Design Guidelines

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This document presents a set of Design Guidelines intended for Electronic Health Record (EHR) developers, which may also be valuable to others who deal with presentation of tables of information. Tables are the most common way of managing users' daily work. Thus, widely accepted principles for tabular displays can improve the design and functionality. A series of design guidelines, integrated with principles for table operations, can be applied to achieve an aesthetically-minimalistic and functionally-effective table approach. These guidelines are devised to foster users' attention to various states and important items so as to rapidly dismiss items that are deemed non-critical. With justifications and examples, this document serves as a reminder to common pitfalls in designing such systems. In addition, the document guides the reader to decide which guidelines are relevant, or should be refined, or which new ones should be added.

Evidence ratings indicate the strength of the evidence for each guideline in the scale of Low, Medium, and High:

- **Low:** No user research findings.
- **Medium:** User research findings are limited and may be conflicting, i.e. there is a mixed agreement between domain experts.
- **High:** User research findings are clear and with a significant number of participants, no known conflicting research-based findings, domain expert opinions agree with the research.

Conformance ratings denote the importance of applying the guideline from Recommended to Mandatory. These are based on Microsoft Common User Interface Guidance [13]. To determine the conformance levels of each guideline, evidence ratings were taken into account at first and finally, the personal opinion of the author – as a designer and implementer of these guidelines – was considered.

- **Recommended:** An implementer is encouraged to follow the guideline.
- **Mandatory:** An implementer must follow the guideline.

These guidelines are imperfect and require a social process to apply them [15, 20]:

- **Education:** Designers and implementers should be motivated with a live or video presentation followed by a discussion of how to apply these guidelines.
- **Enforcement:** An expert manager has to review the interface with a clear process to verify that the guidelines have been applied.
- **Exemption:** To support creative work that was not covered by these guidelines', managers should balance the enforcement process with a simple and rapid exemption process.
- **Enhancement:** Organizations should produce an annual revision that improves these guidelines and extends them to cover novel topics.

These guidelines build on three groups of published guidelines. The first group of guidelines is for presenting statistical data that is dominated by static numeric values [7, 11, 21, 27]. These tables are used in business presentations. The second group of guidelines is for web-based interactive table widgets [3, 4, 9, 19, 22, 26, 28], which are not well-established and are dependent on the developer toolkit settings. These guidelines list different web tools that come with one or two of the principles implemented. However, none are steered toward the medical domain so they do not answer the essential question: which guidelines are for users working under busy and time-critical environments? The third group of guidelines describes tables filled with clinical values [5, 13] but they are the same as the first group of guidelines, with clinician preference ratings. They are limited to formatting and tables with numeric values while table functionality is left out.

The design guidelines in this document are split into three categories. Guidelines for medical results management, low-level table design guidelines that apply general HCI principles, and actions for rapid completion guidelines that focus on the interactive features of tables. The contributions are twofold: (i) new guidelines for results management and actions for rapid completion, (ii) extended table guidelines with examples and ratings. The guidelines for results management and actions for rapid completion presented in this document are the new contributions of [23]. The table design guidelines are refinements of existing guidelines that emerged from author's own experience of designing and building tables. These guidelines are a substantial advance over existing table design guidelines with refinements of 25 guidelines and 28 new guidelines. I believe these guidelines will find widespread use in medical informatics and data presentation in many application domains.

The evidence ratings for results management and actions for rapid completion are derived from [23], while the evidence ratings for the table design guidelines come from existing research. Some of the existing table guidelines have never been tested, but they are well accepted because they have sound theoretical foundations or practitioners have substantial experience of trying out variations. This document contributes refinements to table

design guidelines, some of which have general applicability, while others are tuned to the medical domain. Therefore, my areas of high contribution are likely to have low evidence in the existing literature. Guidelines which are moderately original (either part of the guideline can be found elsewhere and the other part is new or the guideline has been adapted to the case) have medium evidence. The established guidelines, which did not require refinement, have high levels of evidence in the literature.

1 Results Management Design Guidelines

Results management involves the process that starts when an order for a patient is placed by a primary care physician at a clinic and ends when all the follow-up actions for the patient are taken and the physician signs off on the result. While order entry is not part of results management, some follow-up actions may include writing new orders.

These guidelines [24] come from the perceived shortcomings of existing EHR interfaces. In most systems, physicians see a table of results that came back (either for all patients, or per patient), which serves as a reminder to review results. Pending orders are not visible (unless physicians read the details of the individual patient records or use clumsy reporting tools) so physicians are forced to remember orders they have placed. Systems have no notion of expected latency between order and results. Results are sorted by arrival date, with the newer ones at the bottom necessitating users to scroll. If an expected result is not there, there is no way to know what could be wrong. The only resort is to get on the phone and track the order down. Once results have been seen, there is no mechanism to ensure the follow-up is complete. The results management design guidelines are as follows:

1.1 Show pending results (Evidence: High; Conformance: Mandatory)

Whether looking at results of all patients or only one patient, the table should provide access to arrived results, pending orders, and possibly planned orders.

In Figure 1, the bottom half of the window shows results that came back. Here, there is little perceptual help for all orders because showing the results only does not remind users about pending orders. Cognitive load[1] is high since the busy and distracted clinicians may forget the details of the orders they have placed. In terms of motor performance, clinicians have to go to patient records to find out the pending orders, which is multiple clicks away (e.g. select the patient, go to the "Orders" tab).

[1]Cognitive load refers to the control of working memory, i.e. the system that actively holds multiple pieces of information in the mind to be manipulated.

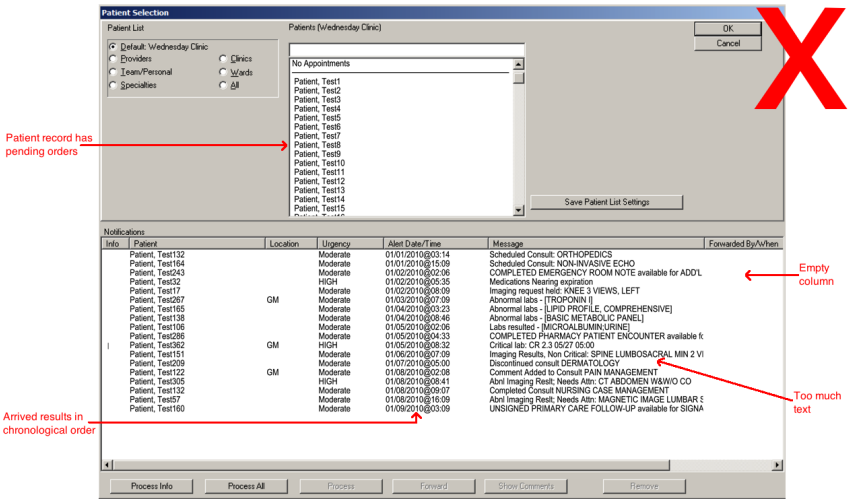


Figure 1: Veterans Administration Electronic Health Record View Alert window lists only returned results.

Figure 2 shows a better example for all the orders of Dr. Brown. The tables show arrived, pending, and planned orders. One way to implement this is to show all incomplete orders (either resulted or pending) from patient records in an inbox view. A controlled experiment showed the effectiveness of this approach [23].

1.2 Prioritize by late and lost status (Evidence: High; Conformance: Mandatory)

The bottom half of Figure 1 has no notion of lateness. Therefore, there is no perceptual help because there is no way to know if an order has been delayed. Cognitive load is high since clinicians need to calculate how much time has passed since the order has been placed to figure out if the expected duration is exceeded. In terms of motor performance, clinicians may bring up a date calculator and enter the information or do the computations in their head (results may be incorrect).

A good example is in Figure 2 that sorts all tables by default so as to visually aid users see late and lost results at the top. This example employs an underlying process model, which requires system administrators to specify durations to calculate deadlines at the time of physician order entry and physicians may override this date [25]. A controlled experiment showed the effectiveness of this approach [23].

For systems, which do not have support for workflow management, it seems difficult to integrate such functionality from scratch. An easier implementation might ask the clinician at order time when they expect results and when orders should be considered lost [12]. When clinicians enter this

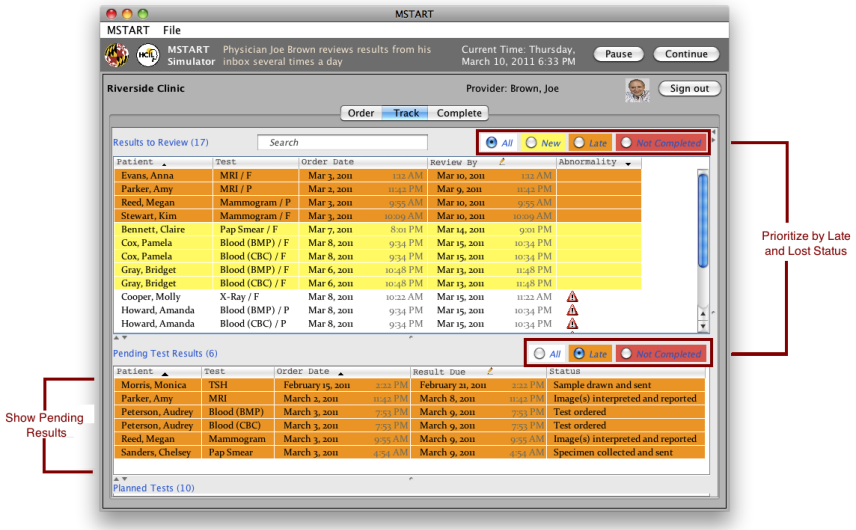


Figure 2: Rich tables adhere to the design guidelines. Results that have returned are listed at the top in "Results to Review", while orders that have not returned to the physician are shown under "Pending Test Results". Orders that have been placed already but will take effect in the future can be accessed in the "Planned Tests" (collapsed here). All tables are sorted by default so as to visually aid users see important results at the top. Newly arrived results are yellow, late orders are orange, and not completed are red.

information, orders can be prioritized by late and lost status based clinician-provided dates.

1.3 Indicate physician acknowledgment and timeliness (Evidence: Medium; Conformance: Mandatory)

When physicians open the results, some systems remove those results from the table and others mark such results reviewed. When results are removed or marked as reviewed, it affects perceptual and motor performance. Clinicians need to figure out the results they have just opened, which is harder if results were opened accidentally. Clinicians may go to other windows to bring results back to their inbox or press extra buttons to change result status from reviewed to unreviewed. In addition, some clinics do not track if physicians are acting timely on their results or not. These have negative effects on perceptual, cognitive, and motor performances due to the same reasons from the 'Prioritize by Late and Lost Status' guideline above.

Instead of excessive marking for unread results, the system should prompt physicians to acknowledge that the results have been reviewed (results with a white background in Figure 2 were marked with "Review Later" button in Figure 3). The table should keep the results until physicians explicitly

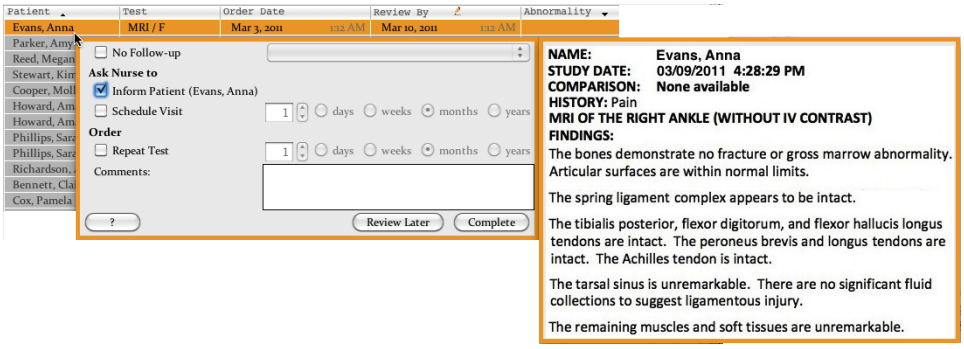


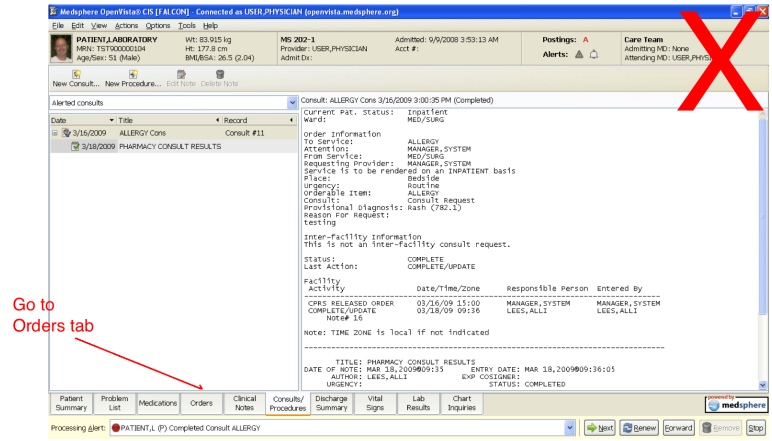
Figure 3: "Complete" finalizes follow-up so the result could be removed from "Results to Review" rich table. On the other hand, "Review Later" button means the result was viewed and/or some actions may have been taken but the follow-up is not complete yet. Such a result is still kept in "Results to Review" table for further processing but is marked as "viewed". In the context of rich tables, Actions for Rapid Completion are close to the mouse-click location and results appear on the right.

indicate completion ("Complete" button in Figure 3). If the same principles for order timeliness are applied to physician review and follow-up step, physicians' work can be marked late or not completed, e.g. Figure 2. A study showed the effectiveness of this approach [23].

