2012


Timothy Ryan McEwen
Wright State University

Follow this and additional works at: https://corescholar.libraries.wright.edu/etd_all

Part of the Industrial and Organizational Psychology Commons

Repository Citation
https://corescholar.libraries.wright.edu/etd_all/1180

This Dissertation is brought to you for free and open access by the Theses and Dissertations at CORE Scholar. It has been accepted for inclusion in Browse all Theses and Dissertations by an authorized administrator of CORE Scholar. For more information, please contact corescholar@www.libraries.wright.edu, library-corescholar@wright.edu.
DEVELOPMENT AND EVALUATION OF AN ECOLOGICAL DISPLAY FOR THE DETECTION, EVALUATION, AND TREATMENT OF CARDIOVASCULAR RISK

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy

By

TIMOTHY RYAN MCEWEN
M.S., Wright State University, 2009

2012
Wright State University
WRIGHT STATE UNIVERSITY

GRADUATE SCHOOL

Date 19 December 2012


__________________________
John Flach, Ph.D.
Dissertation Director

__________________________
Scott Watamaniuk, Ph.D.
Graduate Program Director

__________________________
John Flach, Ph.D.
Chair, Department of Psychology

Committee on Final Examination

__________________________
John Flach, Ph.D.

__________________________
Nancy Elder, M.D.

__________________________
Kevin Bennett, Ph.D.

__________________________
Helen Altman Klein, Ph.D.

__________________________
Andrew T. Hsu, Ph.D.
Dean, Graduate School
ABSTRACT


Ecological interface design (EID; Vicente & Rasmussen, 1992) is a discipline that emphasizes the necessity of understanding the laws and constraints of a domain in order to make meaningful design decisions. We applied EID principles to create an ecological interface aimed at helping physicians with the detection, evaluation, and treatment of cardiovascular disease risk (specifically for hypertension and hyperlipidemia) and then evaluated it in two exploratory studies. In the first study, twenty-three internal medical residents participated viewed data from twelve patients (in six blocks) in a repeated measures study that measured which risk factors participant felt required follow-up and if their treatment decisions agreed with medically established guidelines (e.g., ATP-III for hyperlipidemia and JNC-7 for hypertension). The results indicate that residents were significantly more likely to follow up on metabolic syndrome when using the ecological display ($p < .0004$) and that in 3 of the 6 trial blocks, they were more likely to choose treatment decisions that agreed with medical guidelines when using the ecological display for LDL cholesterol. Two faculty and two residents participated in our follow-up study, which included a simplified version of the first study but utilized an interactive version of the display and where performance and
interactions were recorded and analyzed. It also included interviews regarding usability issues. The results demonstrated a preference for greater guideline agreement when using the ecological display in only one block of trials, even though almost all participants reported high levels of confidence that their decisions were in agreement with medical guidelines. The usability interviews suggested many ways in which the ecological display could be changed in future re-designs in order to better serve various user groups and purposes. The many positive reactions from our participants, in conjunction with our results, suggest that further design and evaluation of the ecological display would likely be beneficial in medical decision-making.
TABLE OF CONTENTS

1. INTRODUCTION .............................................................................................................. 1
   1.1. Medieval Medicine................................................................................................. 1
   1.2. Evidence-Based Medicine & Practice ................................................................. 3
   1.3. Information Technology ...................................................................................... 4
   1.4. Representations of Patient Data and Error ............................................................ 6
   1.5. Graphics as an Alternative ................................................................................... 7
   1.6. Purpose and Design Limitations .......................................................................... 9

2. ECOLOGICAL INTERFACES AND SEMIOTICS .......................................................... 12
   2.1. Ecological Interfaces ........................................................................................... 12
   2.2. Semantic Mapping ............................................................................................... 13
   2.3. Semiotics .............................................................................................................. 15
       2.3.1. Dyadic Systems ............................................................................................. 15
       2.3.2. Triadic Systems ............................................................................................. 19
   2.4. Understanding the Domain .................................................................................. 20

3. THE ECOLOGY OF CARDIOVASCULAR RISK ......................................................... 21
   3.1. Cardiovascular Disease ....................................................................................... 21
   3.2. Cardiovascular Disease Risk ............................................................................... 22
       3.2.1. Risk Types and Studies .................................................................................. 22
       3.2.2. Disease Risk Models ..................................................................................... 24
   3.3. Mapping the Ecology to the Display: Creating the Graphical Display Elements .......................................................... 26
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.3.1.</td>
<td>The Framingham Risk Model and its Representation</td>
<td>26</td>
</tr>
<tr>
<td>3.3.2.</td>
<td>Graphical Representation of the Framingham Risk Model</td>
<td>31</td>
</tr>
<tr>
<td>3.3.3.</td>
<td>Treatment Options and their Representations</td>
<td>33</td>
</tr>
<tr>
<td>3.4.</td>
<td>Mapping the Ecology to the Display: Assembling the Graphical Elements</td>
<td>40</td>
</tr>
<tr>
<td>3.5.</td>
<td>Summary</td>
<td>41</td>
</tr>
<tr>
<td>4.</td>
<td>STATIC DISPLAY EVALUATION</td>
<td>45</td>
</tr>
<tr>
<td>4.1.</td>
<td>Research Overview</td>
<td>45</td>
</tr>
<tr>
<td>4.1.1.</td>
<td>Research Plan and Goals</td>
<td>45</td>
</tr>
<tr>
<td>4.2.</td>
<td>Method</td>
<td>46</td>
</tr>
<tr>
<td>4.2.1.</td>
<td>Participants</td>
<td>46</td>
</tr>
<tr>
<td>4.2.2.</td>
<td>Materials</td>
<td>47</td>
</tr>
<tr>
<td>4.3.</td>
<td>Results</td>
<td>56</td>
</tr>
<tr>
<td>4.3.1.</td>
<td>Concern</td>
<td>56</td>
</tr>
<tr>
<td>4.3.2.</td>
<td>Follow-Up</td>
<td>57</td>
</tr>
<tr>
<td>4.3.3.</td>
<td>Guideline Agreement</td>
<td>60</td>
</tr>
<tr>
<td>4.3.4.</td>
<td>Ranking</td>
<td>61</td>
</tr>
<tr>
<td>4.4.</td>
<td>Discussion</td>
<td>65</td>
</tr>
<tr>
<td>5.</td>
<td>DYNAMIC DISPLAY EVALUATION &amp; USABILITY INTERVIEWS</td>
<td>69</td>
</tr>
<tr>
<td>5.1.</td>
<td>Overview</td>
<td>69</td>
</tr>
<tr>
<td>5.2.</td>
<td>General Method</td>
<td>69</td>
</tr>
<tr>
<td>5.2.1.</td>
<td>Participants</td>
<td>69</td>
</tr>
<tr>
<td>5.3.</td>
<td>Part 1: Interactive Ecological Display Evaluation</td>
<td>70</td>
</tr>
<tr>
<td>5.3.1.</td>
<td>Method</td>
<td>71</td>
</tr>
<tr>
<td>5.3.2.</td>
<td>Simplified DET Task Results</td>
<td>76</td>
</tr>
<tr>
<td>5.4.</td>
<td>Part 2: Ecological Display Usage</td>
<td>78</td>
</tr>
</tbody>
</table>
5.4.1. Method ................................................................. 78
5.4.2. Results .............................................................. 80
5.5. Discussion .................................................................. 87
  5.5.1. DET Task .......................................................... 87
  5.5.2. Interview and Observations .................................. 88
  5.5.3. Weaknesses ....................................................... 89
6. SUMMARY ..................................................................... 90
  6.1. Study Overview ..................................................... 90
  6.2. Ecological Interface Design ................................. 92
  6.3. Future Design ....................................................... 93
  6.4. Concluding Remarks ............................................ 96
Appendix A ................................................................. 98
Appendix B ................................................................. 100
Appendix C ................................................................. 103
REFERENCES .................................................................. 105
LIST OF FIGURES

