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ECOLOGICAL INTERFACE FOR ASSESSING CARDIAC DISEASE

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ABSTRACT

Using the ecological interface design approach, a graphical user interface was developed to show how different factors (e.g., LDL, HDL, triglycerides, systolic blood pressure) contribute to cardiac health. The display is based on an epidemiological model derived from the Framingham study and additional treatment guidelines in the medical literature. This interactive display allows physicians and patients to see how different factors contribute to overall cardiac health and to see the impact of interventions on reducing risk. The display also graphically associates the state of the patient with treatment categories to help physicians to select the best treatment method based on empirical models. It also has the potential to enrich the dialogue between physician and patient through interactive 'experiments' that illustrate the potential benefits of various treatment options.

INTRODUCTION

Conventionally, interface design problems have been framed within a dyadic semiotic system where the fundamental constraints were the information processing (IP) limitations of the human operators. Thus, the interface was seen as the stimulus or symbolic input and the human operator was operationalized as a sequence of limited capacity information processing stages (e.g., perception, memory, decision making, motor control). The research focus was to characterize the information processing capacity for each of the processing stages, and the primary design goal was to ensure that the presentation of information did not exceed the capacity of any of these stages [1].

The limitations of this approach began to become apparent in the context of fault diagnosis in the nuclear power domain [2]. In this context, the role of the interface was to support humans in solving a complex problem that, in many cases, could not be fully anticipated in the design of automatic control systems. It became apparent that it was not sufficient to consider the information processing limits of humans relative to the surface structure of existing interfaces. In addition, it became important to consider the deep structure of the complex problem that was to be solved. If the interfaces were to support 'productive thinking', then the design of interfaces/representations needed to reflect the constraints associated with the 'deep structure' of the problems [3], where deep structure represents the semantics of the work domain. The challenge was often to reshape the surface structure of the interface to better reflect the deep structure of the problem being represented. This often involved replacing single sensor, single indicator display (SSSI) formats with graphical user interfaces (GUI) that better represented the problem constraints.

Thus, it became necessary to frame the interface design problem in the context of a closed-loop, triadic semiotic system that considered the dynamics of 1) human awareness (information processing abilities), 2) the dynamics of problem situations (deep structure), and 3) the interactive coupling through the interface (surface structure). These three semiotic components are linked in a closed-loop dynamic where each interactively shapes and is shaped by the others (i.e., the dynamics of situation awareness) [4,5]. This triadic approach has been articulated as the Ecological Interface Design (EID) approach to emphasize the importance of including the third dimension (i.e., the deep structure of the situation or ecological dynamic) within the semiotic system [6].

The focus of this report will be on the work analysis that was done in order to understand the situation dynamics associated with the diagnosis of cardiovascular disease (CVD). The ultimate goal of this work is to improve the ability of physicians to 'see' patient data in the context of the dynamics of cardiac health. The work analysis described here will document our search to discover the 'deep structure' of the cardiac health problem and to develop a graphical interface that makes this structure 'visible' to the practicing physician. This involved discussions with domain experts and an extensive review of the medical literature to identify models of CVD and validated standards for treatment.

To restate the goal in terms more familiar to the medical domain. The goal is to support evidence-based medicine (EBM) or evidenced-based practice (EBP). That is, to help physicians to make decisions that are guided by the best evidence provided by empirical medical research [7]. In these terms, the

'evidence-base' provides the 'deep structure' of the problem that should be incorporated in display representations.

THE PROBLEM

Figure 1 illustrates the typical format for reporting the laboratory results from 'blood work' to the physician. These reports are typically in the form of alphanumeric lists that often include patient data relative to population-based norms (e.g., ranges) with some highlighting to indicate particular values that exceed normal ranges. Typically, paper-based formats are used that can be inserted as pages in the patient's chart.

Note that physicians in family practice sites were observed to review multiple charts in the short intervals between patient exams, spending less than a minute reviewing each chart. In this context, it is not surprising to learn that physicians can sometimes fail to notice indications of potential problems and thus can mistakenly sign-off on the results as if they were normal [8]. This can result in delays in treatment that could have potentially adverse impact on patient health.