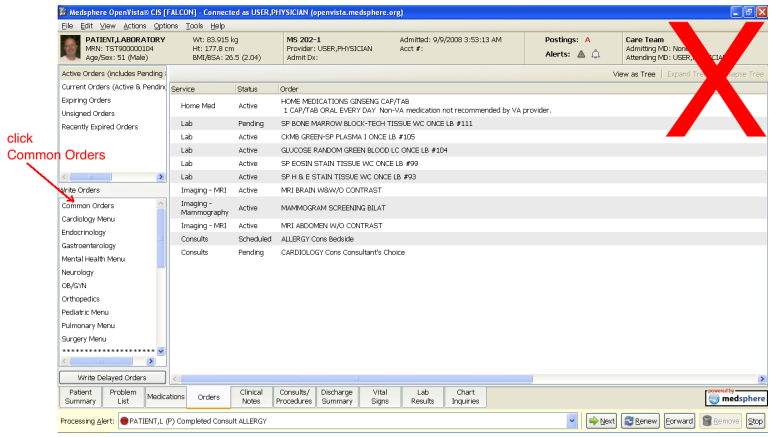
1.4 Embed actions when appropriate (Evidence: Medium; Conformance: Recommended)

While there are some better examples, most patient record windows (Figure 4a, 4b, 4c, 4d, 4e) require users to navigate to different windows to take actions because some results are complex or abnormal and clinicians must check multiple information resources. The perceptual help is low because clinicians need to look elsewhere to find relevant information. Cognitive load is medium since the clinicians must keep in mind the details of the report. In terms of motor performance, clinicians have to switch context, open multiple dialog boxes to take the actions, which necessitate mouse movements of long distances and are multiple clicks away.

While some results require careful review in separate windows with access to patient histories, there are many situations where actions can be taken rapidly [10], e.g. for normal results of routine orders for well-known patients in a primary care office. These situations can be determined by clinicians' familiarity with their patients or orders. If physicians know certain patients or orders well, they can quickly decide what to do based on the result. There are two dangers with this approach: (i) Clinicians will not check the details of the patient record or other orders, (ii) While clinicians complete simple

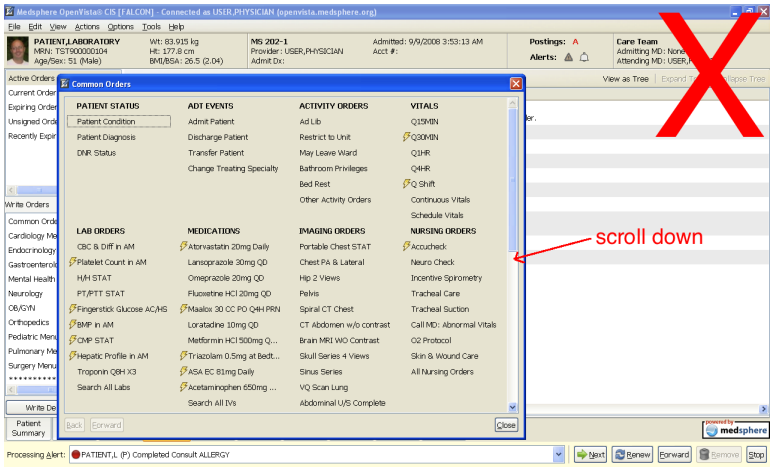


(a) A double click on the results opens the tab that has the consultation report in the patient record.

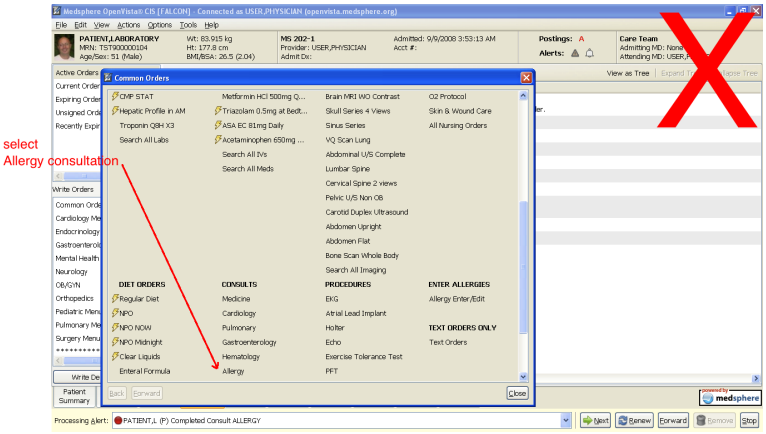


(b) To place an order, users switch to Orders tab.

Figure 4: Steps (a)-(e) correspond to the different screens and interactions to order a repeat consultation.

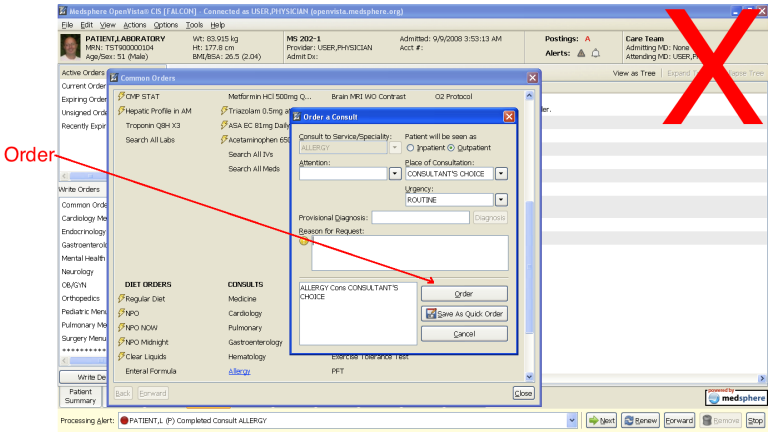


(c) To write an order, Common Orders are brought up.



(d) The desired order type is found by scrolling.

Figure 4: Steps (a)-(e) correspond to the different screens and interactions to order a repeat consultation.



(e) Clicking on the order pops up a new dialog to write the details of the order and place it.

Figure 4: Steps (a)-(e) correspond to the different screens and interactions in OpenVista to order a repeat consultation as part of a follow-up.

cases faster, they can leave complex cases for later.

This guideline proposes to allow users to take actions within the results table. Figure 3 shows an example where the possible follow-up actions are shown alongside the result report. It still gives quick access to the conventional approach (i.e. patient record) with a double-click on the result. A study showed the effectiveness of this approach [23].

1.5 Provide retrospective analysis (Evidence: Medium; Conformance: Recommended)

While most systems log events along with their timestamps, they do not provide retrospective analysis of past data. Hence no aid in perception. If clinics want to improve their results management continuously, managers make use of excel sheets to write formulas that compute some statistics. Thus, clinic managers have high cognitive load as they periodically make decisions based on these statistics.

A retrospective analysis visualization that categorizes completion times for each step into in-time, late, and not completed can be later used to inspect bottlenecks as well as the best and worst performers (Figure 5). If the system employs a workflow model, this information can indeed be used to adjust expected durations of each step. This results in fewer or more late or not-completed orders. A usability test showed the effectiveness of this approach [18].

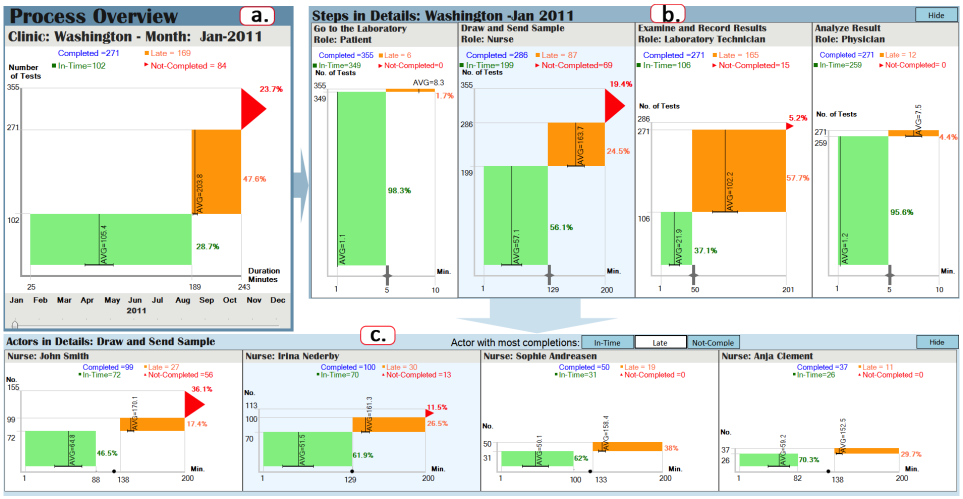


Figure 5: This retrospective analysis visualization has three views: (a) *Process Overview* shows the summary of the entire process (blood test), (b) *Steps in Details* shows each step of the process (four steps), and (c) *Actors in Details* shows the performance of the individuals who performed the selected step ("Draw and Send Sample"). Each view uses one or more Process Completion Diagrams (PCD). A PCD consists of two rectangles (separated by the threshold of lateness) and a triangle. Green and orange are in-time and late performances, respectively. Red is not completed orders. Height is the number of orders and width is the min and max completion times.

1.6 Distinguish preliminary and final results (Evidence: Low; Conformance: Mandatory)

Sometimes the outside facility generates an initial report for physicians to review although the order has not been finished processing [16]. In current systems, this will be documented in textual form (see the "Message" column of Figure 1) that could easily be bypassed by busy and distracted users. Therefore, the system lacks perceptual help.

Physicians' responsibility is to review results but the outside facility is still responsible for finalizing reports. Thus, such results should appear in both pending and results tables but be clearly marked preliminary or final in the results table so that physicians know their status during review. For example, Figure 2 has 'P' and 'F' in the test column for preliminary and final results, respectively. Preliminary results also show up in pending results (e.g. Megan Reed's preliminary mammogram result).

1.7 Support views for different clinician roles (Evidence: Low; Conformance: Recommended)

Various users look at and act on the same orders differently. Current systems either do not support this, make customization too complicated, or do not link separate views (i.e. an action completed in one view is not reflected in another view). This guideline is for enhancing perception and motor performance as users will be able to see orders easily and results management will take less time and effort.

Figure 6: Care provider, Joe Brown, at the Riverside Clinic is currently signed in.

Figure 6 indicates the logged in user. Physicians or residents review and follow-up on results, nurses regularly check if pending orders of patients coming in today have arrived, managers overview the clinic and forward results to alternative clinicians if needed (e.g. in case of physician illness). The table contents and possible actions depend on the role of this user. Lateness information should be available to all users of the system.