Figure 1 Example of Commonly Ordered Laboratory Test Results ........................................7
Figure 2 Individual Health Report Example (Douglas & Caldwell, 2009) ......................... 9
Figure 3 Examples of Different Cue-Feature Mappings (from McGregor & Slovic, 1986) ................................................................................................................................. 16
Figure 4 Model of a Dyadic Semiotic System ........................................................................... 17
Figure 5 Model of a Triadic Semiotic System ........................................................................... 18
Figure 6 The Cox Proportional Hazards Model ....................................................................... 27
Figure 7 The Difference Score from the Cox Model ................................................................. 28
Figure 8 Rearranged Difference Score from the Cox Model ..................................................... 29
Figure 9 Graphical Representations of the Framingham Risk Model and Contribution Bar Chart .............................................................................................................................................. 31
Figure 10 The Treatment Option Matrix ................................................................................... 37
Figure 11 The JNC-7 Bar Graph ................................................................................................. 39
Figure 12 The Number Line Format .......................................................................................... 43
Figure 13 The Ecological Display ............................................................................................ 44
Figure 14 Expressed Concern Levels Across Patient Pairs ...................................................... 57
Figure 15 Number of Correct Identifications by Number of Factors and Display Type for Patient Pair 1 .................................................................................................................. 62
Figure 16 Number of Correct Identifications by Number of Factors and Display Type for Patient Pair 2 .................................................................................................................. 63
Figure 17 Number of Correct Identifications by Number of Factors and Display Type for Patient Pair 3 .................................................................................................................. 63
Figure 18 Number of Correct Identifications by Number of Factors and Display Type for Patient Pair 4

Figure 19 Number of Correct Identifications by Number of Factors and Display Type for Patient Pair 5

Figure 20 Number of Correct Identifications by Number of Factors and Display Type for Patient Pair 6

Figure 21 Ecological Display Usage Statistics by Case and by Graphical Element
LIST OF TABLES

Table 1  Top CVD Risk Factors as Identified in Six Epidemiological Studies........... 24

Table 2  Framingham Risk Model Correlation Coefficients, Baseline Survival Rates, and Summed Means .......................................................... 27

Table 3  Values for Labs and Vitals of a Hypothetical Patient........................................ 30

Table 4  ATP-III Treatment Guidelines....................................................................... 36

Table 5  Blood Pressure Classifications and Recommended Treatments.................... 38

Table 6  Paired Stimulus Scenarios............................................................................. 49

Table 7  Expected Concern across Patient Pairs............................................................ 51

Table 8  Ecological Display Follow-up Differences by Patient Pair............................ 59

Table 9  Guideline Agreement for the Ecological Display by Patient Pair................... 61

Table 10 Paired Stimulus Scenarios for the Interactive Evaluation.............................. 73

Table 11 Guideline Agreement and Confidence Tables.............................................. 77
ACKNOWLEDGMENT

I am deeply indebted to many individuals for their help and support of me while working on this research. I would like to thank John Flach and Kevin Bennett for their guidance and book on interface design (which was the inspiration that ultimately led to this dissertation work). I must also thank Nancy Elder for taking me under her wing, providing great insight, and inviting me into to the healthcare domain. I would also like to thank Helen Altman Klein for getting me to think about things from both the qualitative and patient perspectives.

I am indebted to Michael Pencina and Ralph D’Agostino, Sr., for revisiting their data to provide me with the data I needed to pull this off. Thanks to Randall Green for writing the code to create the interactive prototype. Thanks to Drs. Solomon and Abraham for their input and expertise.

Thanks Again!
DEDICATION

To Rebecca, Karen, & Lillian
1. INTRODUCTION

1.1. Medieval Medicine

From the vantage of over 600 years of history, it is easy to look back at the medieval times with some degree of cynicism about medical beliefs and knowledge of that time. Mortimer (2008) suggests that modern people would likely view medieval English medicine as “a bizarre mixture of arcane ritual, cult religion, domestic invention, and freakshow” (pp. 191).

Medieval physicians (university trained) and doctors (not university trained) relied heavily on various books and manuals to aid the diagnosis and treatment process, which process Mortimer describes in the following:

“[Their manuals] include details of planets’ movements and eclipses of the sun and moon. They also include advice about phlebotomy (letting blood) and all twenty-four varieties of urine, as well as numerological methods of establishing whether you are likely to die or not. The physician will need to know when your illness started, so he can establish where the sun and moon were at the time, as well as the planet governing the health of the inflicted organ. Using these details, he will prepare a series of concoctions for you. First, there is the purgative, to rid it of corrupt matter, either through vomiting, defecation, or urination. Then there is the remedy. Alternatively the physician may open a vein and let your blood. From his diagrams he will...
work out exactly which vein to cut in order to bleed you appropriately. This has as much to do with the moon and stars as with your symptoms. When the moon is in Leo, he should avoid incisions of the nerves and the back. [...] When it is in Scorpio, he should avoid slicing into your testicles, anus, and bladder. [...] After the ordeal is over, you should expect him to advise a final restorative process [...]” (p. 211).

If your remedy process includes a concoction rather than bloodletting, your options might include consuming such colorful and questionable (by today’s standards) treatments such as seven fat bats heads for diseases of the spleen or flayed cat cooked in hedgehog and bear fat for quinsy (Mortimer, 2008).

Again, while English medieval medicine seems backwards to the modern reader, Mortimer makes it a point to note that,

“Medieval people are not ignorant, in the sense of having no knowledge. It is simply that their knowledge is very different from our own. They probably have as much medical “knowledge” as we do, only it is based on astrology, herbology, religion, a little direct experience, philosophy, fundamental misconceptions about how the body works, a lot of hearsay, and a large measure of desperation. When you extend this form of understanding to the physicians and surgeons, and combine it with the ability to charge fees, you realize that medical practitioners have colossal amounts of information at their disposal and a wealth of experience. Unfortunately, not much of it will help you in your sickness, and some of it is seriously dangerous, if not lethal (p. 193).”
Medieval English physicians required years of training and education to earn a medical degree in a manner somewhat similar to the physicians of today. However, as Mortimer puts it, the difference between them and our physicians of today was not in the amount of knowledge *per se*. Medieval physicians and doctors had to consider the relationships of many variables in order to arrive at the proper diagnosis and treatment plan just as the physicians of today do. The difference lies primarily in the quality of their “knowledge.”