M18238 COLL: 02/28/2011 10:00 REC: 02/28/2011 18:03 PHYS: COLMAN MD,PAMELA JANE

METABOLIC PANEL, COM				
SODIUM	142	(135-145)	MEQ/L	[BO]
POTASSIUM	4.3	(3.5-5.0)	MEQ/L	[BO]
CHLORIDE	108	(101-111)	MEQ/L	[BO]
CO2	26	(24-36)	MEQ/L	[BO]
GLUCOSE	92	(70-110)	MG/DL	[BO]
BLD UREA NITROGEN	H **23**	(6-20)	MG/DL	[BO]
CREATININE	0.96	(0.64-1.27)	MG/DL	[no]
CALCIUM	9.4	(8.5-10.5)	MG/DL	[BO]
TOTAL PROTEIN	6.5	(6.0-8.0)	GM/DL	[BO]
ALBUMIN	4.1	(3.5-5.0)	GM/DL	[BO]
TOTAL BILIRUBIN	0.8	(0.0-1.2)	MG/DL	[BO]
ALK PHOSPHATASE	72	(35-135)	IU/L	[BO]
AST	H **47**	(10-40)	IU/L	[BO]
ALT	33	(10-60)	IU/L	[BO]
GFR NON-AFR AMER	>60	(>60)	mL/min/1	[BO]
GFR AFRICAN AMERICAN	>60	(>60)	mL/min/1	[BO]

The estimated GFR was calculated using the IDMS-Traceable MDRD Study Equation. This equation should only be used for adults, ages 18-70. It has not been validated for use with the elderly, pregnant women, patients with serious comorbid conditions, or persons with extremes of body size, muscle mass or nutritional status.

FASTING LIPID PANEL				
CHOLESTEROL	158	(<200)	MG/DL	[BO]
TRIGLYCERIDE	90	(35-160)	MG/DL	[BO]
HDL CHOLESTEROL	L **35**	(>35)	MG/DL	[BO]
LDL (CALCULATED)	105	(0-130)	MG/DL	[BO]
CHOL/HDL RATIO	H **4.5**	(1.9-4.2)		[BO]
LDL/HDL RATIO	3.0	(1.0-4.0)		[BO]

[BO] = Tested at Bethesda Oak Laboratory 619 Oak Street 45206

Figure 1. An example of a typical format used to report results of blood analysis to the physician.

It should be obvious from Figure 1 that the typical formats are problematic from both the conventional dyadic IP approach and the triadic EID approach. The amount of data clearly exceeds the capacity of working memory and the highlighting to indicate potentially problematic values is not very salient. Thus, it is not surprising that given limited time for reviewing results, physicians occasionally missed important information. Additionally, the only structure for grounding the data in the evidence-base are the normal ranges that are included as references. While data that fall outside the normal ranges are highlighted, the current format makes it difficult to see where most of the other data fall within the normal ranges. Finally, there is no indication of the significance of any particular datum with regard to either the overall health of the patient or with regard to treatment decision thresholds. For example, it is important to realize that being low or high on a particular datum (e.g., LDL or HDL cholesterol) can either be good or bad relative to cardiac health (high HDL is good, but high LDL is bad).

Thus, the design in Figure 1 is unsatisfactory in meeting both the constraints associated with human information processing and the constraints associated with the empirical evidence-base for cardiac health. In addition to the obvious limitations of the paper form, we were also attracted to this problem by the opportunities associated with the development of electronic healthcare systems. The challenge was whether we could leverage the power of graphical computer displays to provide a representation that would improve physicians' ability to 'see' a patient's data in the context of current medical research on cardiovascular disease (CVD). This is consistent with previous arguments we have made - that the value of electronic healthcare systems will not rest with replacing fallible humans, but rather with enriching the perception-action coupling with smart humans, through enhanced visualizations of the complex domain of medicine [9]. The first step toward meeting that challenge with respect to cardiac risk was to do a work analysis to discover the deep structure that could potentially guide physician decision-making.