1.8 Clarify responsibility (Evidence: Low; Conformance: Recommended)

None of the results management windows (Figure 1) have any information about who is performing the current step of the process or guidance to contact the responsible parties. There exists no perceptual help as clinicians spend hours on the phone tracking the results down. Cognitive load is high since the clinicians need to estimate who should take care of the current step of the process, and guess where to contact them. In terms of motor performance, clinicians may use a phone/e-mail directory search function within the system to find out the relevant information. Then, they might either write a message or call multiple places to understand what went wrong.

The current window should indicate the status (order status column for pending orders in Figure 2), which can then be expanded (the popup menu in Figure 7 that appears with a click on the row) to enumerate who did what and when, as well as the deadlines. This guideline depends on workflow management capabilities. If the actions of responsible parties are unrecorded, and the responsibilities are not transferred between various systems, the only feedback to provide is 'Test ordered'. Many systems capture most of these data (with or without workflow management) but what is missing is different systems do not communicate on the backend.

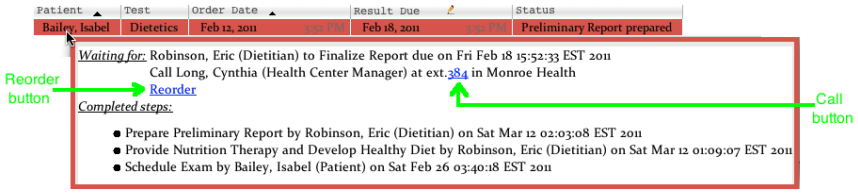


Figure 7: Popup menu for pending orders identifies the responsible person (dietitian, Eric Robinson) who is handling the current step of the order (finalizing the report) along with their deadline (February 18^{th}, 2011) and the manager's contact information (Cynthia Long's phone extension is 384). Below, it has a reorder button for the lost consultation and illustrates the progress of the order step by step.

2 Table Design Guidelines

Tables have conventionally been used in various domains as a place to store large amounts of data as a reference for users to look up and compare values [7]. Table designs have been limited to support these two tasks. Apart from this, users manage their daily workflow through various tables [2]. These are interactive tables that allow users to perform operations on the items. This section will name a look-up table, which is extended with functionality, a rich table (see Figure 2). Rich tabular displays generally consist of multiple rich tables that are related, as in Figure 2.

Rich tables have rows, arranged vertically, which display items of the same type. Rows can be sortable by some criteria. Each item may have multiple attributes or fields that are shown in a column, arranged horizontally in a table. Rows and columns may be filtered to show desired items. When the table size does not accommodate table's all rows or columns, a scrollbar enables users to see the hidden parts of the table. Tables, rows, and columns may all have headers with descriptive titles. A column within a row is called a cell, which holds a value. Rows, columns, headers, and cells may be selectable, single- or double-clickable, or editable. Rows, columns, headers, and cells may reveal an explanatory tooltip on mouse hover.

Given a workflow of items, a rich tabular display is generated automatically with the following principles to assist users in finding the most critical information faster. While some of these principles may apply to tablets or smart phones with touch-based interactions, they are mainly developed for desktop interfaces that are controlled with a mouse device.

2.1 Data Arrangement

2.1.1 Columns/Rows:

1. *Sort the table according to one or more column(s) by default, arranged*

vertically down (Evidence: High; Conformance: Mandatory). The designer should make a list of important information the table is going to convey in a decreasing order of priority [1, 7, 14, 15]. Then, the table is sorted according to these criteria. For example, the most important information in the tables of Figure 2 is whether an item is late since the decision makers are expected to complete their tasks with no or little delays. Thus, the table is sorted according to this information first. Then, it is sorted according to whether items have been viewed so that users can focus on items unseen before. The third sort criteria is whether something is abnormal and needs immediate attention. Finally, the items have to be grouped by similarity since users look at similar items together. Sorting increases perception because it is easier to see the most important data at the top of the table; cognition since the user is relieved from computing the ordering in their head to make sense of the items, and motor performance due to reducing the amount of scrolling needed to find the necessary information.

2. *Permit re-sorting of tables with a click on the column header (Evidence: High; Conformance: Mandatory).* While default sorting gives the most natural ordering of items, users should be able to modify the sorting easily and be given an option to revert back to the default sorting [1, 13, 14, 17, 20]. This improves cognition in situations when different orders have to be considered. Having re-sorting as easy as a click increases motor performance.
3. *Avoid horizontal scrolling in the default view (Evidence: High; Conformance: Recommended).* It is useful to lay the tables out in a readable way initially [1, 14]. After first sight, when users ask for more information, they should be able to access it. Availability of extra columns should be explicitly indicated on the table, e.g. the last column might have an arrow that instructs users to click for more information [1] (Figure 8). This improves perception, cognition, and motor performance.

Figure 8: The rightmost column header indicates extra columns are available.

4. *Focus on the data itself (Evidence: Medium; Conformance: Mandatory).* While the design of the table is important in conveying the data, the primary purpose of a table is to represent information [7]. The data itself should be the most prominent feature (as in Figure 2). See Figure 9 for a bad example, which styles all elements in the window the same way. This facilitates perception, cognition, and motor performance.

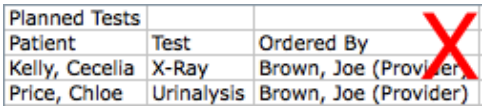


Figure 9: Excel defaults to the same font style and size for the title of the table, column headers, and table contents. Table data is not easily differentiable.

5. *Use sort icons in column headers to communicate that the table is sortable; conventionally upward/downward arrow for ascending/descending values, while the arrow size indicates sort priority (Evidence: Medium; Conformance: Mandatory).* Once the table is sorted, it is important to provide immediate feedback to the user [14]. All this information can be conveniently communicated via arrows in column headers. Arrow direction presents sort order while arrow size indicates priority (see Figure 10). This greatly assists perception as well as cognition for comparison.

Figure 10: Note the sort icons on column headers. Patient and Test columns have categorical values that are placed to the left of Order Date and Review By columns, which hold quantitative values.

6. *Perform computations for users; value, derived from data, should be readily available in the cells (Evidence: Low; Conformance: Mandatory).* If some values have to be calculated from the given data, these should be readily made available in a separate column (e.g. "Review By" or "Result Due" date in Figure 2, neither of which occur in the data itself). This especially improves cognition. See Figure 11 for example columns that require users to compute. However, caution should be given if the number of columns need to increase as this may introduce horizontal scrolling.

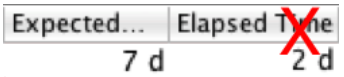


Figure 11: The deadlines need to be calculated based on current time, expected duration, and elapsed time.

7. *Reduce the number of columns whenever possible (Evidence: Low; Conformance: Recommended).* Due to the small size of visual memory and the difficulty of searching through complex information [20], the implementation should remove unnecessary columns as much as possible via preprocessing the data in tables. More importantly, unnecessary

columns of data waste valuable screen space and enforce people to wade though information that they do not need, which wastes their time. This can increase perception by making more important columns pop out, cognition by allowing a quick understanding of what the data presents, and motor performance via decreasing horizontal scrolling.

8. *Remove a column that always has the same value to save space (Evidence: Low; Conformance: Recommended).* Although it is essential to keep some columns, other columns might communicate information that can readily be seen on the display. For instance, the data of Figure 2 contains "Ordered By" field. Within the physician view this is always the same so it is removed to de-clutter the table. Although this may decrease perception of this information, it increases the perception of other elements in the table. It also helps avoid horizontal scrolling in the default view, which may improve motor performance.
9. *Use endless scrolling when all results do not comfortably fit within one page (Evidence: Low; Conformance: Recommended).* To avoid loading time, sometimes designers choose to show only a predefined number of items into the table. When users want to see more data, each time they click a button, such as "More" (Figure 12a) or "Next" (Figure 12b), at the end of the table to load more items. These are both successful commercial examples. When the data is as critical as in the medical domain, adding that additional click after each and every one-page scroll is redundant. The table should permit endless scrolling when all results do not comfortably fit within one page (Figure 2). This increases motor performance as it eliminates the clicks after a scroll per page.

(a) Load more (Youtube) (b) Next (Google)

Figure 12: Buttons that show more items in a list.

10. *Combine columns when appropriate (Evidence: Low; Conformance: Recommended).* Instead of having a column per attribute, information may be aggregated in one column. Especially columns that can only take a predefined set of values may be combined with other columns. For example, the test name and type of result ("Finalized" or "Preliminary") are combined in the "Test" column (Figure 13). This makes the data easier to scan, improving perception. It may have a negative effect on cognition especially if the individual column values have to be compared to each other. One way to circumvent this is to make the most important column the first part in the aggregated column so that any such comparison can be quickly done by simply looking at

the beginning of the column.

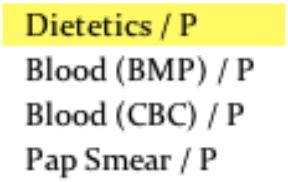
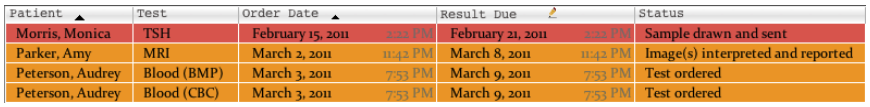


Figure 13: Instead of spelling out 'Preliminary' for each order, the term is abbreviated to 'P' and combined with the order name.

2.1.2 Row Sequence:

1. *Put the most severe row at the top of the table while ensuring that the most important rows are still visible (Evidence: Medium; Conformance: Mandatory).* Tables with severity criteria should be sorted by this row such that the most severe cases appear at the top of the table [15]. It is important that the criteria used to define severity do not cause an overwhelming number of items to be flagged as such. When there are too many alerts, people learn to ignore them or turn them off [6]. The design should enforce the perception of all severe rows in decreasing importance. Otherwise, users need to scroll too much (i.e. poor motor performance). For example, the most severe case in Figure 14 is an incomplete order and such instances are put at the top of the table while still displaying late orders.



Patient	Test	Order Date	Result Due	Status
Morris, Monica	TSH	February 15, 2011 2:22 PM	February 21, 2011 2:22 PM	Sample drawn and sent
Parker, Amy	MRI	March 2, 2011 11:42 PM	March 8, 2011 11:42 PM	Image(s) interpreted and reported
Peterson, Audrey	Blood (BMP)	March 3, 2011 7:53 PM	March 9, 2011 7:53 PM	Test ordered
Peterson, Audrey	Blood (CBC)	March 3, 2011 7:53 PM	March 9, 2011 7:53 PM	Test ordered

Figure 14: The incomplete order appears at the top, followed by late orders. In addition, same patient orders are grouped together.

2. *Group related rows together so they are close in proximity for comparisons (Evidence: Low; Conformance: Recommended).* Groups of rows that will be used for comparisons should be placed together. This could be an option that could be switched on and off. It results in better perception, cognition, and motor performance. For example, Figure 14 groups results by patient name because clinicians tend to look at results per patient.

2.1.3 Column Sequence:

1. *Offer rearranging of columns (Evidence: High; Conformance: Recommended).* To change the default column order, support rearrangement

[1, 14, 17, 20] with a drag-and-drop. Users can drag the column header and drop at their desired location to move any column. It enhances perception and cognition. In cases when rearrangements can become confusing, users should have the option to change back to the default arrangements.

2. *Place sets of categorical values to the left of the quantitative values associated with them (Evidence: Medium; Conformance: Mandatory).* Cells that contain different quantitative values associated with a categorical value should appear on the right [7]. These categorical values will be read first (in most languages that read from left to right) and assist in comparing the quantitative values on the right. It promotes both perception and cognition as it facilitates comparisons. Note that the "Test" column is placed before the date columns in Figure 10.
3. *Place columns containing data that should be compared close together (Evidence: Medium; Conformance: Mandatory).* If comparisons will be performed on one or more columns, such columns should appear one after another to prevent eye movements or scrolling in the window [7]. Cognition and motor skills are impacted by this guideline. The date columns in Figure 10 are placed one after the other. If placing columns next to each other is not possible, placing them as close as possible without the need for scrolling is desired.
4. *Organize the most important columns on the left to permit reading in the conventional left-to-right order (Evidence: Medium; Conformance: Recommended).* Most languages are read from left to right so rows will be read in that order [14]. Keeping the most essential information on the left side of the window reduces eye movement in the window. Figure 10 keeps the "Patient" and "Test" information on the left. This enhances perception and might also speed up motor performance if such columns require scrolling.