Today’s physicians do not have to rely on astrology, philosophy, hearsay, and desperation because they have benefited from advances in anatomy and physiology that have been a result of advances in science. Improved scientific methods have allowed for the accumulation of a great wealth of medical knowledge that is more firmly grounded in ideas and scientific models (i.e., “the Truth”) that lead to more successful outcomes for the patient. This scientific medical knowledge is the heart of what is known as evidence-based medicine.

1.2. Evidence-Based Medicine & Practice

Timmermans and Mauck (2005) remark that evidence-based medicine is broadly applied to many aspects of medicine including “conducting a statistical meta-analysis of accumulated research, promoting randomized clinical trials, to supporting uniform reporting styles for research, to a personal orientation toward critical self-evaluation” (p. 18). Sackett, Rosenberg, Muir Gray, Haynes, and Richardson (1996) define it as “the conscientious, explicit, and judicious use of current best evidence in making decisions about the care of individual patients” (p. 71). This definition focuses more on the provision of care rather than on the
discovery of knowledge, which provides it with a practical slant. This definition provides a good definition of what could be called evidence-based practice.

One of the problems facing physicians wishing to engage in evidence-based practice is simply keeping up with the evidence base. The homepage for PubMed, a database for scientific literature focused on biomedicine, boasts that it is comprised of over 22 million citations and growing (United States Library of Medicine [NLM], n.d.). Even if a physician spent all of their time reading published research, there is obviously no possible way that they could read and absorb everything. Expert panels and committees help reduce some of the burden by creating guidelines and best practices based on the literature. However, there is still a tremendous load on the modern medical practitioner to stay up to date.

1.3. Information Technology

Modern information technological solutions, such as electronic medical record (EMR) systems, have great potential to help with information management. Health information technology (HIT) can be programmed to take the most recent medical evidence into account and provide support to physicians who access these systems. These electronic systems can increase efficiency and potentially reduce physicians’ cognitive load by automatically integrating data in meaningful ways: for example, automatically calculating values such as body mass index (BMI) and 10-year risk of cardiovascular disease (CVD) for the physician or by alerting the physician to indicate that certain values fall outside of pre-specified boundary conditions.
Off-loading some of the overwhelming amount of medical knowledge requirements to HIT is a way of taking knowledge that would normally be expected to be “in the head” and transferring it to “the world” (Norman, 1988). Designing HIT systems to collaborate with and support human expertise leads to the creation of a socio-technical system known as a distributed cognitive system (Lintern, 2007; Hutchins, 1995; Hollan, Hutchins, & Kirsch, 2000). A major benefit of a distributed cognitive system is that it reduces the tremendous cognitive load expected of a single agent (i.e., the physician) for proper system performance (i.e., providing care based on scientific evidence).

Practicing evidence-based medicine requires that physicians have access to (1) patient data, (2) scientific knowledge of how to interpret the patient data, and (3) information about the possible treatment options. If any of these three components is degraded, then there is a significant possibility that the patient’s care will be less than satisfactory. While the information technologies supporting evidence-based medicine promise improved access to patient data, there is concern that insufficient attention is being paid to the other components. Thus, there is a fear that physicians may be simply overwhelmed with data, with little improvement in their capacity to make better treatment decisions. If medical data is not interpreted properly, it does little to aid understanding and is therefore not informative and fails to meet its ultimate objective. Although data from medical tests undoubtedly helps providers and patients make informed decisions that help improve diagnosis and treatment, there are some issues in the interpretation
process that can lead to data failing to become informative, resulting in potentially negative outcomes in diagnosis and treatment.

1.4. Representations of Patient Data and Error

In previous research, we observed one physician review the test results of about 12 patients in less than 10 minutes. While not able to ascertain the accuracy of that physician’s performance, the speed at which that task was performed might explain why the physicians in that office occasionally signed abnormal test results off as normal (McEwen, Elder, & Flach, 2011).

Currently, most laboratory results are reported using alphanumeric characters in a tabular format (see Figure 1). Given the similarities in the alphanumeric characters it is not surprising that data is occasionally misinterpreted or missed, leading to errors in decision-making.

Reason (1990) distinguishes between two types of error: slips and mistakes. Physicians, like all humans, are prone to these types of error. In the context of interpreting test results, a slip can occur when the provider intends to read the numerical value for a particular biochemical (e.g., total protein), but instead accidentally reads the value from the line above or below the correct value (e.g., albumin). A mistake, on the other hand, is a well-executed erroneous plan. That erroneous plan, in turn, may have been the result of the aforementioned slip example or due to the fact that the amount of data that must be considered taxes the human mental capacity.

Healthcare providers often deal with data that is ambiguous (e.g., does the patient’s cough indicate a viral or bacterial infection?). In some cases, many pieces
of information across multiple channels (such as multiple medical tests and patient vital statistics) must be integrated, or prior history must be considered before a proper interpretation can be made. Given the ambiguity inherent in patient health data and the difficulty integrating multiple independent sources of data, it is possible for providers to draw the wrong conclusions and misdiagnose the patient’s condition, potentially leading to a decline in the quality of care.

Given the ambiguity inherent in patient health data and the difficulty integrating multiple independent sources of data, it is possible for providers to draw the wrong conclusions and misdiagnose the patient’s condition, potentially leading to a decline in the quality of care.

Given the ambiguity inherent in patient health data and the difficulty integrating multiple independent sources of data, it is possible for providers to draw the wrong conclusions and misdiagnose the patient’s condition, potentially leading to a decline in the quality of care.

Given the ambiguity inherent in patient health data and the difficulty integrating multiple independent sources of data, it is possible for providers to draw the wrong conclusions and misdiagnose the patient’s condition, potentially leading to a decline in the quality of care.

1.5. Graphics as an Alternative

The general hypothesis motivating this research is our belief that alternative means of data presentation, such as graphics, can potentially aid physicians to gain a deeper understanding of the relationships in the data (Tufte, 2001). Specifically, we
propose to more effectively integrate patient data with the scientific evidence-base concerning judgments about health and choices of treatment options. Our general goal is to explore ways to better support evidence based practice through integral graphic displays. The same information technologies that facilitate storage and access of patient data offer significant opportunities to improve how that data can be represented.

Graphics can have a positive impact on improving the accuracy and decision-making of providers and patients. Although some recommendations for improving graphical displays of patient information have been made (see Figure 2; Douglas & Caldwell, 2009), there are very few examples that have been actually implemented. These few graphical displays—which have been developed in both academia and popular culture (Leckart, 2010; Goetz, 2011)—are likely to have some advantages over the alphanumeric format, but they remain at their core, fairly simple number lines, bar graphs, or line graphs. These formats can make the search for abnormal values quicker and more accurate, but they do little to integrate the data to reflect the scientific knowledge base related to diagnosis and treatment. Thus, while improving access to data, they may fall far short of the full potential to improve the effectiveness of evidence-based practice.
1.6. Purpose and Design Limitations

Current graphical displays for medical information have generally employed a single-sensor-single-indicator format that improves access to specific data, but that provides little structure for integrating that data to reflect underlying relations that may be critical to understanding more global properties, such as the overall

Figure 2 Individual Health Report Example (Douglas & Caldwell, 2009)
health of the patient or the relative merits of various treatment options. Ecological or semantic display design (Bennett & Flach, 2011; Vicente & Rasmussen, 1992) is an approach to interface development that emphasizes the integration of information to support effective decision-making and problem solving. Thus, this brings us to the purpose of this dissertation research—to discuss the development process and evaluation of an ecological graphical display that can be used to detect, evaluate, and treat issues related to cardiovascular disease in a way that supports clinicians in evidence-based practice.