WORK ANALYSIS OVERVIEW

There is an important distinction between 'work analysis' in the context of a triadic semiotic system and 'task analysis' in the context of a dyadic semiotic system. Task analysis has conventionally focused on human activity (i.e., behavioral task analysis) or on the mental models of human operators (i.e., cognitive task analysis). The design targets of these analyses are typically to reduce wasted motions and to develop representations to 'match the mental models' of the human operators. In contrast, the focus of work analysis is to discover the constraints of the work ecology, or in other words, to discover the deep structure of the problem. The design motivation for the work analysis is typically not to match the mental models of current operators. Rather, the design goal is to explore possibilities to improve the mental models, so that they more accurately reflect the problem constraints, and so that the capability for productive thinking is improved through the utilization of representations that make the deep structure of the problem salient.

Our early explorations of the cardiac risk problem were not that different than typical approaches to task analysis. We began with naturalistic field observations in family practice sites and critical incident interviews with the medical staff (physicians and medical assistants) in order to understand current practices for managing the data from medical tests. One of the motivations for this work was to compare processes in practices using electronic healthcare systems with practices using the conventional paper systems. We were particularly searching for errors in this process (e.g., lost tests and other failures to inform the physician or the patient about potentially critical test results) [10, 11].

It was through the naturalistic field observations that we discovered the problem associated with the standard formats to data presentation as illustrated in Figure 1. However, once we

took the challenge to improve this representation, the work analysis shifted focus from activity and mental models of the medical staff, to focus on the evidence-base for medical decisions. In addition to talking with practicing physicians, we felt compelled to go beyond these 'operators' to consider the scientific research literature. Experience in other domains, such as aviation, suggested to us that in addition to talking to the operators, it was important to consider the perspectives of the technical or scientific experts (e.g., aeronautical engineers) [12,13]. We have found that the technical experts are often aware of problem constraints (i.e., deep structure) that are not obvious to operators. This is typically due to the fact that scientific experts often utilize multiple representations that are not available to the operators. These representations are typically structured so that high-level constraints (e.g., physical laws) can be more easily visualized. These alternative representations can sometimes provide inspiration for improving the operational displays for operators by making these high-level functional constraints salient.

EVIDENCE-BASED MODELS OF CVD RISK

In searching for the deep structure relative to managing cardiac health, it is reasonable to start by considering the dimensionality of the problem or state space. That is, what are the variables that need to be considered in order to determine the general state of health? Or, with respect to Figure 1, which of these values are most important for judging the overall health of the patient?

Table 1 lists the variables that are considered in two widely used models of cardiac risk for US populations. The Framingham risk score is based on a longitudinal study of cardiac health using a population from Framingham, Massachusetts that began in 1948 with an initial cohort of 5,209 adult men and women. This study continues today and has added additional cohorts [14]. The Reynolds Risk score is based on 10-year longitudinal studies involving large cohorts of adult women and men [15, 16]. Both models are based on the Cox proportional hazard function that has the following form:

$$\hat{p} = 1 - s_0(10)^{e^{\left(\sum_{i=1}^{p}\beta_i x_i - \sum_{i=1}^{p}\beta_i \bar{x}_i\right)}}$$

where $\hat{p}$ is the risk of experiencing an adverse cardiac event within the next 10 years; s_o (10) is the empirically derived baseline survival rate; the x_i represents each observed predictor variable listed in Table 1; the $\bar{x}_i$ represents the empirically derived population means for each of these predictor variables; and finally the β_i represents the regression weights for each variable. A positive weight indicates a positive correlation with risk (e.g., increases in total cholesterol lead to increased risk) and a negative weight indicates a negative correlation with risk (increases in HDL or 'good' cholesterol leads to decreased risk).

In the same way that the physics of mass and energy balance provide an abstract functional context for evaluating the state of feedwater control processes [17, 18], the Framingham and Reynolds models provide an abstract functional context for understanding the dynamics of cardiac risk. The challenge in developing an ecological interface is to organize the information about the individual variables in a way that reflects the structure of the model. For example, it would be ideal if a physician could see how each variable contributes to total cardiac risk. To better isolate the specific contributions of each variable the model terms were rearranged in the following form:

$$\hat{p} = 1 - s_0(10)^{e^{\left[\sum_{i=1}^{p}\beta_i(x_i - \bar{x}_i)\right]}}$$

In this form, the $\beta_i(x_i - \bar{x})$ term provides the unique contribution of each variable to risk. Note that this requires that the population norms $(\bar{x}_i)$ for each of the variables is available. The norms for the Framingham model were obtained directly from the authors of the Framingham model [14].

