization in hospitals). A keyword search can be initiated by tapping the magnifying glass button next to the category buttons, which triggers a search field and touch keyboard to be displayed. During a keyword search, matches will be indicated by a blue mark on the respective category chip(s), the document icon(s) on the timeline (if currently displayed), and in the text (if the document is opened; see Fig. 1).

IV. User Study

The user study was conducted at the University Clinic of Tübingen in July 2019. Overall, we had three major goals in this study. First, we aimed to assess the overall usability of the *Ward Round Table*. Second, we wanted to assess whether the individual features are intuitively usable. Third, we aimed to obtain an estimate of how the MTT UI compares to the system currently in use at the university clinic (see Section II) with regard to clinicians' satisfaction and perceived ease of use. Because the system currently in use is mostly operated in an individual setting (see Section II.), clinicians took part in the study in individual sessions.

A. *Methods*

Eleven clinicians (5 female; 4 between 24 and 29 years, 3 between 30 and 34 years, 1 between 40 and 44, 1 between 45 and 49, and 1 between 50 and 54 years of age) from the University Clinic of Tübingen with varying experience in operating the currently used system (min = 4 months, max = 5 years) were recruited to take part in this study. Participants first gave their informed consent and filled out a short questionnaire about the currently used system in which they were asked since when, approximately (how many days, weeks, months, or years) and how frequently (5-point Likert scale with 1 = very seldom, 2 = approximately once a week, 3 = several times a week, 4 = approximately once a day, 5 = several times daily) they operated it, how satisfied they were with it, and how easy or cumbersome finding information was (5-point Likert scales). Finally they rated its usability with the System Usability Scale (SUS, 10 items [31]). Afterwards, participants were given a worksheet with ten tasks (see Table 3) they were supposed to carry out on the *Ward Round Table* (run on an MTT; Alvaro Edge, 3840 x 2160 px, 60 Hz, 65). Because we wanted to investigate whether the specific features are intuitively usable, we decided to refrain from giving participants instructions regarding the UI. Rather, the first nine tasks required participants to operate single features and the final task required participants to use the full UI (see Table 3). Thus, Task 10 reflects a typical task in clinicians' workday. The two patient records relevant for the tasks contained 334 and 123 documents, respectively. In order to

better understand where participants might encounter difficulties in using the *Ward Round Table*, we asked them to think aloud while performing the tasks, while being observed by the experimenter (as suggested in, e.g., [32]). In case participants could not finish a task, the experimenter shortly demonstrated the respective feature and took notes about the encountered difficulties. Finally, participants filled out a questionnaire in which they rated the usability of the UI (again by means of the SUS questionnaire, [31]) as well as how useful for their work they deemed the simultaneous presentation of documents, relevance-marking of documents or text, and the notification of newly added documents to a patient record (5-point Likert scales). Afterwards, participants were asked to state aspects they liked and disliked about the UI and were monetarily reimbursed.

B. Results

Participants were moderately satisfied with the currently used system ($M = 3.36$, $SD = 0.81$; 1 = not at all satisfied, 5 = very satisfied) and rated finding information as moderately cumbersome ($M = 3.09$, $SD = 0.70$; 1 = very cumbersome, 5 = not at all cumbersome). Furthermore, with an average SUS score of 52.95 ($SD = 14.44$), which corresponds to a grade D [33], the usability of the currently used system was rated rather low. Comparing these ratings with those for the *Ward Round Table* (also see Fig. 4), finding information on the *Ward Round Table* was rated as easier ($M = 3.91$, $SD = 0.83$, $t(10) = 3.11$, $p = .011$) and the *Ward Round Table* achieved a higher SUS score ($M = 74.77$, $SD = 12.13$, corresponding to grade A-, $t(10) = 4.22$, $p = .002$). Participants were also somewhat more satisfied with the *Ward Round Table* ($M = 3.73$, $SD = 0.65$). However, this difference was not significant, $t(10) = 1.49$, $p = .167$.