2.1.4 Related Tables:

1. *Use just enough space between tables to make them noticeable (Evidence: Medium; Conformance: Recommended).* When the tables are lined up vertically or horizontally, there is just enough empty space between tables [20]. This facilitates perception and cognition when tables contain similar data.
2. *Size the tables according to their frequency of usage (Evidence: Medium; Conformance: Recommended).* The most frequently used table could have the largest size in the window to allow rapid access and interaction. The benefits are in terms of perception and motor skills according to Fitts' law [8]. The largest table of Figure 2 is "Results to Review" while "Planned Tests" are collapsed because the most frequently used table is "Results to Review". Users can customize this layout by drag-

ging the split panes vertically as needed (Figure 15). In addition to using size to create a hierarchy of importance, there may be other visual attributes to make tables more salient than others, such as borders of varying intensities.

Figure 15: The split pane between the tables permit users to modify default table sizes. While the upward/downward arrows (leftmost) are to expand/collapse, dragging the dot (middle) resizes.

3. *Filter a table that is not used often to show only the important data or stretch the table with support for full-view or expansion on-demand (Evidence: Low; Conformance: Mandatory).* When a table is not used often, such as "Pending Test Results", it is filtered to show only the important data or collapsed like "Planned Tests" with expansion on-demand (Figure 16). This improves perception and motor performance for more important tables but reduces perception and motor performance for less important tables.

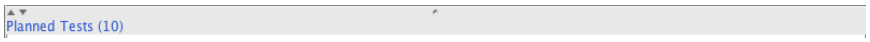


Figure 16: The collapsed planned table can be expanded by clicking the upward arrow on the leftmost.

4. *Order the tables according to their frequency of usage (Evidence: Low; Conformance: Recommended).* Either vertically or horizontally, the order of tables could be assigned by their frequency of usage. For example, the most frequent table "Arrived Results" appears at the top while "Planned Tests" appears at the bottom in Figure 2. This promotes perception and motor skills because the more accessible table is the most frequently used table (when scrolling is unnecessary).
5. *Keep table structure consistent from table to table (Evidence: Low; Conformance: Recommended).* If all the tables have the same columns this is easier to achieve by using the same order for the columns. However, if the tables contain different columns or a different number of columns, one way to keep the structure consistent is to place the distinct columns at the rightmost end to allow for alignment of the same columns on the left side. Figure 2 aligns "Patient", "Test", and "Order Date" columns on the left side for "Results to Review" and "Pending Test Results". The advantages include faster perceptual and cognitive performance because the columns in different tables can be read and compared quickly.

2.2 Labeling

2.2.1 Style headers differently but ensure consistency (Evidence: High; Conformance: Mandatory)

Regardless of whether it is a column, row, or table header, the font style should be consistent within its own group but different from each other and the table data [20]. This particularly helps with perception because various information communicated through headers stands out against others. "Results to Review", "Pending Test Results", and "Planned Tests" all have the same font style and a different style from column headers or table data (Figure 2).

2.2.2 Give the table a descriptive title with a total row count (Evidence: High; Conformance: Mandatory)

A table should have a title placed at the top of the table that clearly describes in a couple of words what the table contains [1, 14, 15, 20]. Row counts can be appended to table titles. Tables that dynamically grow or allow filtering should automatically update their counts. These counts help perception and cognition. "Pending Test Results" table (Figure 17) shows the number of items after applying the filters.

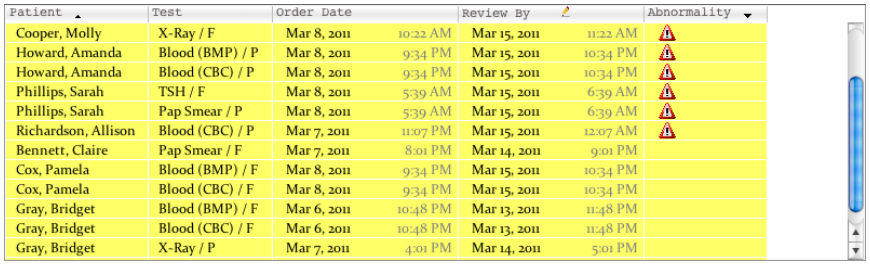
Figure 17: Table title contains row count (after filters are applied).

2.2.3 Keep the headers visible in the window at all times (Evidence: High; Conformance: Mandatory)

If the table becomes large, make the table headers stay visible in the window [13] as users scroll up/down and left/right a page to remind users of the rows and columns in the table (Figure 18). This is useful for perception [15]. In addition, motor performance improves as this guideline eliminates scrolling to the beginning of the table. However, one row space is wasted for the header.

2.2.4 Align column headers with their associated data (Evidence: High; Conformance: Mandatory)

Headers and their associated data should be aligned correspondingly [13, 14]. It shows that the data is associated with the header, i.e. improves perception. It becomes handy when different alignments are used throughout the table. Note that "Patient" column header is left-aligned as well as all the patient names that appear below it (Figure 19).



Patient	Test	Order Date	Review By	Abnormality
Cooper, Molly	X-Ray / F	Mar 8, 2011 10:22 AM	Mar 15, 2011 11:22 AM	⚠
Howard, Amanda	Blood (BMP) / P	Mar 8, 2011 9:34 PM	Mar 15, 2011 10:34 PM	⚠
Howard, Amanda	Blood (CBC) / P	Mar 8, 2011 9:34 PM	Mar 15, 2011 10:34 PM	⚠
Phillips, Sarah	TSH / F	Mar 8, 2011 5:39 AM	Mar 15, 2011 6:39 AM	⚠
Phillips, Sarah	Pap Smear / P	Mar 8, 2011 5:39 AM	Mar 15, 2011 6:39 AM	⚠
Richardson, Allison	Blood (CBC) / P	Mar 7, 2011 11:07 PM	Mar 15, 2011 12:07 AM	⚠
Bennett, Claire	Pap Smear / F	Mar 7, 2011 8:01 PM	Mar 14, 2011 9:01 PM	
Cox, Pamela	Blood (BMP) / F	Mar 8, 2011 9:34 PM	Mar 15, 2011 10:34 PM	
Cox, Pamela	Blood (CBC) / F	Mar 8, 2011 9:34 PM	Mar 15, 2011 10:34 PM	
Gray, Bridget	Blood (BMP) / F	Mar 6, 2011 10:48 PM	Mar 13, 2011 11:48 PM	
Gray, Bridget	Blood (CBC) / F	Mar 6, 2011 10:48 PM	Mar 13, 2011 11:48 PM	
Gray, Bridget	X-Ray / P	Mar 7, 2011 4:01 PM	Mar 14, 2011 5:01 PM	

Figure 18: Column headers are still visible when the table is scrolled down.

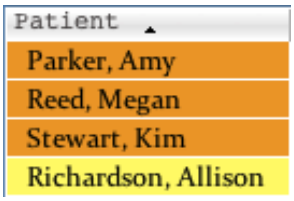


Figure 19: Patient column header and the patient names are left-aligned.

2.2.5 Avoid a header that is significantly wider than the data it is indicating by spreading such headers into two or more lines (Evidence: Medium; Conformance: Mandatory)

Headers that are significantly wider than the data impede horizontal scanning of cell values. Therefore, they should be spread into two or more lines to reduce the width of the column or avoid truncation [13] (Figure 20). This positively impacts perception and motor skills for horizontal scrolling. However, this guideline may require more vertical scrolling (motor skills) as the new header covers an extra row.

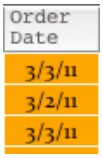


Figure 20: Long headers are split into two or more lines

2.2.6 Indicate editable columns (Evidence: Low; Conformance: Mandatory)

Include a pen icon (e.g. "Result Due" column header in Figure 21) or a visual indicator next to the header or each cell to point out that the value could be edited in place. If an entire column is editable moving the icon to the header saves space and minimizes distractions from data. This guideline

is for perceptual performance.

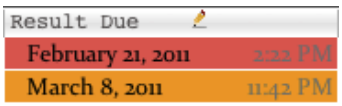


Figure 21: Result Due column header has a pen icon to indicate the cells can be edited.

2.2.7 Show a tooltip for the title that describes the table's function (Evidence: Low; Conformance: Recommended)

While the title is compact to leave room for the table contents, the title should display on hover a tooltip with a more comprehensive explanation (in one or two sentences) of the table's function (Figure 22). It could even include concrete examples for clarification. This mostly assists in cognition of the table. The duration of the tooltip on screen can be increased depending on the length of the description.

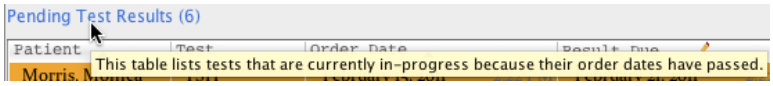


Figure 22: A tooltip for the table title describes the table's function.

2.2.8 Do not truncate column headers; break long headers by full words whenever possible, otherwise split in the middle with a hyphen (Evidence: Low; Conformance: Recommended)

Column headers should not be truncated because they communicate information that applies to the entire table. If there are many columns, users might not remember the meaning. Use familiar or otherwise clear abbreviations as they save space. If there are no abbreviations with clear meanings, split long headers by full words in two or more lines. When this is not possible (i.e. there is one long word), split the word in the middle with a hyphen (Figure 23). This affects perception. However, this guideline may require more vertical scrolling (motor skills) as the new header covers an extra row.

2.3 Settings & Help

2.3.1 Provide custom filtering on-demand (Evidence: High; Conformance: Mandatory)

When users do not remember what they are searching for, filters become practical. For more important and frequently used features, filters could

Figure 23: Column header is split with a hyphen when the data itself takes little space or the column is dragged.

appear on the main display (e.g. "Late" and "Not Completed" radio buttons in Figure 24) while for more complex features, this could be performed on a separate panel that does not distract from the table (Figure 24). Filters can be selected from radio buttons when only one selection is possible or from checkboxes when multiple selections are possible [15, 20]. This guideline promotes perception since filtered values will no longer distract from the desired values and motor performance as it reduces scrolling.

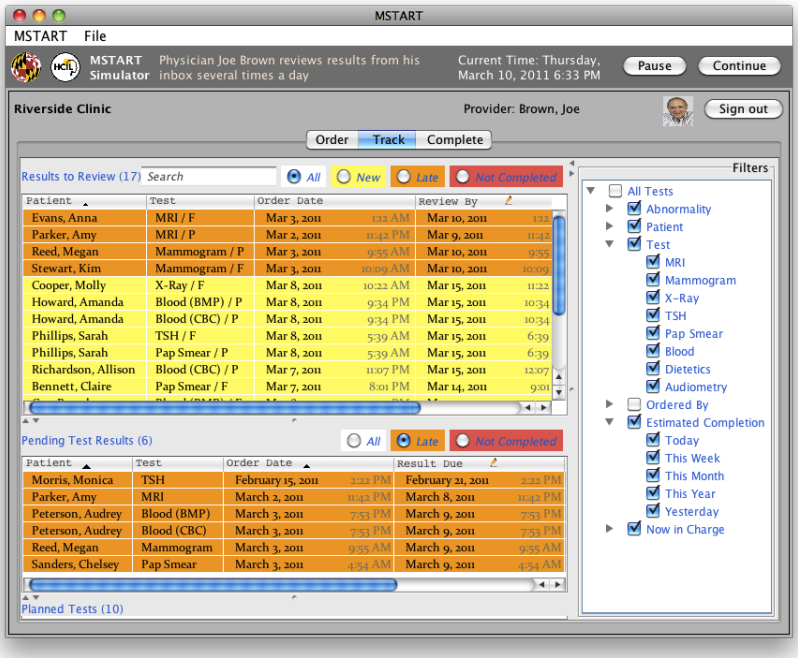


Figure 24: The panel on the right is opened (by clicking collapse/expand arrows at the top left of the panel) to allow for custom filtering. Users can customize their filter selections from here.

2.3.2 Allow settings to be saved and loaded (Evidence: Medium; Conformance: Recommended)

Although tables support views based on user roles, users should also be able to make changes on the default table preferences [14]. These changes should persist automatically. Next time when the table is displayed, the table should load with the saved settings. In addition, users should be allowed to revert to default settings at any time. This could be done through a preference pane. This guideline has to do with perception and motor skills because the default settings might not be optimized for certain users.