Table 1: Beta weights for variables contributing to cardiac risk.

Variable	Framingham	Reynolds
Age	3.061 (m) 2.329 (w)	4.385 (m) 0.08 (w)
Systolic BP	1.933 (m) 2.761 (w)	2.607 (m) 3.137 (w)
Systolic BP (treated)	1.999 (m) 2.823 (w)	NA
Total Cholesterol	1.124 (m) 1.209 (w)	0.963 (m) 1.382 (w)
HDL Cholesterol	-0.933 (m) -0.708 (w)	-0.772 (m) -1.172 (w)
Smoker	0.655 (m) 0.529 (w)	0.405 (m) 0.818 (w)
Diabetes	0.574 (m) 0.692 (w)	NA
c-Reactive Protein	NA	0.102 (m) 0.18 (w)
Family History	NA	0.541 (m) 0.483 (w)

TREATMENT DECISION CRITERIA

In addition to visualizing the data in the context of a global index of health as reflected in the Framingham and Reynolds models, evidence-based medicine requires that physicians can relate the data to treatment decision criteria. For example, if the patient is at high risk of a cardiac event, what treatment would be suggested based on the scientific evidence? For cardiac health two major concerns are hyperlipidemia and hypertension, and treatment guidelines for both are available in the literature. Unfortunately, these guidelines are typically presented in verbal, rule-based formats, with little visualization support.

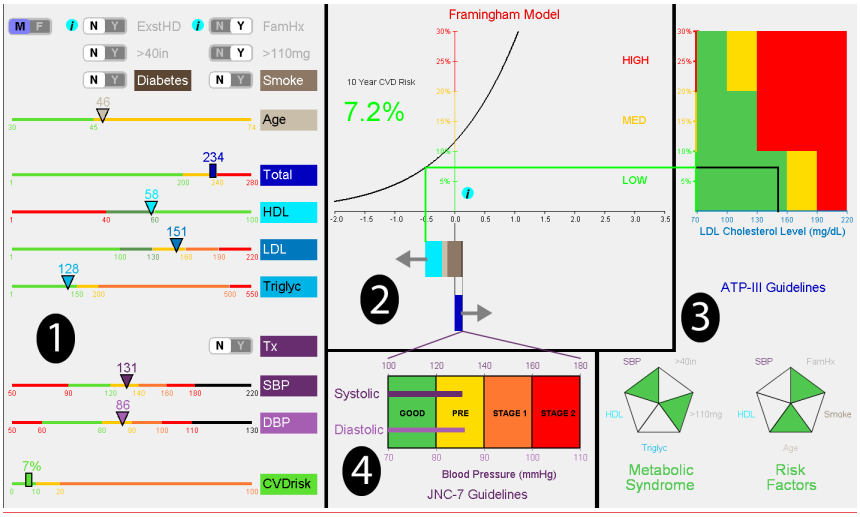
In the case of hyperlipidemia, widely held standards for treatment are based on the Third Report of the Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults (Adult Treatment Panel-III or ATP-III) [19]. The ATP-III guidelines require one to compute the CVD

risk using the Framingham model and to consider multiple other factors including the LDL Cholesterol level, age, systolic blood pressure, family history, whether the person smokes, and additional factors that contribute to a condition referred to as Metabolic Syndrome. The ATP-III guidelines map these multiple factors into three different treatment options: no treatment required; therapeutic life style change recommended; or drug treatment recommended (e.g., statins). Software (e.g., online websites) is available to help physicians to evaluate data with respect to the ATP III guidelines. However, these require multiple steps described over 9 pages of instructions. It is clear that remembering and applying the ATP guidelines is very difficult, even with the aid of these calculators.