The success of the ecological approach depends on the value of the underlying scientific evidence-base. For example, an ecological approach applied to medieval medicine would still not have produced an as effective of a display as one based on modern medical knowledge. The effectiveness of evidence-based practice will always be bounded by the quality of the underlying scientific models of cardiovascular disease and treatment.

The goal of this research is simply to ensure that clinical decisions about CVD are informed by the existing evidence-base. It is important not to confuse this work with another potential goal for electronic medical systems – that is, to improve the evidence-base through improved representations/models for medical researchers (e.g., epidemiologists). This alternative goal is typically referred to as ‘scientific visualization.’ While ecological interface design seeks to configure graphical displays to represent patterns that reflect current scientific knowledge (i.e., existing models of health), the goal of scientific visualization is to help medical researchers to discover previously undetected patterns in the data (i.e., new models of health). For
example, our display is not aimed at helping cardiologists discover new cardiovascular risk variables in the data. Instead we are focused on creating something that can help early and mid-career primary care practitioners see the data in the light of the health models and guidelines for treatment so that they can use this information as the starting point in the decision making process.
2. ECOLOGICAL INTERFACES AND SEMIOTICS

2.1. Ecological Interfaces

What is an ecological interface? It is important, first, to understand what it is not. Some erroneously believe that ease-of-use or simplicity define an ecological display. This is not true. An ecological display may require significant training before use because the system being represented may be extremely complicated and complex. It would be ideal if an ecological display could be so intuitive that no training would be required, but the designer must balance this with the need to represent the intricacies of the domain in question. In other words, the law of requisite variety must be respected (Ashby, 1958), or else the display runs the risk of inadequately representing the work domain and runs the risk of being unhelpful or irrelevant at times. Neither the display nor designer should trivialize the work domain in order to develop an overly simple display at the expense of one that accurately reflects the work and the domain.

Bennett & Flach (2011) have defined an ecological display as an interface that “must provide global and local structure (or invariants) in the representation that correspond to the inherent structure in the domain and that specify the potential in the relation to goals and values” [p. 137; italics in original]. In other words, it is an interface or display that attempts to connect the underlying ecology (the structure, rules, laws, regulations, opinions, etc.) of the domain to the graphical elements.
2.2. **Semantic Mapping**

The definition provided by Bennett and Flach (2011) may be understood more readily by understanding the concept of semantic mapping, which is the fundamental principle of ecological display design. McGregor and Slovic (1986) demonstrated the role of semantic mapping with a series of studies that required participants to estimate runners’ marathon times using multiple low-level cues about each runner (i.e., age, fastest 10K race time in the past year, number of miles run for training in the 2 months prior to the marathon, and motivation).

In their first study, participants evaluated several graphical display types (e.g., a bar graph, polar coordinate, deviation display, and Chernoff face) to investigate which provided superior support to the time estimation task. Each of these display formats had the various marathon run time cues mapped to the various graphical elements. For instance, the cues were represented as the height of a bar in the bar graph or the curvature of the mouth (or other facial feature) in the Chernoff face display. The results of the first study indicated that participants were more accurate when the using the Chernoff face displays. These results might lead one to believe that this represents the power of configural or “object” displays.

Although the Chernoff face display led to more accurate responses, there was some uncertainty about the reason. Was it due to the fact that the Chernoff faces allowed all cues to be represented simultaneously in an integrated framework that allowed for parallel processing (i.e., because it was a perceptually integrated “object”), or was it due to something else? McGregor and Slovic considered that there might be another reason for the performance difference, namely that some
facial features in the Chernoff faces were more salient than others (e.g. the mouth curvature versus the height of the nose), which might lead participants to give more credence to the cues that were mapped onto the more salient features. If parallel processing and an integrated framework for the cues were the reason for more accurate estimates, then similar performance should be obtained for any feature-to-cue mapping. After all, all cues would be presented as an “object” display and share whatever benefits gained from that format.

To test the effect of facial feature-to-cue mapping, McGregor and Slovic conducted a second study in which they represented information from the same marathon runners, but had mapped the cues in one of two mapping schemes: a well-mapped face and a poorly-mapped face. The well-mapped face display was designed so that the more indicative the cue was (as measured by the amount of variance that could be explained), the more salient the facial cue (as derived from Brunswick’s lens model) assigned to it was. The poorly-mapped display took the opposite approach and mapped the more predictive cues to the least salient facial cues. These reverse mappings led to cases where the same information could result in extremely different faces (see Figure 3).

The results of the second study found that the well-mapped faces led to better performance than the poorly-mapped displays. In fact, the poorly-mapped facial display led to worse performance than some of the original formats presented in their first experiment, such as the deviation and polar-coordinate display. These findings suggest that the superiority of the Chernoff face display was not due to the fact that all cues were placed together in a coherent framework that allowed for
parallel processing. If so, then both the poorly- and well-mapped faces should have led to similar outcomes. The fact that the same information presented in the same graphical format could lead to disparate results is evidence that the mapping between cues from the domain (e.g., running marathons) and display elements is meaningful. It is this relationship between the domain and graphical elements that is known as semantic mapping or semantics.

2.3. **Semiotics**

What do semantics have to do with graphical displays? To answer this question, it is important to have an understanding of semiotics, or the study of signs and signifying, because the creation of a graphic display is the creation of Signs (Nadin, 1988).

2.3.1. **Dyadic Systems**

A dyadic semiotic system is comprised of a Sign and a Concept (see Figure 4). The Sign is sometimes referred to as a medium, representation, or interface. The Concept is a belief, mental model, or knowledge that an agent has. Knowing what a literal sign (such as a stop sign) means is a question of semiotics as is arriving at a medical diagnosis. In both cases, an agent or observer must make sense of the Sign. In a dyadic semiotic system, a physician would examine a patient’s symptoms (the Sign) and arrive at a diagnosis and treatment plan (the Concept). Under a strictly dyadic semiotic model, any diagnosis would be valid as long as the diagnosis/treatment matched the symptom, such as prescribing antibiotics for a patient who has all of the symptoms of a cold. In other words, the dyadic model
would fail to differentiate between a modern physician and the medieval English doctor.