2.3.3 Do not let tooltips go outside of screen space (Evidence: Low; Conformance: Mandatory)

Tooltips stay at the point of mouse location for a short amount of time but if the mouse is close to a screen corner, some parts of tooltips might leave the screen space. To prevent this, the designer has to slide the tooltips such that they are still close to the mouse location but do not partially disappear. It supports perception because the tooltip is in sight; cognition as the description is understandable; and motor skills since users do not have to move the mouse or the application window to read tooltips.

2.3.4 Provide help in a separate window (Evidence: Low; Conformance: Mandatory)

While tooltips guide users, a help window that compiles together all descriptions in one-page is still beneficial. Tooltips stay on the screen for a short period and users might prefer to read or search them in a separate window. In addition, novice users would like to start by reading a help menu to learn more. Because a window stays on screen longer than a tooltip, this guideline serves perception and cognition. Although this may hinder motor performance because users have to open up a new window from the menu, mouse movements on the screen to read tooltips are reduced significantly which might result in better performance overall.

2.3.5 Derive filter values from current table entries, not all database entries (Evidence: Low; Conformance: Recommended)

One option for creating filter values is to provide a list of all entries in the database, i.e. there will be filter values with no matches in the table. To limit the number of possibilities users have to deal with (such as unavailable filter options), filters can be derived from the current table values. When there are modifications in the table, filters should be updated accordingly. 'Test' filter in Figure 24 lists only test values that appear in the tables, not all possible tests. This is effective for perception because users can focus on

only relevant data and motor skills because there are fewer filters to scroll and click.

2.3.6 Group filter values by range if possible (Evidence: Low; Conformance: Recommended)

One way to reduce possible filters is grouping them into ranges when columns represent integers or dates. 'Estimated Completion' filter in Figure 24 has 'Yesterday', 'Today', 'This Week', 'This Month', 'This Year' rather than each day. Due to the same reasons from the previous guideline, it helps with perception and motor skills.

2.3.7 Support search for large tables (Evidence: Low; Conformance: Recommended)

In large tables, users should be allowed to search by keywords when they know what they are looking for. One possibility is a fuzzy search, which returns results similar to the given keyword. Even for exact keyword searches, there needs to be a suggestion in case of misspellings. Figure 25 has a search box at the top of the tables. This guideline should be applied for perception and motor skills.

Figure 25: Large tables need a search option.

2.3.8 Show a description for columns in a tooltip (Evidence: Low; Conformance: Recommended)

If there is ambiguous data, such as columns with the same type of values, tooltips on header hovers can display their description (Figure 26). The advantage is better cognition of the columns meaning.

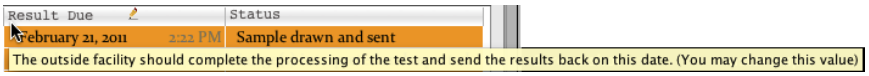


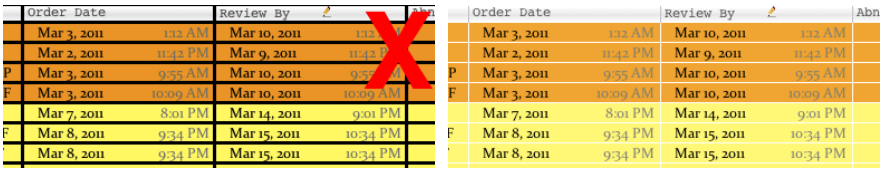
Figure 26: Tooltips for headers provide more information about the column.

2.4 Delineation

2.4.1 Feature light white space between the rows, no heavy gridlines (Evidence: High; Conformance: Mandatory)

To be able to scan the table efficiently from top to bottom, some delimiters need to be between the rows of the table. This helps the eye to differentiate

one row from another. Otherwise, users are confused when they reach the middle of the table. While one option is to alternate the fill colors (in a striped style) for the table entries [1, 7], this is not applicable when the table is color-coded. Featuring light white space between the rows [15, 27] serves the same purpose (Figure 27b). If such delimiters dominate the table content (e.g. thick lines in Figure 27a, long white spaces) then data occupies less space and is harder to scan. Perception and motor performance is slower with extra space due to eye movement and scrolling. Light white space means a color that is faint, i.e. just visible enough to do the job and no more. White against a dark background would stand out too much, just as black against a light background does.



(a) Heavy gridlines (b) Light white space

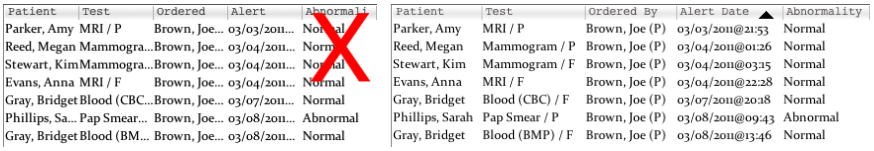
Figure 27: Heavy gridlines versus light white space between the rows.

2.4.2 Allow sufficient space between columns to clearly separate them but no more (Evidence: High; Conformance: Mandatory)

To scan an entry efficiently from left to right, delimiters should be used between columns (Figure 27). This helps users differentiate information regarding the entry. Otherwise, users can not understand the attributes of an item. On the other hand, excessive space impedes horizontal scanning [13, 27]. Perception and motor performance suffer in such cases due to eye movements and scrolling. Cognition may be affected in a negative way if users perform operations on more than one column (e.g. comparing values in two columns that are far apart require temporary memorization).

2.4.3 Calculate initial column widths from data but offer resizing of columns (Evidence: Medium; Conformance: Recommended)

Instead of assigning a default equal width to each column (Figure 28a), compute widths from the given data for the table. This lays out the data with no truncations or excessive spacing so that users do not need to adjust column widths (Figure 28b). This, in turn, assists in perception and motor performance because readability is increased and there is no need to drag and resize columns. Offer resizing on demand [1, 17].



Patient	Test	Ordered	Alert	Abnormali
Parker, Amy	MRI / P	Brown, Joe...	03/03/2011...	Normal
Reed, Megan	Mammogra...	Brown, Joe...	03/04/2011...	Normal
Stewart, Kim	Mammogra...	Brown, Joe...	03/04/2011...	Normal
Evans, Anna	MRI / F	Brown, Joe...	03/04/2011...	Normal
Gray, Bridget	Blood (CBC...	Brown, Joe...	03/07/2011...	Normal
Phillips, Sa...	Pap Smear...	Brown, Joe...	03/08/2011...	Abnormal
Gray, Bridget	Blood (BM...	Brown, Joe...	03/08/2011...	Normal

(a) Equal column widths

Patient	Test	Ordered By	Alert Date	Abnormality
Parker, Amy	MRI / P	Brown, Joe (P)	03/03/2011@21:53	Normal
Reed, Megan	Mammogram / P	Brown, Joe (P)	03/04/2011@01:26	Normal
Stewart, Kim	Mammogram / F	Brown, Joe (P)	03/04/2011@03:15	Normal
Evans, Anna	MRI / F	Brown, Joe (P)	03/04/2011@22:28	Normal
Gray, Bridget	Blood (CBC) / F	Brown, Joe (P)	03/07/2011@20:18	Normal
Phillips, Sarah	Pap Smear / P	Brown, Joe (P)	03/08/2011@09:43	Abnormal
Gray, Bridget	Blood (BMP) / F	Brown, Joe (P)	03/08/2011@13:46	Normal

(b) Column widths calculated from data

Figure 28: Column widths that are equal versus calculated from data.

2.4.4 Define a min and max width for each column depending on the data it presents; these widths should be user changeable (Evidence: Medium; Conformance: Recommended)

Columns should not be allowed to shrink to the extent that cell values are not readable anymore or they should not be stretched out to the extent they impede with horizontal scanning (see Figure 29 for a bad example). Such examples negatively affect both perception and motor performance. Default min and max widths could be calculated from the possible cell values [14] and could be changed by users.

Cooper, Moll...	X-Ray / F	Mar 8, 2011	10:22 AM
Howard, Am...	Blood (BMP) / P	Mar 8, 2011	9:34 PM
Howard, Am...	Blood (CBC) / P	Mar 8, 2011	9:34 PM
Phillips, Sara...	TSH / F	Mar 8, 2011	5:39 AM
Phillips, Sara...	Pap Smear / P	Mar 8, 2011	5:39 AM
Richardson,...	Blood (CBC) / P	Mar 7, 2011	11:07 PM
Bennett, Clai...	Pap Smear / F	Mar 7, 2011	8:01 PM

Figure 29: While the first column is not readable in full, second column impedes horizontal scanning.

2.4.5 Do not stretch tables to fill available space; only the last column may be stretched, if not right-aligned, to align with other tables (Evidence: Medium; Conformance: Recommended)

To fill out extra space on the window, table size should not be stretched out in a way that harms users' visual scanning [13]. Table size should instead be dependent on the data it presents. The last column of a table could be stretched to align with another table. This is only possible if the last column is not right-aligned. If a right-aligned column is stretched, this might interfere with horizontal scanning and thus, perception.

2.4.6 Add some padding to columns if there is room; allow user-defined values (Evidence: Medium; Conformance: Recommended)

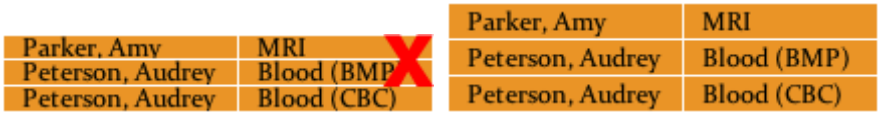
All values should stand out against the ones in other cells. While avoiding excess space between columns aids in horizontal scanning, some padding separates different columns [20]. Placing values in adjacent cells too close together impedes perception and cognition (Figure 30a). In particular, columns that have the same type of data should be distinguishable to allow for comparison (Figure 30b). In contrast, less spacing and padding might provide better motor performance due to little need for scrolling. But, if cells or rows are clickable, motor performance improves with enough spacing and padding because they become easily clickable, thereby preventing mis-clicks.

(a) No padding (b) Padding

Figure 30: Columns without and with padding.

2.4.7 Add some padding to rows for easy visual scanning; allow this to be set by the user (Evidence: Medium; Conformance: Recommended)

First of all, row height should be set so that the text fits perfectly [14] (Figure 30a). To scan down the rows, each row needs some space between to be able to read it easily [20] (Figure 30b). However, adding padding results in smaller fonts, which decreases readability for many users. Maintaining font size will reduce the number of items displayed, which will increase short term memory load if users want to compare list items, and will increase navigation time as scrolling is increased. Based on the previous guideline, this guideline improves perception, cognition, and motor performance.



(a) No padding (b) Padding

Figure 31: Rows without and with padding.

2.5 Formatting

2.5.1 Orientation

Avoid text orientations other than horizontal, left to right (Evidence: Medium; Conformance: Mandatory). Since most languages are read in left to right order, vertical or diagonal orientations interfere readability [7]. Fast reading improves cognition. In addition, various text orientations result in different scrolling patterns.

2.5.2 Alignment

1. *Ensure consistency in the alignment of similar data (Evidence: Medium; Conformance: Mandatory).* Similar data types should be aligned in a consistent manner throughout the table [20]. For example, if a column that can take a set of values is left-aligned, another column that can take a similar set of values should also be left-aligned. Note that 'Patient' and 'Test' columns take text values and both are left-aligned (Figure 32). This guideline attends to perceptual and cognitive performance because users can see and understand that different columns have similar data.

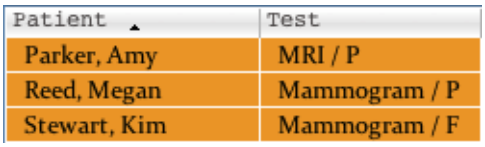


Figure 32: Patient and Test columns with text values are both consistently left-aligned.