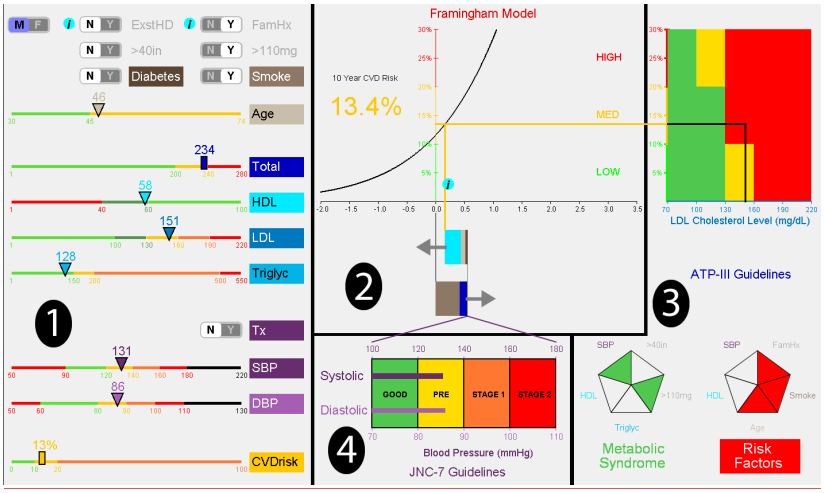
In the case of hypertension, the guidelines for treatment are based on the Seventh Report of the Joint National Committee on Prevention, Detection, Evaluations, and Treatment of High Blood Pressure (JNC-7) [20]. These guidelines are much simpler than the guidelines for hyperlipidemia. They are simply based on the systolic and diastolic blood pressure levels. Four treatments classes are discriminated based on the pressure levels: no treatment, pre-hypertension (life style change), Stage 1 hypertension (medication recommended), and Stage 2 hypertension (multiple medications recommended).

THE LOGIC OF THE GRAPHICAL USER INTERFACE

Figure 2 shows two examples of the GUI that was developed as a result of the work analysis. The GUI is divided into four regions that are linked using color and connected graphs: 1) the values for individual variables; 2) a graphical display of risk of CVD using the Framingham Model; 3) decision criteria associated with the ATP-III guidelines; and 4) decision criteria associated with the JNC-7 guidelines.



(A)



(B)

Figure 2. Two examples of a GUI interface to support evidence-based clinical decision making for coronary heart disease. (A) shows results for a nonsmoker and (B) shows the increased risks for a patient with similar lab work who is a smoker.

In **Region 1** of the GUI, the basic data relative to the risk of cardiovascular disease (CVD) is presented. The data formats include number lines for continuous variables and switches for discrete, dichotomous variables. Continuous variables include age, Cholesterol values (Total, LDL, HDL, and triglycerides), blood pressure (Systolic and Diastolic), and the total risk of CVD based on the Framingham model.

Each continuous variable is presented on a number line that is color coded to reflect clinical norms: bright red indicates a dangerous level; bright green indicates a healthy level; and yellow reflects moderate levels. Shadings of these three colors are used to indicate intermediate levels where appropriate. Specific values are indicated by the position of indicators (either triangles or squares) on the number lines. The position information is supplemented with the numerical value specified digitally above the indicators. The triangle indicators are sliders that can be directly manipulated to change a value. The square indicators are used for variables that are computed based on other variables. These cannot be manipulated directly, but will change when the lower order variables that they depend on are changed. For example, total cholesterol is determined as the sum of the lower order cholesterol variables [e.g., LDL + HDL + (5 x Triglycerides)].

The discrete variables include whether the person has existing heart disease; whether there is a family history of heart disease; whether glucose levels are above 110 mg; whether the person is diabetic; whether the person smokes; whether the person is obese (waist > 40 in.); and whether the person is under treatment for blood pressure. These variables are indicated by switches: Y indicates that the discrete criterion is satisfied (e.g., yes the person smokes; or yes the person is diabetic): N indicates that the discrete criterion is not satisfied (e.g., there is no family history of heart disease).