Figure 3 Examples of Different Cue-Feature Mappings (from McGregor & Slovic, 1986)
However, most healthcare providers would probably believe that prescribing antibiotics to treat the patient's symptoms would be ludicrous without further investigation because there would be no guarantee that the symptoms would be tied to the patient’s health and disease pathogenesis. The symptoms do not specify whether they are the result of a bacterial, viral, or allergic origin. Instead, the semiotic model must be expanded to include the health of the patient and the pathogenesis of the disease in order to provide the appropriate care to the patient. By broadening the semiotic system to include the health and pathogenesis, the dyadic model becomes a triadic model (Pierce, 1931-1935; see Figure 5) by adding another circle to the semiotic model. This third circle, representing the Ecology (e.g., the health and pathogenesis of the patient), now allows the diagnosis to be mapped to something deeper than the manifest symptoms.
In the first study by McGregor and Slovic, they hypothesized that the marathon time estimate (i.e., Concept) should be more accurate with some graphical display formats (i.e., Signs) than with others. The supposed reason for any differences in display performance would be that there was something inherently superior about the Sign that allowed the viewer to form a better Concept, such as providing an integrated framework allowing for parallel processing. This reasoning is dyadic.

However, the second study illustrated that even the same graphical format can lead to different time estimates. That different times could result from the same format is strong evidence that the time estimate must be based on something else in addition to the display. It is difficult to describe what this other “thing” might be within a dyadic framework because the dyadic ontology is limited to only the Sign and Concept. A triadic framework can account for these findings by considering the mapping to the Ecology. In the McGregor and Slovic studies, the Ecology is the
domain of marathon running and the cues that predict run times. The second study demonstrates that the relationship between the Ecology and the Sign (i.e., the variance accounted for in the cues and the salience of the facial features in the display) was meaningful for participants. This meaningful relationship does not exist in a dyadic semiotic system because it does not exist within the ontology.

### 2.3.2. Triadic Systems

In a triadic system, the relationship between Ecology and Sign is known as Meaning, while the relationship between Sign and Concept is the Interpretation (Bennett & Flach, 2011). In a dyadic system, Meaning and Interpretation are equivalent terms because the dyadic ontology does not contain more than one relationship.

The traditional approach to display design has primarily been a dyadic systems approach. In a dyadic framework of display design, the semiotic problem is how to create a Sign that is related to the Concept (i.e. the focus is on the Interpretation). This relationship usually takes form in the preoccupation of ensuring that graphs and displays are utilizing the optimum colors, proper sizes, proper positioning, type of graph (e.g., bar versus line graphs), proper typefaces, etc., so that the observer can understand the display. However, just as a diagnosis would be shortsighted if only the Interpretation relationship was considered, a graphical display format would also be equally shortsighted if this were the case.

All graphical displays have a mapping between the Concept, Sign, and Ecology, but if no effort is taken to ensure a quality mapping between the Sign and the Ecology, then the mapping is arbitrary. This was the case in the first study in
McGregor and Slovic (1986); their initial results that led to the superiority of the Chernoff face format was the result of the accidental initial arbitrary mapping of facial features to risk factors. If another mapping had been used for the facial displays instead, the second study may very well have been a follow-up on one of the other graphical formats.

Effective display design requires a conscious effort to map the display features to the factors that are relevant to the domain “behind” the display (i.e., semantic map). Semantic mapping is the alignment of Interpretation and Meaning. It changes the focus from getting an observer to understand the display to that of understanding the domain, via the display. In some respects, this relationship can be understood by the transitive property: if $a = b$ and $b = c$, then $a = c$. In other words, if the Ecology is accurately represented in the Sign (i.e., the display), the observer’s Concept should be reflective of the Ecology. Thus, an ecological display is one that has a strong semantic mapping.

2.4. Understanding the Domain

If the fundamental principle of ecological interface design is semantic mapping, then researching the domain is requisite in order for a designer to create an ecological interface that will have a strong semantic mapping. The display must be representative of the complexities within the domain to avoid trivializing the domain ecology. The next chapter will describe the laws and constraints of the detection, evaluation, and treatment (DET) of cardiovascular disease (CVD) in order to describe the ecology.
3. THE ECOLOGY OF CARDIOVASCULAR RISK

“Essentially, all models are wrong, but some are useful.”

--George Box (1987; p 424)

3.1. Cardiovascular Disease

Cardiovascular disease (CVD) is an umbrella term for diseases related to the heart and vasculature (Mendis, Puska, & Norrving, 2011). Some examples of common cardiovascular diseases include coronary heart disease (CHD), myocardial infarction, coronary insufficiency, angina, ischemic stroke, hemorrhagic stroke, transient ischemic attack, peripheral artery disease, intermittent claudication, heart failure, ischemic heart disease, coronary artery disease, and cerebral vascular disease (also abbreviated to CVD).

There are many factors that contribute to cardiovascular disease. These include biochemical factors, sometimes referred to as clinical indicators (e.g., c-reactive protein, high density lipoproteins [HDL], low density lipoproteins [LDL]), hemodynamics (e.g., systolic blood pressure), hereditary factors (e.g., family history of CVD), and personal lifestyle factors (e.g., eating habits, alcohol/tobacco use, Body Mass Index [BMI]).

The list of risk factors is much longer than what we have just identified here, but when designing a visual display to aid medical decision-making, there is a question of how many risk factors must be accounted for to make adequate
decisions about diagnosis and treatment. Designers must make a decision about how much data will be represented and how integrated that data will be. For instance, if values for every single risk factor for cardiovascular risk were presented in a display, it could easily overwhelm the user (and be prohibitively expensive to obtain via laboratory tests). On the other hand, integrating all the data into a single easy-to-read piece of information (e.g., healthy/unhealthy) could mean that domain has been oversimplified to the point that the user will fail when dealing with abnormal cases. Mathematical models are one way of accomplishing the reduction in the system’s complexity by focusing on the risk factors that are the most informative. Having a model to work from seemed like an excellent place to begin to understand the domain and became our entry point into the creative process.

3.2. Cardiovascular Disease Risk

3.2.1. Risk Types and Studies

There are two main classes of risk used in the medical literature, both of which are products of their respective research methods and analysis techniques. The first type is relative risk which is the probability of contracting/developing/experiencing some health related event relative to exposure. The outcome of a relative risk study is a ratio of the probability of the event occurring in the exposed sample to that of a control sample. For example, a relative risk study might produce a quantitative estimation of how much more likely smokers are likely to develop CVD than non-smokers.
The benefit of these types of studies is that they are, relatively speaking, easy
to conduct. However, the down side is that the risk factors identified from relative
risk studies do not lend themselves to integration with more sophisticated risk
models. Without these more sophisticated and comprehensive studies that can
simultaneously account for multiple factors and their interactions, it is difficult to
know how multiple factors might work in concert with each other to influence risk.
Fortunately, a number of these more sophisticated studies, large-scale
epidemiological studies with thousands of participants providing information on
many factors over the course of years and decades, have been conducted.

The second class of risk is absolute risk or the absolute percentage of risk for
experiencing an event given certain parameters. In the domain of CVD risk, one of
the most accepted and used definitions of general cardiovascular risk is the
probability of experiencing a cardiovascular event within the next 10-years
(D’Agostino, Vasan, Pencina, et al., 2008; Ridker, et al., 2007, 2008). The benefit of
using absolute risk is that the models used to derive risk from the various risk
factors can be used to reduce some of the system’s complexity and provide a
framework for understanding the domain.