2. *Align the time and date markers for all numerals in a column (Evidence: Medium; Conformance: Recommended).* Just like decimal separators, date and time markers (colon, period, AM/PM indicator) in a column have to be aligned for fast perceptual and cognitive performances [20]. Note that this means a consistent number of digits for months, days, and years (Figure 33). Some space might need to be wasted in the cell to allow for alignment.
3. *Bottom-align column headers (Evidence: Low; Conformance: Mandatory).* When all columns are one line only, top and bottom alignment are essentially the same. When some column headers are split into two or more lines, one line headers can either be top or bottom aligned with the rest (Figure 34). Top alignment will create a distance between the header and the cells below it so bottom alignment is a better choice in this case. This guideline has to do with the perception of the column headers.

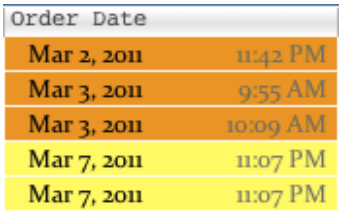


Figure 33: Order Date is double-aligned, meaning date values are left-aligned and time is right-aligned.

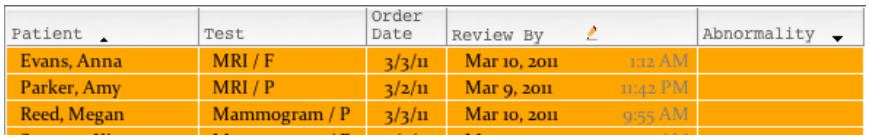


Figure 34: Headers are bottom-aligned when they are split in two or more lines.

4. *Align numeric (time) values to the right while keeping all other values in the table left-aligned (Evidence: Low; Conformance: Recommended).* Time values, which depict numerical data, are aligned to the right for rapid comparison. Note that this means date values are left-aligned (Figure 33). All other cells that include text remain left-aligned since text is read from left to right. This guideline enhances cognitive performance.
5. *Left-align columns with icons for horizontal continuity (Evidence: Low; Conformance: Recommended).* One way to align columns with an icon or a single character is center-alignment since the content will not take much space (Figure 35). This introduces space on both ends of the cell and interferes with eye movement. Moving such columns to the far right end and left-aligning for horizontal continuity boosts perception. If the column is in the middle of the table, then center-alignment might be a better choice.
6. *Double-align the day and time in a date column (Evidence: Low; Conformance: Recommended).* A column that conveys more than one type of information can utilize double-alignment to simplify the complex data format. One such column type is a date column that contains both day and time information. To allow for the comparison of time values and still use a consistent alignment for days, days can be left-aligned while the times are right-aligned (Figure 33). This helps the perception and cognition of these cell values. Note that different fonts are also used to communicate the double-alignment as the adjacent columns might be associated with left or right-aligned data.

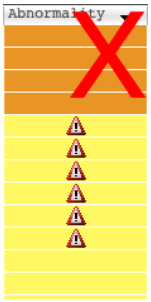


Figure 35: Abnormality column makes use of center-alignment. Thus, it introduces extra spaces on the left and right end of the column.

2.5.3 Number and Date Precision

1. *Round values displayed in table cells where it is not misleading to do so (Evidence: Medium; Conformance: Mandatory).* Numeric values that have too high precision could be simplified for readability by rounding [13]. For instance, time values could be hidden when there is no room in the date column (Figure 37c). Perceptual, cognitive, and indirectly motor performance are affected by this guideline. This partially reduces the perception of the precision but increases the perception of other table elements. Cognition deteriorates with less precision but may result in less scrolling.
2. *Use abbreviation for those values that have the same substring (Evidence: Medium; Conformance: Recommended).* Abbreviating text in a column that repeatedly contains a particular substring can significantly reduce the cell size. Figure 34 writes 'P' for preliminary results rather than the full word, 'Preliminary'. However, a list of the abbreviations should be available to users [20]. It could be in a menu or shown alongside with the tables. If the list of abbreviations is visible, it is helpful for perception. Abbreviations may hinder cognitive performance but reduce the amount of scrolling significantly if the original text is too long.
3. *Truncate values if abbreviation does not apply, but use tooltips for showing details of values that do not fit in the cell (Evidence: Medium; Conformance: Recommended).* Abbreviation does not always apply in cases such as numerical values, when there is no universal agreement on the term, or if abbreviation might confuse the meaning. In such cases, truncation could be done by inserting an ellipsis at the end [1] but tooltips should still show details of values that do not fit in the cell (Figure 36). While truncation reduces perception and cognition, tooltips can help with these. Truncations have both pros and cons for motor performance by reducing scrolling but introducing an extra hover over.

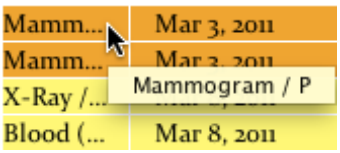
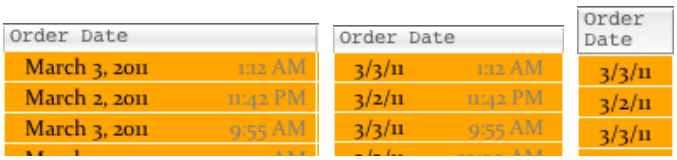


Figure 36: After users change the column width, cells that do not fit in the given width get truncated. The full cell value appears in a tooltip.

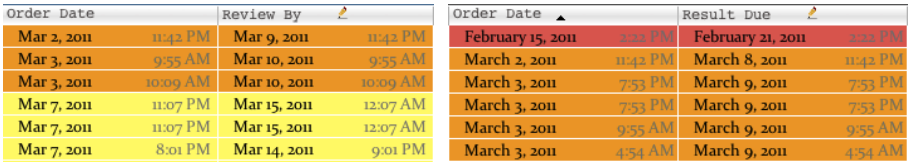
4. *Gradually show more precision if space permits or users seek (Evidence: Low; Conformance: Recommended).* When columns are rounded, users should be able to see the full precision when they want to and if there is enough space in the window. This is usually implemented with a drag of column delimiters. More precision can be shown gradually (perhaps with a transitioning effect) via dragging (see Figure 37a, 37b, 37c). This smoothens the perception and cognition of the precision. One danger is motor performance deteriorates as columns' sizes increase and horizontal scrollbars appear.



(a) Max (b) Mid (c) Min

Figure 37: As users drag the column header to the left, less information is presented gradually.

5. *Keep the precision consistent from column to column (Evidence: Low; Conformance: Recommended).* If there are multiple columns of the same type in a table, initially display them using the same precision. For example, the Results table uses a short month format (e.g. Mar 3, 2011) format in both 'Order Date' and 'Review by Date' columns (Figure 38a), while the Pending table employs the longer month format (March 3, 2011) in both 'Order Date' and 'Result Due' columns (Figure 38b). This does not mean as users interact with one of these columns, the others should be updated accordingly. In fact, users may prefer not to change them simultaneously. In addition, this guideline should be applied with care as one column may need to be seen at a particular precision while another column at a different precision. This guideline assists in perceptual performance.
6. *Split cells into two lines when a value is too long after abbreviation and truncation (Evidence: Low; Conformance: Recommended).* After abbreviation and truncation, if the cell still does not fit, one option is to split the row into two lines (Figure 39). Such an action has an effect



Order Date	Review By
Mar 2, 2011 11:42 PM	Mar 9, 2011 11:42 PM
Mar 3, 2011 9:55 AM	Mar 10, 2011 9:55 AM
Mar 3, 2011 10:09 AM	Mar 10, 2011 10:09 AM
Mar 7, 2011 11:07 PM	Mar 15, 2011 12:07 AM
Mar 7, 2011 11:07 PM	Mar 15, 2011 12:07 AM
Mar 7, 2011 8:01 PM	Mar 14, 2011 9:01 PM

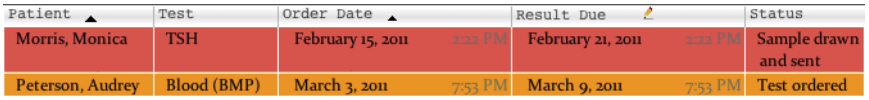
(a) Results

Order Date	Result Due
February 15, 2011 2:22 PM	February 21, 2011 2:22 PM
March 2, 2011 11:42 PM	March 8, 2011 11:42 PM
March 3, 2011 7:53 PM	March 9, 2011 7:53 PM
March 3, 2011 7:53 PM	March 9, 2011 7:53 PM
March 3, 2011 9:55 AM	March 9, 2011 9:55 AM
March 3, 2011 4:54 AM	March 9, 2011 4:54 AM

(b) Orders

Figure 38: By default, both tables make use of consistent precisions for columns with same type.

on the entire row and introduces extra vertical space in the table view, which pushes possible rows from the bottom of the table out of the current page. Thus, this guideline should be used with caution. For example, it is preferable for rows that have more than some threshold number of long columns and should not be used for more than another threshold number of rows in one table page. This guideline considers perception, cognition, and motor skills. While perception and cognition is increased for the particular cell value, the perception of other rows in the current view is decreased. Also, it introduces more scrolling (hence poor motor performance).



Patient	Test	Order Date	Result Due	Status
Morris, Monica	TSH	February 15, 2011 2:22 PM	February 21, 2011 2:22 PM	Sample drawn and sent
Peterson, Audrey	Blood (BMP)	March 3, 2011 7:53 PM	March 9, 2011 7:53 PM	Test ordered

Figure 39: Because the value in the last column does not fit, the cell is split into two lines.

2.5.4 Font

1. *Select a font family and size that is legible (Evidence: High; Conformance: Mandatory).* The font style and size should be readable [7]. Both sans (e.g. Arial, Helvetica) and serif (e.g. Times) typefaces are good for this, however, the tiny embellishments in serif fonts need extremely high definition to avoid looking blurry. While the font size may depend on the screen space, size of 12 is the most legible [15, 27]. This guideline aims at increasing perceptual and cognitive performance.
2. *Ensure consistency in the typeface (Evidence: Medium; Conformance: Mandatory).* While distinct elements are distinguished by their typeface styles, similar elements in the window need to have the same typeface to show the relationship [20]. This guideline is for perceptual and cognitive performance.
3. *Make table values prominent with a font style that is easily distinguishable from others used throughout the interface (Evidence: Medium;*

Conformance: Recommended). The main focus of a window with a table is the contents of the table. Thus, table data should be the most distinguishable factor on such a window. To achieve this, designers can choose darker font colors, a bigger font size, a more readable font family than the rest of the widgets on the window [20]. This complements perception and cognition of the information in the table.

4. *Do not drop to a smaller font to fit a table on the window (Evidence: Low; Conformance: Recommended).* Font sizes must not be altered unless users set them manually. Automatic modification of the font interferes with perception and cognition of table contents. Any changes should be done with transition effects. In this case, the risks are higher. When the font size changes, the table layout will be recomputed again and this may require even more changes.

2.5.5 Color and Icons

1. *Change color saturation to make important information stand out (Evidence: Medium; Conformance: Recommended).* If there are levels of severity in the color-coded information (Figure 40), saturation can be employed [20]. This helps with perception and cognition of the color coded data. For people with color deficiencies, this might be difficult to see.

Evans, Anna	MRI / F	Mar 3, 2011	1:12 AM	Mar 10, 2011	1:12 AM	
Parker, Amy	MRI / P	Mar 2, 2011	11:42 PM	Mar 9, 2011	11:42 PM	
Reed, Megan	Mammogram / P	Mar 3, 2011	9:55 AM	Mar 10, 2011	9:55 AM	
Stewart, Kim	Mammogram / F	Mar 3, 2011	10:09 AM	Mar 10, 2011	10:09 AM	

Figure 40: Use of saturation in color-coding for levels of severity.

2. *Use icons whenever possible (Evidence: Medium; Conformance: Recommended).* By cutting down the necessary reading, distinctive and meaningful icons can dramatically improve the speed at which a user can comprehend the information, i.e. better cognitive performance [1]. Icons can especially be used for boolean values such as when some condition evaluates to true (see 'Abnormality' column in Figure 2). On the other hand, people can only remember a few icons and a screen with too many different icons can become overwhelming.
3. *Provide a color legend to show and filter based on the coding (Evidence: Low; Conformance: Mandatory).* The legend shows color coding and allows filtering. While the color coding displays important information in the table, the legend shows the meaning of different colors for cognition. The color background decreases text legibility by decreasing contrast. In addition to an external filter panel, the legend allows quick filtering to enhance motor performance for this important criteria. Figure 41 presents a color legend example that allows filtering

with radio buttons.