Region 1 represents an incremental improvement in design relative to the purely digital format illustrated in Figure 1. The number lines provide a clearer representation of the values of the continuous variables relative to clinical norms. Others have suggested similar formats as a means to make the information more salient to the physician [21]. However, the representation in Region 1, fails to meet the challenge of EID, to integrate and structure the information to reflect higher order constraints associated with the dynamics of cardiac health and the treatment decisions. The format in Region 1, illustrates what is typically referred to as a single sensor, single indicator (SSSI) format. This form enhances the salience of specific datum, but does little to reflect the deep structure of the domain in order to support productive thinking.

Region 2 was added to represent the deep structure associated with the dynamics of cardiac risk. The graph in Region 2 was designed to illustrate the Framingham Risk model. The risk of CVD, based on the Framingham model (i.e., $\hat{p}$) is represented in the vertical axis of the graph. This axis is color coded to reflect three general categories of risk (red – high risk; yellow – moderate risk; green – low risk). These categories are based on decision criteria associated with the ATP-III guidelines. The vertical axis of the graph is the sum of the weighted variables that are used in the Framingham model (i.e., $\sum_{i=1}^{p} \beta_i \left(x_i - \overline{x}_i \right)$). Below the vertical axis is a contribution graphic to illustrate the impact of specific variables on the Framingham model. Variables where the product of the beta weight and the value relative to the population mean is positive are represented in the bottom portion of the contribution graphic with the arrow pointing to the right. These variables contribute to increase the risk of CVD. Variables where the product of the beta weight and the value relative to the population mean is negative are represented in the top portion of the contribution graphic with the arrow pointing to the left. These variables contribute to reduced risk of CVD. The contribution graphic is configured so that the sum of the positive and negative contributions is aligned with the left edge of the top portion of the contribution graphic. This line then projects through the horizontal axis to intersect with the graph of the risk function (i.e., $1 - s_0(10)^{e^{[Weighted\_Total\_of\_Risk\_Variables]}}$). From the intersection point with the risk function, the line is projected parallel to the horizontal axis to intersect with the total risk value on the vertical axis. The total risk is also indicated with a redundant digital display that changes color to correspond with the category of total risk.

Color is used to link the individual variables in Region 1 with their contribution to total risk in Region 2. For example, the cholesterol variables are colored in shades of blue and the blood pressure variables are colored in shades of purple. For the examples in Figure 2 the systolic blood pressure is a bit high and the HDL cholesterol is a bit lower than desired. Thus, these factors contribute to increasing risk of CVD. However, total cholesterol is low which reduces the risk for CVD.

Region 1 and 2 are also dynamically linked so that any changes made to variables in Region 1 will be automatically reflected in changes within Region 2. For example, the only difference between the two parts of Figure 2 is the value for the smoking variable. Figure 2(A) shows total risk for a nonsmoker and Figure 2(B) shows total risk for a smoker. Note that in Figure 2(A) the smoking variable (brown) makes a negative contribution (i.e., reducing total risk), but in Figure 2(B) the smoking variable makes a positive contribution (i.e., increasing total risk). Thus, changing the state of the smoking variable moves this person from a healthy, low-risk category of total risk (green), to a moderate-risk category (yellow). One use-scenario that has been envisioned for this interface is that a physician could use it to illustrate to a smoker, the risk associated with smoking by manipulating the smoking switch, so that the patient can 'see' the reduction in risk associated with not smoking.

Region 3 is designed to reflect the decision criteria associated with the ATP-III guidelines for treating hyperlipidemia. Remember that there were three treatment categories associated with the ATP-III guideline: no treatment; therapeutic lifestyle change; and drug treatment. These three

treatment categories are illustrated as the three color regions in the graph to the left of the Framingham graph in Region 2: red – drug therapy; yellow – therapeutic lifestyle change; and green – no treatment.

One of the factors to consider with respect to the ATP-III guidelines is the CVD risk computed using the Framingham model. Thus, the vertical axis of the ATP-III graphic corresponds with the vertical axis in the Framingham graphic. These are linked by the horizontal line that projects to total risk on the vertical axes of both graphics. A second factor to consider with respect to the ATP-III guidelines is the level of LDL cholesterol. This variable is represented on the horizontal axis. The value for the patient is projected vertically to intersect with the total CVD line. The color of the region in which these two variables intersect reflects which of the three treatment options is recommended by the evidence-base.