Some of the epidemiological studies that have led to models of absolute risk
for CVD include the Prospective Cardiovascular Münster Heart Study with German
citizens (PROCAM; Assmann, Cullen, & Schulte, 2002), CUORE project with Italians
(Ferrario, Chiodini, Chambless, Cesana, Vanuzzo, Sega, et al., 2005), the Beijing
Cohort (Zhang, Attia, D’Este, Yu, & Wu, 2005), and the World Health Organization’s
MONICA project (multinational monitoring of trends and determinants in
cardiovascular disease) which included 38 populations from 21 countries (Evans, Tolonene, Hense, Ferrario, Sans & Kuulasmaa, 2001). Although each study differs from the others (and therefore leading to different CVD risk models), many risk factors are shared across models (see Table 1). As could be guessed, having multiple models is an indication of disagreement of which model is more accurate, and by extension, which risk factors to use.

### Table 1  Top CVD Risk Factors as Identified in Six Epidemiological Studies

<table>
<thead>
<tr>
<th>Research Study/Model</th>
<th>FHS</th>
<th>Reynolds</th>
<th>Beijing</th>
<th>MONICA</th>
<th>CUORE</th>
<th>PROCAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Total Cholesterol (TC)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Low-density lipoprotein (LDL)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>High-density lipoprotein (HDL)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Triglycerides</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Systolic Blood Pressure (SBP)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diabetes Mellitus (DM)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Antihypertensive Medication Use</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Smoker</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Body Mass Index (BMI)</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hemoglobin A1c (HBA1c)</td>
<td>X</td>
<td></td>
<td>(If DM)‡</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Family CVD History (FHx)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>High Sensitivity C-Reactive Protein (hsCRP)</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note.* X BMI replaces the biochemistry levels in a simplified Framingham Risk Model

‡ The initial all-female cohort used HBA1c as a covariate, but the all-male cohort did not. HBA1c has been subsequently removed from the risk calculation for both men and women.

### 3.2.2. Disease Risk Models

In the United States, there are two main competing risk models for CVD. The first model, the Framingham risk model, is derived from the Framingham Heart Study (D'Agostino, Ramachandran, Pencina, Wolf, Cobain, Massaro, et al., 2008), which has led to more than 1200 research articles (Framingham Heart Study, 2011) and is one of the most widely cited epidemiological studies. The Framingham risk model is commonly used as a comparison for other epidemiological studies and risk

However, the competing Reynolds risk model has demonstrated that it can more accurately classify patients into respective risk categories (e.g., <10%, 10-20%, >20% risk) than the Framingham model. The differences in reclassification are not trivial or mildly incremental; some patients would be reclassified to highest risk in the Reynolds risk model from lowest risk in the Framingham risk model and vice versa. The reclassification would have a tremendous impact on treatment.

In spite of the apparent superiority of the Reynolds risk model over the Framingham risk model, there are two factors against using it as a model for our graphical display. First, the Framingham risk model only requires the information obtained through the commonly ordered lipid panel test whereas the Reynolds risk model requires the high sensitivity c-reactive protein (CRP) level in addition to the lipid panel. The fact that a second test must be ordered in order to use this model makes it more difficult and expensive to implement in a clinical setting. However, the primary reason for not using the Reynolds risk model is that the Framingham risk model has found greater acceptance among experts, including its adoption for use in 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; National Heart, Lung, and Blood Institute, 2001).

The ATP-III report and guidelines have been based on a review of over 1100 scientific sources by leading experts in the field of cholesterol management/CVD risk and is sponsored by the National Heart Lung and Blood Institute (NHLBI; part
of the US Department of Health and Human Services [DHHS] and US National Institute of Health[NIH]). This report has established a number of guidelines for the treatment of hyperlipidemia. Given the preference by experts for the Framingham risk model and due to its incorporation into the ATP-III, it would seem to be a better source for understanding the domain until additional medical research can establish a different model that is clearly superior and has broader consensus.

3.3. Mapping the Ecology to the Display: Creating the Graphical Display Elements

3.3.1. The Framingham Risk Model and its Representation

By adopting the Framingham risk model as the model for the basis for our work, the factors that we must consider are patient sex, age, total cholesterol level, high-density lipoprotein level, systolic blood pressure, whether the patient is taking medication for controlling their blood pressure, smoking status, and whether the patient has diabetes mellitus. However, simply knowing which factors are relevant does not constitute a useful risk model.

What exactly is the Framingham risk model? The general cardiovascular risk model, as calculated from the Framingham risk model, is a mathematical model that is based on the Cox proportional hazards model (Cox, 1972), which is a multiple regression technique. This model is typically used in the healthcare domain for calculating expectancies of contracting, developing, or experiencing various healthcare problems or mortality within a specified window of time (usually 10 years for CVD risk models). The Framingham risk model is noted as:
\[
\hat{p} = 1 - s_0(10) e^{(\sum_{i=1}^{p} \beta_i X_i - \sum_{i=1}^{p} \beta_i \bar{X}_i)}
\]

Figure 6 The Cox Proportional Hazards Model

In Figure 6, the probability of experiencing a cardiovascular event within a certain time frame (e.g., 10 years) is noted as \(\hat{p}\). The baseline survival rate, or percent of those who have not experienced a CVD event within 10 years, is denoted as \(s_0(10)\). The variable \(X\) represents the individual’s score on some risk factor \(I\) and \(\bar{X}\) is the population mean for risk factor \(i\). The \(\beta\)s are the regression coefficients associated with each of the risk factors (see Table 2).

<table>
<thead>
<tr>
<th>Formula Component</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correlation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural Log of:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>3.061</td>
<td>2.329</td>
</tr>
<tr>
<td>Total</td>
<td>1.124</td>
<td>1.209</td>
</tr>
<tr>
<td>HDL</td>
<td>-0.933</td>
<td>-0.708</td>
</tr>
<tr>
<td>SBP (if not treated)</td>
<td>1.933</td>
<td>2.761</td>
</tr>
<tr>
<td>SBP if treated</td>
<td>1.999</td>
<td>2.823</td>
</tr>
<tr>
<td>Smoking</td>
<td>0.655</td>
<td>0.529</td>
</tr>
<tr>
<td>Diabetes</td>
<td>0.574</td>
<td>0.692</td>
</tr>
<tr>
<td>Baseline Survival (S_0(t))</td>
<td>0.88936</td>
<td>0.95012</td>
</tr>
<tr>
<td>Summed Means (\sum\beta \bar{X})</td>
<td>23.9802</td>
<td>26.1931</td>
</tr>
</tbody>
</table>

In that both the baseline survival rate and \(e\) are constants, the primary drivers for the risk are expressions in the exponential function in Figure 7 or difference score.
Risk is based on the difference between the sum of an individual’s scores (multiplied by associated regression coefficients) and the sum of the mean scores (also multiplied by the respective coefficients). If there is no difference between these two summed products, then the sum of the product containing the observed values is equal to the sum of the product containing the population means. In other words, the difference score represents how different an individual is from the population mean in terms of risk.

3.3.1.1. **A Note on Language.**

The language of risk and risk factors can be hard to follow, so care must be taken when reading and thinking about them. For instance, if a patient is unhealthy, they will have a difference score that is positive. Usually, the word positive carries a good connotation, but this is not the case. When a difference is positive, it is negative, or detrimental, in the sense that it means that the patient has a higher than average risk score. A negative difference is positive, or beneficial, in that it means the patient has a good risk score.