One participant was not able to successfully finish Tasks 3 and 10, and ten out of the eleven participants could not successfully finish Task 4. Furthermore, one participant encountered issues in de-activating the previously activated category-chips when proceeding from Task 2 to Task 3, and in Task 10 when attempting to drag a document in active highlighting-mode. Please note that when highlighting is activated, dragging is only possible in the document frame; when highlighting is de-activated, dragging is possible also in the text part of the document. The remaining tasks could be successfully finished by all participants. The average time participants took to successfully finish the tasks is provided in Table 3.

TABLE III. DESCRIPTION OF THE USER STUDY TASKS AND MEANS (AND SD) OF TASK TIMES FOR PARTICIPANTS WHO SUCCESSFULLY FINISHED THE TASK.

No.	Task description	No. types of gestures required	Mean task time [sec] (SD; #participants)
1	open a specific patient's record	1	13.00 (10.87; $N = 11$)
2	activate three document category chips (previously none active)	1	29.27 (13.69; $N = 11$)
3	de-activate previously activated category chips and activate "test results" chip	1	17.50 (11.47; $N = 10$)
4	open one specific "test result" document (i.e., category already active) for a given creation date; requires manipulating the timeline and comprehending the connection of the icons to the timeline	2	73 sec ($N = 1$)
5	open three further "test result" documents for given creation dates	1	30.91 (16.31; $N = 11$)
6	re-arrange (group) documents and scale one document up	2	34.64 (16.67; $N = 11$)
7	mark a specific document as relevant (i.e., the full document)	1	20.18 (12.23; $N = 11$)
8	text-highlighting in p. 2, thus requiring switching to the next page	2	27.20 (12.18; $N = 11$)
9	remove highlighting	1	22.64 (20.86; $N = 11$)
10	switch to another patient's record, open specific documents of two different categories, and highlight a specific value on page 2 in each document	6	133.90 (37.18; $N = 10$)

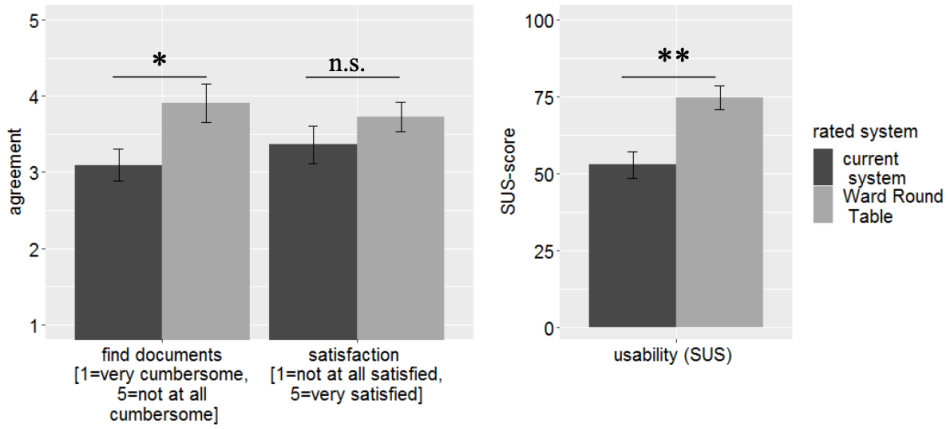

Fig. 4: Results of the user study: Participants rated the currently used system (before using the new user interface) and the *Ward Round Table* UI (after using it) regarding the ease of finding documents, their satisfaction with the system, and its usability. (**: $p < .01$, *: $p < .05$, n.s.: not significant)