In addition to the total CVD risk and the level of LDL cholesterol, five risk factors are also consider in the ATP-III guidelines: smoking, whether blood pressure exceeds 140/90 mm/Hg or on a hypertensive medication; low HDL cholesterol (<40 mg/dL); family history of CVD; and age (men ≥ 45; women ≥ 55). The pentagon labeled Risk Factors indicates the state of each of these variables (green – factor present). The presence of any three of these factors can change the treatment criterion. This is indicated by highlighting the Risk Factor label and the pentagon elements in red (compare Figure 2 A and B). Note that in Figure 2(A) only two factors are present, but in Figure 2(B) three factors are present. Note also that the boundaries for the treatment levels in the CVD x LDL space changed when the third risk factor (i.e., smoking) was added. Thus, the presence of the risk factors changes the treatment criteria associated with CVD and LDL levels. As can be seen by comparing Figure 2 A and B, according to the ATP-III guidelines, smoking causes a change in the treatment category from no treatment required for the nonsmoker, to drug treatment recommended for the smoker.

Finally, an additional five factors are considered in relation to a condition called Metabolic Syndrome. Factors associated with Metabolic Syndrome include HDL level, triglyceride levels, blood pressure, obesity, and blood sugar levels. The presence of any three of these factors would require additional attention to therapeutic lifestyle interventions and could impact decisions about drug treatment. The logic behind this graphic is similar to that for the Risk Factors. If a factor is present, the corresponding slice in the pentagon will change to green. If three or more factors exceed the criterion the Metabolic Syndrome label will be highlighted in red to alert the physician to the presence of this condition.

Region 4 is designed to reflect the decision criteria associated with the JNC-7 guidelines for treating hypertension. This is a fairly simple graphic that illustrates four categories of treatment that are contingent on blood pressure measures: No Treatment; Pre-Hypertension (monitoring); Stage 1 Hypertension (drug treatment); Stage 2 (more aggressive drug treatment). The key to this graphic is that the boundaries for each of these stages are contingent or either Systolic (SBP) or Diastolic (DBP) blood pressures. Note that SBP will always be higher than DBP. Thus, for example, Stage 1 Hypertension would be indicated by either SBP greater than 140 mm/Hg or DBP greater than 90 mm/Hg. In the graphic, different scales are used for SBP and DBP such that they align with the clinical categories of hypertension.

THE DYNAMICS OF THE GUI

In addition to the EID approach, this work has also been inspired by principles associated with direct manipulation interfaces [22]. Unfortunately, it is difficult to illustrate or to appreciate the direct manipulation facets of this design through static Figures. The direct manipulation aspects of this display relate to the ability for physicians to 'experiment' by manipulating values of specific variables. For example, by switching the smoking variable from Y to N, the physician will be able to immediately see the consequences for both the overall CVD risk and with respect to the ATP-III treatment guidelines. Note that the changes will be a very salient indication that the smoking variable is a major factor affecting overall health and driving the treatment recommendations.

With respect to evidence-based medicine, it should be clear that the goal is not that physicians mindlessly follow the published criteria, such as the ATP-III guidelines. The goal is not to eliminate the need for expert clinical judgment, but rather to place the data in the larger context of the scientific evidence-base, so that the clinical judgment can be informed by that base. Note that the models in the literature and the published guidelines reflect empirical based hypotheses, but not absolute truth. Our scientific understanding of health is constantly evolving and ultimately the state of health and the choice of treatment may depend on variables that are difficult to quantify or that have not been recognized in the scientific literature.

For example, in this instance, given the profile for the smoker [Figure 2(B)] and the ability to experiment by seeing what the pattern would be if the patient quit smoking, it might be reasonable for a physician to suggest a lifestyle change, before or in addition to initiating the drug treatment recommended by the ATP-III guidelines.

Thus, an important feature of this GUI is the ability of the physician to do 'experiments' by directly manipulating specific variables to see how changes in those variables are reflected in the overall CVD risk and in terms of the treatment guidelines. We expect that the information provided through the GUI will be supplemented by other information that the physicians have in relation to both the patient and to the treatment options. We hypothesize that these 'experiments' will contribute to helping physicians to 'see' the deep structure of cardiac health and to be more productive in their problem solving.

