Chapter 3
Using Symbols for Semantic Representations: A Pilot Study of Clinician Opinions of a Web 3.0 Medical Application

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3.1 Introduction

Technologies such as Resource Description Framework (RDF), domain ontologies, NoSQL, sophisticated search techniques, reasoners, and analytics have greatly improved solutions to "big data" problems. However, research into information visualization has lagged far behind these other technologies. Although tremendous importance has been placed on visual displays with regard to physical layout and the encapsulation of what might be termed "world semantics" (Shneiderman 1992), they have neglected relational and contextual aspects that facilitate meaning making or what might be called display semantics (Bederson et al. 2002). This is particularly true of high-density displays, such as those often found in health care.

Physicians must evaluate the complex relationships among indicators of illnesses, symptoms, laboratory information, and results of cases to diagnose acute patient conditions and decide on treatments. The consequences from misinterpretations or information overload from poorly rendered display media can be devastating as was noted when physicians removed the wrong kidney from a patient in a surgical operation (Dyer 2002).

Many, if not most, clinical displays of medical information in use today render linear forms of media, such as texts, line graphs, and charts, which are inefficient (Lohr 2003). Some previous research has explored replacing conventional linear renderings with more holistic information such as glyphs and graphical linguistics in the medical arena, but these have had mixed results (Workman 2008; Yost and North 2005). Thus, to help advance our understanding of how and why some display media work better than others in a medical setting, we conducted an exploratory study of an in-use medical display technology with a comparable symbol-based

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technology at a hospital in central Florida (USA). Theory-grounded empirical research into medical displays should help move the current largely subjective and anecdotal body of literature toward a greater understanding of what constitutes more effective display designs (Loft et al. 2007; Bradshaw 2006).

Our study used a point-of-care application that displayed all relevant information at the patient's bedside on a fixed display, and on caregiver's mobile devices. The application included all of the functionality to automate the patient care process using the terminology the hospital had validated. Performance thresholds were set to drive care priorities based on the displays. The intent of the designs was to enable the caregiver to glance at all of the patients' vital information simultaneously to gain situational awareness, and determine what the most important next activity should be. In the sections that follow, we briefly present our theoretical foundation along with design principles, then we describe our study in more detail, and finally we present our results and conclusions.

3.2 Theory Foundations and Design Principles

Visual perception occurs on several levels depending on one's focus. For example, normal vision encompasses approximately 60° (with peripheral vision extending out about 20° on either side of the eye), but narrows to between 6 and 10° when focused on an object. Furthermore, since only a fraction of the original light energy from an environment is registered on the retina and the rest is absorbed and diffused by the fluid and structures within the eye, once focused, the optic nerves are more sensitized to moving and changing (e.g., color) objects over stationary and static ones, which helps the perceptual processing in the visual cortex to distinguish the object from foreground, background and parallel objects, and the "meaning" it conveys or that is interpreted (e.g., predator or prey; Doneva and De Fockert 2014).

Known as feature detection, visual stimuli such as lines, edges, angles, and movements are differentially perceived. A feature is a pattern or fragment or component that can appear in combination with other features across a wide range of stimulus patterns. Unelaborated features (those without surrounding context) are difficult to discern. This becomes clear when we consider that we read printed text by first extracting individual features from the patterns, then combining the features into recognizable letters, and finally combining the letters to identify the words. Moreover, words without additional context are often "meaningless." With surrounding context, we use the cognitive heuristic of "likeness" to infer correct from misspelled words in our language if there is enough context from which to make an inference (Elliott et al. 2014).

As an example, most English speaking people are unable to see that a single word in isolation such as "slevin" is misspelled unless we write (in the USA) that "four score and slevin years ago" (a segment from the Gettysburg Address, Abraham Lincoln). Noteworthy is that even with this added context, nationalities other than in the USA may not understand. We might further highlight that "wave" may not make sense unless with the context that we should "wave to the crowd" versus "let's catch the next wave"—because this latter idiom is something easily misunderstood even in the USA unless living near an ocean where "surfing the wave" is a common cognitive script or schema to prime "wave" in experiential context. Therefore, influences of surrounding information along with a person's own previous knowledge are critically important to understand visual information (Khemlania and Johnson-Laird 2013).

Principles 1a–c: (a) A medium must present a visual stimulus in a small area and (b) under urgent conditions "change" to focus one's attention on the area, and (c) must have sufficient situated context for an objective interpretation.

When we read linear information such as prose, we get the sense that our eyes consume the visual information in a continuous fashion. However, the eye sweeps from one point to another in movements (saccades), then pauses or fixates while the eye encodes the visual information. Although this eye movement is fairly rapid (about 100 ms), it takes about twice that long to trigger the movement itself. Next, during the saccade, there is suppression of the normal visual processes and, for the most part, the eye only takes in visual information during the fixation period (roughly 20 ms; Elliot et al. 2014).