Also relevant to this discussion on language is with the term risk factor. Colloquially, risk factor carries a connotation of bad or something that increases risk. However, a risk factor, as used in this document, refers to any factor that was included in the ATP-III model, regardless of whether it has a negative or positive
regression coefficient. Consider that HDL has a negative regression coefficient (see Table 2), which one might expect to reduce risk. However, this is not always the case. Sometimes the risk factors that one might consider to be detrimental or beneficial have the opposite effect. The reason becomes more clear when Figure 7 is rewritten as:

$$\sum_{i=1}^{p} (\beta_i X_i - \beta_i \bar{X}_i)$$

Figure 8 Rearranged Difference Score from the Cox Model

Although the sum of the differences of $X$ and $\bar{X}$ (multiplied by their respective coefficients) is mathematically equivalent to the difference between the sum of all $X$s and sum of all $\bar{X}$s (also multiplied by their respective coefficients), Figure 8 allows one to calculate the unique contribution of each factor in the risk model. Due to the fact that this expression is a comparison between an observed value from the patient and the population mean, how much a risk factor influences risk is a function of whether the observed value is greater than or less than its respective mean. With this information, a contribution graph can be constructed to illustrate which factors are the primary drivers of risk for a particular patient, which is the main purpose for rewriting the Figure 7 expression in this manner. The benefit of determining the unique contributions is that physicians can now be provided with a means of quantitatively evaluating the severity of each risk factor in order to better support treatment decisions.
Consider the patient in Table 3. The extent to which each factor influences risk is not immediately clear. For example, which risk factor is the most important to address first? Does that risk factor increase 10-year risk the most? Is it worse to have total cholesterol at 254 mg/dL, an LDL cholesterol level of 173 mg/dL, or a systolic blood pressure of 138? We believed that our graphical representation of the Framingham risk model could help with this problem (see Figure 9).
3.3.2. Graphical Representation of the Framingham Risk Model

The graphical representation for the Framingham risk model consists of two major components (see Figure 9). The bottom half of Figure 9 is a contribution bar graph based on the differences in observed scores from their respective means as described earlier in Figure 8 (i.e., their unique contribution). The x-axis (ranging...
from -2.0 to 3.5 demarcated in increments of 0.5 units) is shared between the top and bottom halves of this graph. This number line represents the range of possible difference scores as calculated from the expression in Figure 8. There are two contribution bars in the display. The bottom bar represents the (summed) contribution of all risk factors that increase 10-year risk, while the top bar represents the (summed) contribution of all risk factors that decrease 10-year risk for the patient. Arrows serve to guide to the direction to which the bar is extending. In Figure 9, age, total cholesterol, HDL, and systolic blood pressure increase risk while smoking status decreases it.

Due to biological range restrictions (e.g., no person will have a blood pressure of 500 mmHg or a total serum cholesterol level of 0) and to the fact that continuous variables (i.e., everything but smoking status and whether the patient is a diabetic) have been transformed using the natural log, the difference of the sum of weighted patient scores and the sum of weighted population means will rarely be more than 3.5 or less than -2. These values set the range of the graph's horizontal axes.

The top half of Figure 9 contains a graphical representation of the Cox proportional hazard function that has been aligned to the Framingham model parameters. The y-axis of the Cartesian plane is divided into three areas using three colors. The coloring scheme follows the traditional convention of green, yellow, and red to indicate good, warning, and bad, respectively. More specifically, these areas and colors map onto a treatment options matrix (derived from the ATP-III guidelines) that will be discussed shortly. For now, it should be sufficient to say that
the risk levels used for the treatment option table are broken into three categories of risk: less than 10% (green), 10-20% (yellow), and greater than 20% (red). The patient’s 10-year risk value is plotted along the curve as a function of the difference score mentioned earlier in Figure 8. We have drawn a line from the difference point, to the curve, and to the patient’s risk score. We also project a horizontal line from this point that reaches beyond this component to the treatment option matrix.

The purpose of an ecological or semantically mapped graph is to tie the domain to the display, so that the domain is more transparent to the observer. This graph has attempted to achieve this goal by showing how much each factor contributes to the patient’s risk. Additionally, it demonstrates that risk is a curvilinear function, which explains in part why sometimes risk factors with large regression coefficients may only raise the patient’s risk a trivial amount. By now, it is hoped that the concept of mapping graphical features to the domain should be clear to the reader. Now that a model allowing for the calculation of risk based on a number of risk factors has been represented graphically, the next step is to map them to the diagnosis and treatment process. The next section will focus on this mapping between the model and the treatment options for both cholesterol and blood pressure.

3.3.3. Treatment Options and their Representations

3.3.3.1. Treatment Options

This research is aimed at developing an aid for physicians and patients to gain a better understanding of a patient’s CVD risk and allow them to make
treatment decisions that use the guidelines as a basis. In treating a patient at risk for CVD, each risk factor is important to address. We have chosen to address two of these components in our display. The first is hyperlipidemia, or elevated lipid levels, as a way of preventing atherosclerosis (a precondition of CVD). Hypertension is the other component that we focused on, primarily due to its prevalence and convenient access to relevant data. Obtaining a blood pressure from a patient is a standard part of providing care, and given that it is a required part of the Framingham risk model, there would always be blood pressure data available without the expense of additional lab tests (as in the case of the c-reactive protein).

We have already briefly mentioned the ATP-III guidelines for treating hyperlipidemia. Hypertension also has its own set of treatment guidelines as put forth in the Seventh Report on the Joint National Committee on Prevention, Detection, Evaluations, and Treatment of High Blood Pressure (JNC-7; Chobanion et al., 2003). Both the ATP-III and JNC-7 guidelines from these reports create constraints in the detection, evaluation, and treatment (DET) processes for physicians. As constraints, these guidelines are important to incorporate into a graphical display intended to aid providers in the DET process.

*The ATP-III Treatment Options Matrix.*

Although, the ATP-III explicitly states that it should not be considered a standard of care (p I-2), it is likely the most comprehensive document on the topic and is referenced frequently in the literature. As such, the ATP-III guidelines serve as an excellent model for understanding the diagnosis and treatment process for hyperlipidemia.
The relationship between hyperlipidemia, atherosclerosis, and CVD stresses the importance of the use of the lipid panel to screen for abnormal values in order to treat dyslipidemia as the primary means of preventing CVD. Accordingly, the ATP-III guidelines give LDL cholesterol the preeminent position in the treatment process, where it is the primary target for reduction.

Curiously enough, it should be recalled that LDL is not included in the Framingham risk model as a risk factor (although it is counted indirectly in obtained “Total Cholesterol” value), in spite of its role in the treatment process. According to the ATP-III guidelines, LDL is the primary target for cholesterol reduction for treating hyperlipidemia. The second factor used to determine treatment for hyperlipidemia is the 10-year risk as calculated from the Framingham risk model. The ATP-III guidelines suggest treatments for the various combinations of LDL and 10-year Risk levels. The treatment options include Therapeutic Lifestyle Changes (TLC; such as avoiding certain foods and increasing physical activity), as well as the Drug Therapy (DT) treatment option. No Treatment (NT) is a third option if the patient is healthy enough. These guidelines can be seen in Table 4. We have taken these guidelines and created a graphical interpretation, which we call the treatment option matrix (TOM; see Figure 10).
The purpose of the TOM is to help the viewer visualize the treatment option space. The red area represents the space where DT is recommended by the ATP-III guidelines, while the yellow area represent the TLC recommendation. The green area represents the NT space. This display contains a very explicit mapping from the guideline data to the treatment options. Finding the recommended treatment in the TOM is a matter of plotting a point using a two-dimensional Cartesian coordinate system, where LDL level and 10-year risk are the respective abscissa and ordinate. When the TOM is integrated fully into the ecological display, we include visible lines that project from the axes to meet at the specified coordinates.