SUMMARY & DISCUSSION

This paper summarizes initial work to improve clinical judgment with respect to cardiovascular disease (CVD) through the design of a graphical user interface (GUI) that reflects the deep structure associated with the scientific evidence-base about CVD. The hypothesis guiding this work is that

representations that are structured to reflect the deep structure of the problem will lead to better clinical judgment (i.e., more productive thinking). This hypothesis reflects the basic literature on human problem solving [4] and is consistent with principles associated with both Ecological Interface Design (EID) [4,6] and direct manipulation [22]. In other words, the ultimate goal is to use the GUI to enhance the situation awareness of physicians [5].

This paper focused on one step toward this ultimate goal – to better understand the situation dynamics associated with CVD risk. A work analysis was initiated that involved extensive search through the scientific literature associated with CVD. As a result of the work analysis, it was possible to identify models of CVD risk (e.g., the Framingham model) and treatment guidelines associated with hyperlipidemia (ATP-III) and hypertension (JNC-7).

A GUI is described that represents our attempt to represent the deep structure of CVD risk in a way that will support direct perception of higher order constraints (e.g., general state of CVD risk and treatment category boundaries) and that will allow direct manipulation to see how lower order variables interact with the higher order constraints.

It is important to understand that, as an artifact, the GUI is both a product of the work analysis and an integral component of the continuing work analysis process. That is, in building and interacting with the GUI we have learned about aspects of the deep structure of CVD that we did not understand or appreciate through reading the scientific literature and talking to experts. In line with Schrage's [23] thesis in Serious Play, we found that having an artifact greatly facilitated our ability to learn from interactions with both the scientific and clinical medical communities.

With regard to our ultimate practical goal, we fully appreciate that we have a long way to go. Next steps will include continuing work analysis through use-ability evaluations with domain experts and controlled empirical evaluations of decision processes with and without the graphical support provided by the GUI that we have developed. These steps have been initiated and preliminary feedback from domain experts has consistently been positive and enthusiastic.

At a higher level, we hope that by demonstrating the benefits of GUI interfaces we can help to shape discussions about electronic medicine from a focus on replacing human functions with automatic systems, to a focus on utilizing the power of information technologies to more fully engage humans in productive thinking about health. We hope to emphasize the role that information technologies can play in enhancing the situation awareness of medical experts [9]. In this larger context, another factor that will impact the ultimate utility of this GUI will be its ability to interface seamlessly with electronic medical record (EMR) systems for easy access to patient data. Finally, the GUI will need to be accessible to physicians in the context of their daily interactions with patients. Thus, we envision that this will ultimately be implemented on a handheld device (e.g., an iPad).

In addition to our practical goals relative to improved clinical judgment, we also have a pedagogical goal with respect to user interface design. We hope that this work will help to clarify the distinction between dyadic and triadic approaches to interface design. We hope that this work will help to illustrate how work analysis can address the third semiotic dimension (the deep structure of situations or problem dynamics) that tends to be underemphasized in dyadic approaches motivated by the information processing paradigm. Further, we hope that this work will help to illustrate the value added to the interface design process by considering the deep structure of the situation dynamics (i.e., by grounding the interface in the work domain constraints).

Despite over a decade of development, there remains significant confusion about the EID approach to interface design. The 'ecological' label is often associated with 'naturalness,' 'ease' or 'intuitiveness' of acquiring the information. However, there can be a danger. Approaches that focus exclusively on the ease of processing, without considering the domain dynamics, can end up with representations that trivialize the problems. These representations are likely to reinforce misconceptions and will be potentially serious obstacles to productive thinking and creative problem solving. The goal of EID is to support productive thinking for solving complex problems, or, in other words, to 'ground' the representation in the situated dynamics of the work ecology.

Thus, the rational for EID is not to reduce the complexity, but rather to reduce the difficulty of managing that complexity. The hypothesis is that this can be done by enriching the perception-action coupling between the human and the problem. One means of doing this is through direct perception/manipulation interfaces where the deep structure of the problem is represented, so that this structure can be organized/chunked and visualized in ways that are compatible with the information processing abilities of domain experts.

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