This means that there is enough time for about three complete visual cycles of fixation-then-saccade per second. Each cycle of the process registers a distinct and separate visual image, although, generally speaking, the scenes are fairly similar and only a radical shift in gaze would make one input completely different from the previous one. Another important characteristic is that visual information is only briefly stored in iconic memory. The duration of time that an image persists in memory beyond its physical duration depends on the complexity of the information that is absorbed during the encoding process (Doneva and De Fockert 2014).

Principles 2a–b: (a) Encoding and comprehension from linear information is cognitively uneconomical and inappropriate for time-sensitive decision-making from complex data, and thus (b) when practical, complex or dense data should be presented in holistic forms.

Studies (e.g., Endsley et al. 2003) show that there are differences in visual perception between viewing a natural "world" environment versus a computer screen. For one thing, the focus of our field of vision is narrower when working with a computer screen than attending to visual stimuli in a natural environment. Aside from that, part of what makes this feature interesting comes from the notion of encoding specificity, where people store not only the information they are taught but also the environment in which the information was learned.

For instance, studies (e.g., Tulving and Thomson 1973) have shown that students perform better on tests when they take the test in the same classroom where they learned the information compared to when they take the test in a different classroom. Going further, relative to computer displays versus a natural environment, no matter how information may appear on a computer screen (even an image rendered in high-definition 3D), the screen can only display on a flat surface (at present). In sum, people tend to perceive natural stimuli more quickly and effectively than they do in artificial settings. Together, these characteristics are referred to as environmental (or ecological) dimensionality, which suggests that display media should most reflect a natural ecology (Doneva and De Fockert 2014).

Principle 3: Displays should take into account (and incorporate from) the ecosystem in which the information is normally or frequently situated.

Averbach and Sperling (1961) performed a series of interesting experiments that showed, on average, people have deterioration in visual recollection as the information complexity increases. For example, when up to four items were presented in their studies (a "chunk"), subjects' recollection was nearly complete, but when up to 12 items were presented, recollection deteriorated to only a 37% level of accuracy. Furthermore, they found that this poor level of accuracy remained essentially the same even for exposures of the visual stimuli lasting for a long time—in a visual sense (about 500 ms). Consequently, in general, people have a span of visual apprehension consisting of approximately five items presented simultaneously. Newer studies (cf. Cowan 2000; Halford et al. 2005) have found some variability relative to visual persistence based on complexity, and the contrast and background upon which images were rendered.

When dark fields were presented before and after a visual stimulus, visual memory was enhanced (just as a lightning bolt was more visible in a nighttime storm than a daytime storm because of the contrast illumination). Furthermore, these studies indicated that over 50% of items presented were recalled well after a 2-s delay when dark fields were used but, in contrast, accuracy dropped to 50% after only a quarter of a second when light fields were used. Finally, because of backward masking between stimuli, an "erasure" stimulus should be presented in order for the visuospatial sketch pad (VSSP) to rid iconic memory of the previously rendered image because a later visual stimulus can drastically affect the perception of an earlier one (Barnhardt 2005). Although in some cases this can be helpful, such as it can facilitate the priming of information that might appear next (proactive interference), it often creates false perceptions and illusions.

Principles 4a–c: (a) Displays should limit the number of rendered concepts to a "chunk" at a time, (b) should use a light image on a dark background, and (c) before a new image rendering, display an erasure stimulus.

3.3 Method

Participants and Preparations

We enlisted clinical caregivers from a regional hospital in central Florida (USA) to participate in our study. The hospital was being acquired by a large hospital chain and was tasked with evaluating new clinical systems. There were 42 clinicians who took part in the study.

We developed an active symbol display from their currently used ("regular") medical informatics system for patient clinical information. The regular system, provided by one of the top five commercial vendors in the USA, presented mainly linear data displays of information such as line graphs, charts, and text messages. Messages, such as patient status would change color (e.g., from black text to red text) to indicate a condition such as an abnormal laboratory result. We created 25 cases for rendering patient information in both the regular system and a new "symbolic" system. Participants were then given a short (1 h) training session on the symbolic system.

Instrumentation

To address the first, second, and forth set of principles, the symbolic system utilized familiar glyphs along with color changes, augmentation such as illuminating a circle around a glyph when there was a change in status, and highlighting (see Fig. 3.1).