Out of the four features for which we asked participants to rate their usefulness (on a scale from 1 = not at all useful to 5 = very useful), participants rated the simultaneous presentation as most useful (M = 4.82, SD = 0.60), followed by relevance-marking of full documents (M = 4.64, SD = 0.51), text-highlighting (M = 3.91, SD = 1.05), and the interactive timeline (M = 3.82, SD = 1.08). The fact that participants' ratings were lowest for the interactive timeline (although still well above the scale average) can be explained by both the observations made during task processing and participants' statements about what they did not like about the UI: In Task 4 (i.e., the first time operating the timeline), all but one participants were not able to operate the timeline because they intuitively tried to tap, double-tap, swipe horizontally, or hold down a finger in order to operate it instead of using a pinching gesture. This was reflected in participants' statements about what they did not like about the UI, where eight participants mentioned that the handling of the timeline was inconvenient, dates were not always visible, and the timeline was often crowded with document icons. However, all participants were able to use the timeline in the complex task (Task 10) after being explained its handling in Task 4. Further, when we asked participants what they liked about the *Ward Round Table*, four of them (two of which had also stated they found the handling of the timeline inconvenient) stated that the timeline offered a good overview of a patient's clinical history. Furthermore, partitipants stated that they particularly liked about the *Ward Round Table* that it enabled a simultaneous presentation of documents (7 participants), that it could be operated intuitively without cumbersome mouse-clicking (7 participants), and that it offered relevance marking (3 participants). In addition, participants stated that an inclusion of a patient's vital signs in the UI (3 participants) and highlighting in different line widths (1 participant) could be beneficial.

V. Discussion

The user study revealed that clinicians rated the usability as well as the ease of finding information to be better in the *Ward Round Table* than in their currently used system, but there was no significant difference in participants' overall satisfaction. However, it should be noted that while all participants had considerable experience in operating their currently used system, they were operating the *Ward Round Table* for the first time, and, moreover, without having received any instructions for use. Previous research suggests that users learn to operate new UIs quickly and that users' satisfaction increases once they become more familiar with them [34]. We thus believe that most of the issues participants encountered during task processing can be learned quickly, especially after introduction. For instance, once participants become more experienced in using the categorical and temporal filtering, the encountered issues with not seeing dates or finding the timeline too crowded may dissolve. Overall, the interactive timeline caused the most usability issues in this user study. However, all participants operated it successfully after a short demonstration, and the overall rating of the timeline's usefulness was still rather positive.

Fig. 5: Graphical representation of the patient's vital signs (red: heart rate, green: blood pressure, blue: temperature) for the selected time period. The semitransparent colored areas represent the respective normal range.

Based on the results of the user study, we have adapted the UI as follows:

- We incorporated the graphical representation of participants' vital signs, which can be opened (and closed) via the category chip "Meona" (see Fig. 5), including the patient's heart rate, blood pressure, and body temperature. Each vital sign curve is aligned to the document timeline.
- The connecting lines between the interactive timeline, the document icons, and opened documents have been made more salient.
- Highlighting in two different line widths has been implemented.

VI. Conclusion

The *Ward Round Table* is a far-developed prototype of a UI for MTTs that aims to support clinicians in preparing their ward rounds, by offering features motivated by research findings in the areas of text comprehension and human computer interaction (see Section I.). Overall, the user study revealed that the implemented features are promising in that regard: In line with the requirements analysis, the key features of the *Ward Round Table* were rated as highly useful in the user study. Moreover, the usability of the *Ward Round Table* was rated significantly higher compared to the system currently used at the University Clinic of Tübingen. This suggests that the systems currently used in hospitals might not fully support clinicians in the cognitive processes required for clinical diagnosis. Thus, thorough research and careful implementation of features is necessary when developing such systems.

On a critical note regarding the *Ward Round Table*, further research is needed to investigate to what extent users can benefit from an initial introduction regarding the handling of these features, as well as to understand how these features affect the cognitive processes involved in diagnostic reasoning. Furthermore, other features than those motivated and tested within this project may further support clinicians. For example, summarized written or graphical representations of patient-related information have been found to be beneficial for discussions in molecular tumor boards [35]. Such summaries of a patient's pre-existing conditions, current medication, or the intended further procedure could easily be included in the patient view as new document types.

We hope that future projects developing patient record systems can profit from the psychological motivation of the features and results presented.

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