Figure 41: Color legend shows and filters based on color coding.

4. *Use color coding to show grouping (Evidence: Low; Conformance: Recommended).* Most tables do not utilize colors, i.e. white background with black font. When rows are marked and grouped based on an important criteria, color coding the rows can communicate this information. It advances perception and cognition skills. To help universal accessibility, font style (such as boldface) can be used instead of color. This guideline should be reserved for very critical information that requires attention. In Figure 2, the grouping is based on urgency and the colors also indicate this because it is the most crucial information in the table.

3 Actions for Rapid Completion (ARC) Design Guidelines

This section uses various terms for user interface components that can hold multiple widgets (labels, buttons, text boxes, drop-downs, tables). Screen refers to a computer monitor which may show one or more windows. Users can open, move, resize, minimize, maximize, or close windows. Windows are visible until users explicitly close them. A dialog or dialog box is a special window that is limited to communicating a message with users (e.g. present feedback to the user, prompt the user for a response). Users have to acknowledge or explicitly dismiss the message to close dialogs. Dialogs disable interaction with other windows. Popups or popup menus appear upon user interaction and may offer information and/or a limited set of choices that are available in the current state or context. Popups disappear when users select one choice or click away from the popup. Panels are generally part of windows but they do not always have to be. Unlike popups, they allow multiple selections. They disappear when users confirm their selections or click/move outside of the panel. Tooltips appear when mouse hovers on a widget without clicking it and disappear automatically after some delay.

3.1 Allow In-place Editing for Cells (Evidence: High; Conformance: Mandatory)

If a table contains data users can edit, it is best to let users edit individual cells [1, 20] without having to open a secondary window to speed up motor performance (Figure 42).

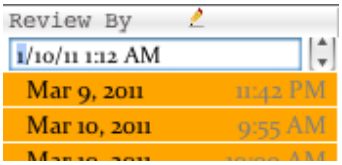


Figure 42: In-place edit for a table cell value.

3.2 Reveal a panel on hover or click of a row for more complex actions (Evidence: Medium; Conformance: Mandatory)

If there is more than one action to perform on a row, a panel can be revealed on hover or click [14] (Figure 3). Other options may be opening a dialog box or putting the actions on a separate window (Figure 43). A panel is more light-weight than these options in the sense that panels do not obscure the main window (context-switch), disallow access to the main window, or have to be dismissed with a "close" or "back" action. Note that a popup is not possible in this case because multiple choices need to be selected. Therefore, panels offer better perception, cognition, and motor performance compared to their counterparts. An affordance to popup the panel may be color or sound indication during hover. With frequent users, a typical solution would be to have training to let them know.

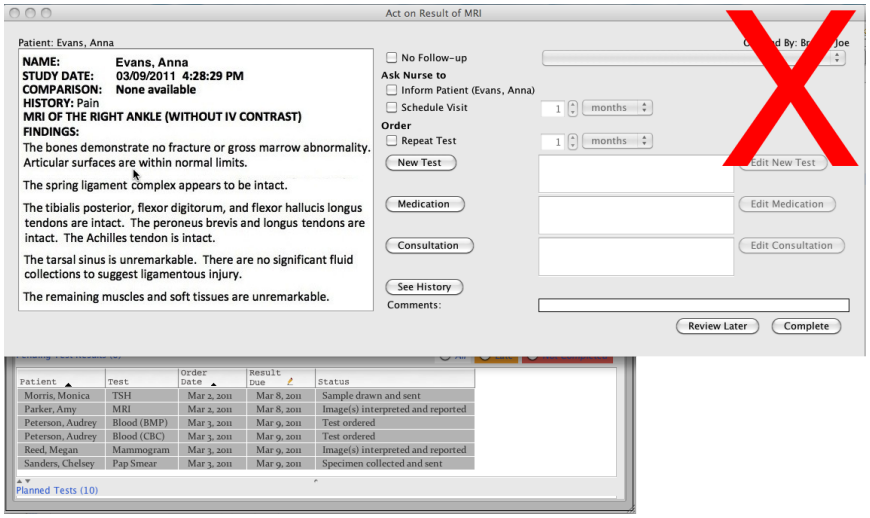


Figure 43: A dialog box enumerates actions that can be performed on a row. The main drawbacks are it obscures the table and the row, and needs to be closed to return to the previous window.

3.3 Make the entire row clickable if there is one action set on a row (Evidence: Medium; Conformance: Mandatory)

If specific columns have actions associated with them and each column has a disjoint set of actions, only those cells should be interactive [17]. For a single action that concerns the entire row, the entire row should be clickable (single-click) for faster motor performance. This is based on Fitts' Law [8] that implies wider targets are easier to click.

3.4 Support key accelerators to speed up action taking (Evidence: Medium; Conformance: Mandatory)

When speed is vital, a keyboard shortcut is an excellent strategy, which is especially appreciated by power users [20]. This significantly improves motor performance. Not only there should be a help button for key commands, key commands can also be highlighted on the panel to further increase perception. As a reminder, when users hold an activating key (such as Alt, Command, Control, and Shift), the key to select an action is underlined on the panel (Figure 44). Note that quick undo/redo operations are crucial.

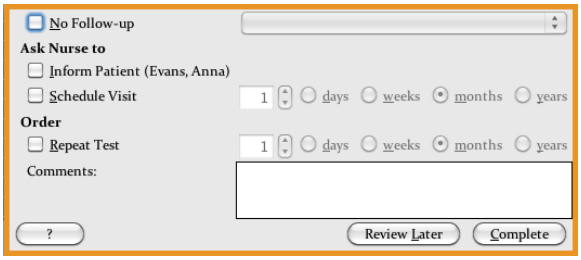


Figure 44: An activating key reveals all letters underlined to press for shortcuts.

3.5 Spell everything out while keeping the content compact for visual scanning (Evidence: Medium; Conformance: Mandatory)

The goal of a panel is to improve efficiency and reduce memory load so that the most frequent actions are one-click away. Designers need to keep the content compact for visual scanning and simplify the language to achieve better perception [20]. For cognition, minimal text with no abbreviations is desired.

3.6 Support undo/redo of actions (Evidence: Medium; Conformance: Mandatory)

Any action – including saved ones – should be reversible [20]. An undo/redo option must be supported not only shortly after the action has been taken but also from the table where completed items are kept.

3.7 Avoid drop-downs that necessitate multiple clicks to access and select (Evidence: Medium; Conformance: Recommended)

Selections should be made with a single click on radio buttons, check boxes, etc. Drop-downs (a.k.a. combo boxes) require selection to see a list of items, move and scroll, and click on the desired item. Drop-downs introduce more errors, impair perception of the items and motor performance [15]. However, with multiple widgets laid out on the panel, mouse may travel longer distances than with drop-downs. Figure 45 has only one drop-down, which lists long words that would not fit on such a small panel.

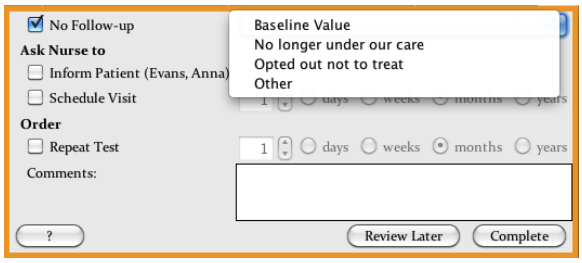


Figure 45: Drop-downs require a click to see the list of items, cursor move, and a click on to the desired item.

3.8 Provide sounds for feedback (Evidence: Medium; Conformance: Recommended)

To provide extra feedback and support accessibility, a sound may give confirmation of the action status [20] by extending the perception and cognition. When "Complete" is clicked (Figure 3), a sound gives confirmation. This may not be of help to users with hearing disabilities.

3.9 Keep the panels and popups on the screen until the user intentionally dismisses them (Evidence: Low; Conformance: Mandatory)

Users should have as much time as they need to process all the information in the popups and select their actions on the panels. This is suggested for

improvements in perception and cognition. Because panels or popups do not have a close or a cancel button, they are dismissed on click/hover somewhere else on the screen than the panel/popup itself. This will close both the panel and popup (if any) simultaneously without affecting anything in cases when users unintentionally clicked on a row by mistake or want actions to remain unsaved. This has benefits for motor performance. For example, the mouse cursor is on the panel in Figure 46 but as soon as the mouse leaves the panel and popup, both of them disappear.

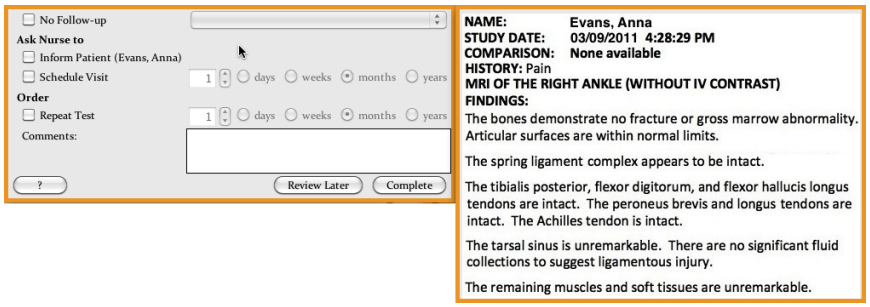


Figure 46: The panel (left) and popup (right) stay visible until the mouse moves outside of their borders.

3.10 Keep the row visible when the panels are shown (Evidence: Low; Conformance: Mandatory)

No matter where the panels or popups open, the row provides context and acts as an information resource for users to choose their decisions on the panels. This is useful for perception.

3.11 Highlight the selected row while unhighlighting the rest of the data in all tables (Evidence: Low; Conformance: Mandatory)

The selected row should be highlighted while the rest of the data in all tables gets grayed out (Figure 3). With a sheer amount of data on a tabular display, this dissipates the distracting information and brings the focus onto the item which is being handled. Perception is under consideration for this guideline.

3.12 Rows that appear in more than one table should be linked (Evidence: Low; Conformance: Mandatory)

If the same row appears in more than one table, any interaction with one of the rows should also bring up the other one. For example, Amy Parker's pre-

liminary late MRI result is shown in both tables and selecting one highlights the other one (Figure 47). This is important for perceptual performance.

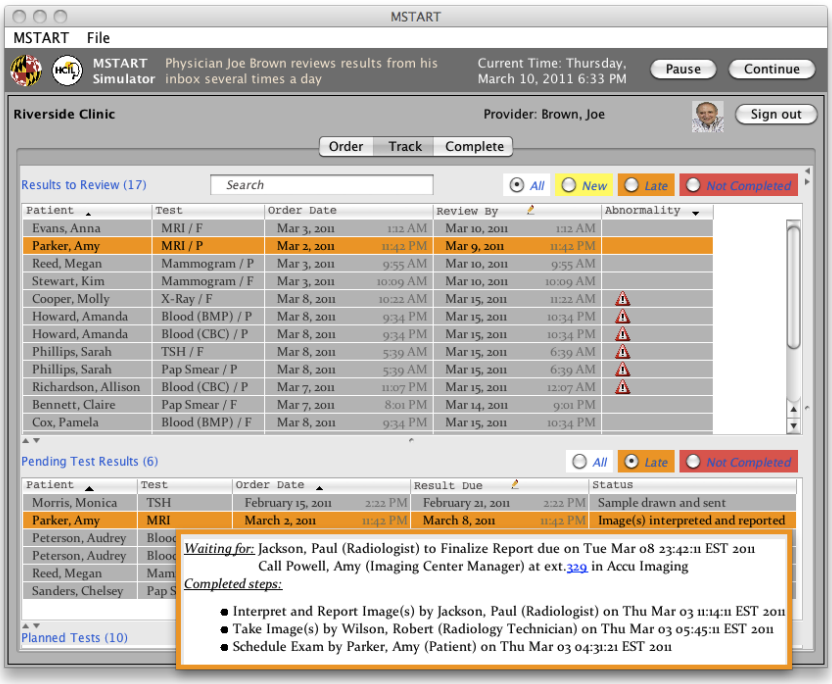


Figure 47: Selecting one item in the pending table highlights the same item in the results table.