For example, a green icon for an empty surgical table indicated that a surgery was scheduled and a surgical room was ready. A yellow icon indicated in transit, for example, a yellow surgical table along with a directional arrow indicated that a patient was either in transit from surgery or to surgery depending on the direction of the arrow. A white surgical table with a patient on the table indicated that the patient was in surgery. Other symbols included pharmacy orders, laboratory tests, X-rays, and so forth. These had modifiers, for example, when a laboratory test was ordered, a microscope was displayed. When the test was completed, a circle was illuminated around the microscope. If the laboratory test was abnormal, it would change color to red, and optionally vibrate. Other indicators included patient at risk for a fall,

Fig. 3.1 Symbolic display

aspiration risk, nonambulatory, etc. Finally, there were length-of-stay indicators for standard of care.

To address principle 3, the symbols were placed on a "mobile phone" metaphor such that the display appeared exactly the same whether on a mobile phone, a tablet, or large computer screen. The only difference among these was the number of phone metaphor displays that could be shown on a device. For example, 60 displays were possible on a 46-in. monitor. With the symbolic system, at a glance, a clinician could ascertain situational awareness, for instance, that a patient was male, had pharmacy and laboratory work ordered, was at risk for a fall, was a third of the way through a treatment, and vitals appeared normal. For equivalent situational awareness using the regular (linear) system, a large amount of screen real estate was required, cognitive processing of a large number of data points and linear line graph data were factored.

Procedures

For the study, a computer program was written to present cases in random order, but alternating between a regular display and a symbolic display. The program rendered each case for 10 s, after which a list of five descriptions was presented for the participant to select the case event (e.g., male patient at risk for fall has abnormal laboratory result returned, white blood cells (WBC) elevated). At the end of the session, participants answered an opinion questionnaire on a 7-point Likert scale comparing the regular and symbolic displays based on time to interpret, goal facilitation, effectiveness, quality, and potential to prevent interpretation errors.

3.4 Results

We tested the opinion data using nonparametric statistics and the accuracy results using dependent *t* test. The descriptive statistics for the display are shown in Table 3.1.

Compared to the regular display, participants felt that the symbolic system saved them time ($\chi^2 = 16.57$, $p < 0.01$), better facilitated their goals ($\chi^2 = 17.43$, $p < 0.01$),

Table 3.1 Descriptive statistics

	N	Mean	Standard deviation
Time	42	5.59	1.02
Goals	42	4.53	1.22
Effective	42	4.56	1.47
Quality	42	4.81	0.94
Errors	42	4.33	0.99

was more effective in rendering information ($\chi^2 = 28.33$, $p < 0.001$), was of higher quality ($\chi^2 = 37.76$, $p < 0.001$), and had a great potential to reduce errors ($\chi^2 = 44.85$, $p < 0.001$). The timed test for accuracy indicated that participants were better able to accurately determine the actual case condition ($t = -4.79$, $p < 0.001$, $\mu = -3.69$, $\sigma = 5.00$). The questionnaire allowed for comments, which we present in the "Discussion" section that follows.

3.5 Discussion

Although our pilot study was far from explanatory, it does lend empirical support for the theoretical foundation. Since much of the human factors literature on information displays has been qualitative and anecdotal, more theory-grounded research, especially drawing from cognitive and visual physiology, is needed to inform practice. This has been particularly the case in medical informatics, where the sophistication of display media has lagged far behind other technologies such as medical ontologies, semantic integration, and reasoning and inferential systems.

Participants in our study indicated that the display features in the symbolic system may save up to 2 h per shift per clinician by reducing time required to examine the textual and linear data and search multiple displays for relevant information. They felt also that the use of shapes and color was more effective in highlighting the conditions over the stationary and static line graphs and pie charts utilized by the regular system. In addition, they felt that they were able to distinguish the features much more readily than the simple color changes in the text in the regular system. Beyond these attributes, respondents commented that the symbolic display would enable better communications across disparate groups resulting in process improvements; an example given was that particular metrics such as discharge time would improve because team members from disparate groups who would influence the results would be able to view the same data.

Symbolic systems are not new; however, what has only been fairly recently appreciated is that symbols can convey semantics when augmented with contexts and even attributes that resemble vocabularies. One advantage of symbolic systems is that more information can be conveyed in a reduced area compared to linear and textual information. Another advantage is that they may help reduce cognitive information overload because they present information more holistically and are more cognitively economical. Continued research is needed into developing ways of rendering symbols that can be objectively interpreted, since in many if not most instances the glyphs lack a well-defined, universal, or standard grammar—i.e., they cannot be juxtaposed in relational or subject–predicate forms that can be related across broad areas. Combining the display layer with underlying medical lower domain ontology may help resolve the issue, but this remains unfinished business with many opportunities for the future in semantic visualization.

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