3.13 Open panels as close to the mouse click location as possible (Evidence: Low; Conformance: Mandatory)

With a click on a row, the panels and popups should appear either just a little below or above for perception and cognition motives. Putting them far away would have a negative effect on motor performance because the eye and mouse will need to jump a greater distance between the rows and the panels. Figure 3 presents popups along with the panels but to the right so as to give quick access to the actions. On the other hand, opening the panel at a specific location might prove useful for consistency.

3.14 Make sure the panels and popups are visible at all times (Evidence: Low; Conformance: Mandatory)

This means that popups should not overlap with panels. In addition, neither of them must go off the screen (Figure 48). The system should automatically compute the optimum location for the panel within the screen space without

obscuring the row or the popup. This guideline concerns with perception mostly.

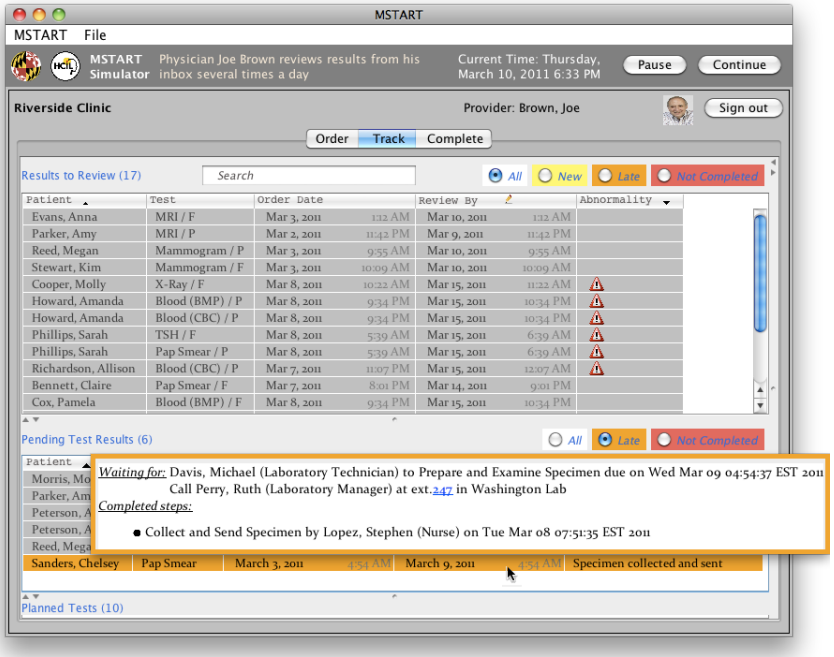


Figure 48: Assuming that there is no screen space available below this application window, the location is computed so that the popup does not go off the screen and the row is still visible. Normally, the popups display right beneath the point of click location, however, the mouse cursor is very close to the edge.

3.15 Save and allow access to completed actions (Evidence: Low; Conformance: Mandatory)

Items with completed action status should be saved automatically. This helps with perception of completed items. Completed items can be kept in the same table but may increase the table size significantly over time as more items are completed, impairing motor performance. One option is to provide a filter to show/hide completed items. Another option is to move them to a separate table where users can access when desired (see "Complete" tab at the top of the tables in Figure 2). In the latter case, animation can be used to illustrate the item is moving to another table.

3.16 Present a popup of row information along with the actions (Evidence: Low; Conformance: Recommended)

Sometimes there is external data about the row that does not fit in a column (e.g. an image) or is intentionally hidden. Users who take actions on such rows should know all the data to make the best decisions. In these cases, a popup menu showing this information along with the actions is helpful for perception and cognition of the extra information (see the MRI report in Figure 3). Another way to implement this guideline is by interleaving the actions with the information in the popup menu (Figure 7). Then, accessing the actions may require more mouse travel. This is only optimal if there are not too many actions and these actions can be put close in proximity.

3.17 Color the panel and popup the same as the color coding of the row (Evidence: Low; Conformance: Recommended)

Row colors could be missed when new panels or popups appear as panels and popups may partially hide the table. It does not hurt to remind the color coding. For color coded tables, colors should be repeated in the panels and popups. To avoid extensive color usage, a good choice is border coloring (Figure 3). Perception is reinforced here.

4 Summary

These guidelines are developed by studying existing systems, interviewing medical informatics experts, demonstrations to expert users, and reviews by HCI professionals. These guidelines were sent to researchers for review and seven of them replied with detailed feedback. There were three negative and four positive comments; the rest were suggestions for improvement within the document. Here are four positive followed by three negative comments from researchers:

> The guideline content looks great! There is a lot of useful information in them that we could use for mocking things up. If we think of these guidelines in terms of the National Institute of Standards and Technology use cases, there is great potential for implementation. Incorporating these guidelines to our current mockups and design would further improve readability and interaction.
>
> You have compiled an impressive list of guidelines and supportive evidence that strike me as valuable on face value as well, as a family physician.

> I think this a great beginning. There has been a lot of work put into these guidelines and there are a lot of really great points.
>
> Overall, the guidelines are well-done and helpful for human factors professionals. Some would be helpful to non-human factors professionals. Most guidelines are well-written and would be useful for the human factors professional working on electronic health/medical records.
>
> My main suggestions are aimed at making it easier to comprehend for software engineers and managers who lack a lot of human factors training.
>
> I see now the document is very specific to the Veterans Affairs Electronic Health Record system. If the goal is to make this more generalizable I would focus less on the "bad" examples and the errant problems and provide more and better examples of the various list information found in tables from medication lists, to problem lists, to lists of orderable items in Computerized Physician Order Entry.
>
> I don't think many folks from the vendor side who are making these decisions will take the time to read the document. I wish it was different but, I think that is the way it is.

Tables 1, 2, 3 summarize all 90 guidelines (8 results management guidelines, 65 table design guidelines, 17 actions for rapid completion guidelines) along with their evidence and conformance ratings. For each guideline the perceptual, cognitive, and motor skills of users were considered, with the goal of reducing the load on users so as to speed performance while reducing errors. Each guideline suggests a direction for research to validate and refine it, especially to refine it for new platforms such as small or large displays, use of voice controls, use by medical professionals with disabilities, and other special situations.

Table 1: Summary of Results Management design guidelines and ratings for evidence (High, Medium, Low) and conformance (Mandatory, Recommended).

Results Management design guideline	**Evidence**	**Conformance**
1. Show pending results	H	M
2. Prioritize by late and lost status	H	M
3. Indicate physician acknowledgment and timeliness	M	M
4. Embed actions when appropriate	M	R
5. Provide retrospective analysis	M	R
6. Distinguish preliminary and final results	L	M
7. Support views for different clinician roles	L	R
8. Clarify responsibility	L	R

Table 2: Summary of table design guidelines and ratings for evidence (High, Medium, Low) and conformance (Mandatory, Recommended).

Table design guideline	**Evidence**	**Conformance**
Data Arrangement		
Columns / Rows:		
1. Sort the table according to one or more column(s) by default, arranged vertically down	H	M
2. Permit re-sorting of tables with a click on the column header	H	M
3. Avoid horizontal scrolling in the default view	H	R
4. Focus on the data itself	M	M
5. Use sort icons in column headers to communicate that the table is sortable; conventionally upward/downward arrow for ascending/descending values while the arrow size indicates sort priority	M	M
6. Perform computations for users; value, derived from data, should be readily available in the cells	L	M
7. Reduce the number of columns whenever possible	L	R
8. Remove a column that always has the same value to save space	L	R
9. Use endless scrolling when all results do not comfortably fit within one page	L	R
10. Combine columns when appropriate	L	R
Row Sequence:		
1. Put the most severe row at the top of the table while ensuring that the most important rows are still visible	M	M
2. Group related rows together so they are close in proximity for comparisons	L	R

Column Sequence:		
1. Offer rearranging of columns	H	R
2. Place sets of categorical values to the left of the quantitative values associated with them	M	M
3. Place columns containing data that should be compared close together	M	M
4. Organize the most important columns on the left to permit reading in the conventional left-to-right order	M	R
Related Tables:		
1. Use just enough space between tables to make them noticeable	M	R
2. Size the tables according to their frequency of usage	M	R
3. Filter a table that is not used often to show only the important data or stretch the table with support for full-view or expansion on-demand	L	M
4. Order the tables according to their frequency of usage	L	R
5. Keep table structure consistent from table to table	L	R
Labeling		
1. Style headers differently but ensure consistency	H	M
2. Give the table a descriptive title with a total row count	H	M
3. Keep the headers visible in the window at all times	H	M
4. Align column headers with their associated data	H	M
5. Avoid a header that is significantly wider than the data it is indicating by spreading such headers into two or more lines	M	M
6. Indicate editable columns	L	M
7. Show a tooltip for the title that describes the table's function	L	R
8. Do not truncate column headers; break long headers by full words whenever possible, otherwise split in the middle with a hyphen	L	R
Settings & Help		
1. Provide custom filtering on-demand	H	M
2. Allow settings to be saved and loaded	M	R
3. Do not let tooltips go outside of screen space	L	M
4. Provide help in a separate window	L	M
5. Derive filter values from current table entries, not all database entries	L	R
6. Group filter values by range if possible	L	R
7. Support search for large tables	L	R
8. Show a description for columns in a tooltip	L	R
Delineation		
1. Feature light white space between the rows, no heavy gridlines	H	M
2. Allow sufficient space between columns to clearly separate them but no more	H	M
3. Calculate initial column widths from data but offer resizing of columns	M	R
4. Define a min and max width for each column depending on the data it presents; these widths should be user changeable	M	R
5. Do not stretch tables to fill available space; only the last column may be stretched, if not right-aligned, to align with other tables	M	R

6. Add some padding to columns if there is room; allow user-defined values	M	R
7. Add some padding to rows for easy visual scanning; allow this to be set by the user	M	R
Formatting		
Orientation:		
1. Avoid text orientations other than horizontal, left to right	M	M
Alignment:		
1. Ensure consistency in the alignment of similar data	M	M
2. Align the time and date markers for all numerals in a column	M	R
3. Bottom-align column headers	L	M
4. Align numeric (time) values to the right while keeping all other values in the table left-aligned	L	R
5. Left-align columns with icons for horizontal continuity	L	R
6. Double-align the day and time in a date column	L	R
Number and Date Precision:		
1. Round values displayed in table cells where it is not misleading to do so	M	M
2. Use abbreviation for those values that have the same substring	M	R
3. Truncate values if abbreviation does not apply, but use tooltips for showing details of values that do not fit in the cell	M	R
4. Gradually show more precision if space permits or users seek	L	R
5. Keep the precision consistent from column to column	L	R
6. Split cells into two lines when a value is too long after abbreviation and truncation	L	R
Font:		
1. Select a font family and size that is legible	H	M
2. Ensure consistency in the typeface	M	M
3. Make table values prominent with a font style that is easily distinguishable from others used throughout the interface	M	R
4. Do not drop to a smaller font to fit a table on the window	L	R
Color and Icons:		
1. Change color saturation to make important information stand out	M	R
2. Use icons whenever possible	M	R
3. Provide a color legend to show and filter based on the coding	L	M
4. Use color coding to show grouping	L	R

Table 3: Summary of Actions for Rapid Completion (ARC) design guidelines and ratings for evidence (High, Medium, Low) and conformance (Mandatory, Recommended).

Actions for Rapid Completion (ARC) design guideline	**Evidence**	**Conformance**
1. Allow in-place editing for cells	H	M
2. Reveal a panel on hover or click of a row for more complex actions	M	M
3. Make the entire row clickable if there is one action set on a row	M	M
4. Support key accelerators to speed up action taking	M	M
5. Spell everything out while keeping the content compact for visual scanning	M	M
6. Support undo/redo of actions	M	M
7. Avoid drop-downs that necessitate multiple clicks to access and select	M	R
8. Provide sounds for feedback	M	R
9. Keep the panels and popups on the screen until the user intentionally dismisses them	L	M
10. Keep the row visible when the panels are shown	L	M
11. Highlight the selected row while unhighlighting the rest of the data in all tables	L	M
12. Rows that appear in more than one table should be linked	L	M
13. Open panels as close to the mouse click location as possible	L	M
14. Make sure the panels and popups are visible at all times	L	M
15. Save and allow access to completed actions	L	M
16. Present a popup of row information along with the actions	L	R
17. Color the panel and popup the same as the color coding of the row	L	R

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