<table>
<thead>
<tr>
<th>Risk Category</th>
<th>LDL Goal</th>
<th>LDL level to initiate Therapeutic Lifestyle Change (TLC)</th>
<th>LDL level to initiate Drug Therapy (DT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHD or CHD Risk equivalent</td>
<td>&lt;100 mg/dL</td>
<td>≥ 100 mg/dL</td>
<td>≥ 130 mg/dL</td>
</tr>
<tr>
<td>2+ Risk Factors</td>
<td>&lt;130 mg/dL</td>
<td>≥ 130 mg/dL</td>
<td>10-year risk 10-20%: ≥ 130 mg/dL</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10-year risk &lt;10%: ≥ 160 mg/dL</td>
</tr>
<tr>
<td>0-1 Risk Factor</td>
<td>&lt;160 mg/dL</td>
<td>≥ 160 mg/dL</td>
<td>≥ 190 mg/dL (160-189 mg/dL: LDL lowering drug optional)</td>
</tr>
</tbody>
</table>
The JNC-7 Bar Graph.

The Seventh Report on the Joint National Committee on Prevention, Detection, Evaluations, and Treatment of High Blood Pressure provides guidelines for treating hypertension. However, these guidelines are much simpler than the multidimensional guidelines used in the ATP-III for cholesterol. The JNC-7 guidelines consider hypertension a condition of either elevated systolic or diastolic blood pressure (SBP and DBP respectively). The specific guidelines for classification can be found in Table 5.
<table>
<thead>
<tr>
<th>BP Classification</th>
<th>SBP (mmHg)</th>
<th>DBP (mmHg)</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>&lt;120</td>
<td>and &lt;80</td>
<td>NT</td>
</tr>
<tr>
<td>Prehypertension</td>
<td>120-139</td>
<td>or 80-89</td>
<td>TLC</td>
</tr>
<tr>
<td>Stage 1 Hypertension</td>
<td>140-159</td>
<td>or 90-99</td>
<td>DT</td>
</tr>
<tr>
<td>Stage 2 Hypertension</td>
<td>≥ 160</td>
<td>or ≥ 100</td>
<td>DT</td>
</tr>
</tbody>
</table>

The information contained in Table 5 lends itself easily to the creation of two number lines in an ecological display for systolic and diastolic blood pressure respectively. A number-line/bar-graph hybrid (known simply as the JNC-7 bar graph) was created for representing blood pressure and can be seen in Figure 11. Treatment for elevated blood pressure is somewhat similar to that of hyperlipidemia in that treatment options are comprised of NT, TLC, and DT. The green area (labeled “good”) in Figure 11 has the recommendation of NT. The yellow area (labeled “pre” for pre-hypertension) has the recommendation of TLC. The areas labeled “Stage 1” and “Stage 2” (the orange and red areas respectively) refer to degrees of hypertension and both have the recommendation of DT. It is recommended that although both should be considered with DT, those in Stage 1 should begin their DT regimen with a single blood pressure reducing drug, while those in Stage 2 should begin their initial regimen with two or more drugs.
Figure 11 The JNC-7 Bar Graph.
3.4. **Mapping the Ecology to the Display: Assembling the Graphical Elements**

We hired a software developer to help us create a prototype of the ecological display. This prototype included the Framingham model and contribution bar chart, the TOM, and the JNC-7 bar graph. We also added a number line display (see Figure 12) as a means to enter and change patient data in the system (we did not have a real database of patient data to draw upon).

The number line format consisted of number line representations of some continuous data (e.g., age, total cholesterol, etc.) as well as some dichotomous variables such as whether the patient had an existing heart disease or equivalent (ExstHD). Some variables are dichotomous by nature (e.g., Is there a family history of CHD?; FamHx). Others were (or could have been) continuous variables that were treated dichotomously by the model (e.g., was the waist circumference greater than 40 inches [>40in] or fasting blood glucose greater than 110mg/dL [>110mg]). These dichotomous variables were created as sliding buttons, such that the white portion of the button indicated the selection (e.g., a white box surrounding the “N” indicates that the patient does not meet the criteria).

The color disruptions along each number line correspond to different severity categorizations for each respective risk factor. The boundary for the factor “Age” at 45 does not come from any published research, but is simply the point at
which age begins to have a detrimental effect on 10-year risk according to the Framingham risk model.

The blue-ish box in the top left corner of Figure 12 is a button intended to switch between male and female models (M/F), but this functionality was not complete at the time of the study and was therefore ignored. The implication for this was that all of our stimuli were males.

The colored boxes and arrows for some of the risk factors correspond to the colors used for risk factors elsewhere in the ecological display. The colors serve as a sort of legend for distinguishing among the various risk factors. For instance, the dark brown color of diabetes in the number line interface is the same as the color used to denote the unique contribution of diabetes in the contribution bar chart.

When all of the graphical components come together, they form the entire ecological display (see Figure 13). This display is what we evaluated in this research.

### 3.5 Summary

This chapter has laid the foundation for understanding the work Ecology of detecting, evaluating, and treating cardiovascular risk and associated diseases. The Framingham risk model provides a list of important risk factors necessary to determine the 10-year risk of experiencing a cardiovascular event for a patient. This model also allows the unique contribution of each risk factor to be calculated, allowing for comparisons about their influence, which in turn, can guide treatment decisions. The ATP-III treatment model allows 10-year risk to be combined with LDL cholesterol level in order to arrive at the recommended treatment for
hyperlipidemia. The JNC-7 treatment model accomplishes the same, but for hypertension. We have attempted to illustrate Meaning by mapping the Ecology to a graphical representation in order to aid physicians and patients to understand this Ecology. The next chapter will discuss how the aims of this display will be evaluated.
Figure 12 The Number Line Format
Figure 13 The Ecological Display
4. STATIC DISPLAY EVALUATION

“If we knew what we were doing it wouldn’t be [called] research.”

--Attributed to Albert Einstein

4.1. Research Overview

4.1.1. Research Plan and Goals

In order to evaluate the ecological display, we decided that the basic research method would entail having participants complete four tasks under what we call the detection, evaluation, and treatment (DET) framework, which was modeled after the implied workflow processes in the ATP-III and JNC-7 guidelines (NHLBI, 2001; Chobanion, 2003). The tasks under the DET framework would require participants to view the data from a number of patient cases in one of multiple display formats and then make decisions and judgments regarding the presence, risk, and treatment of hyperlipidemia and hypertension.

These four tasks were: (1) the concern task to measure participants’ concern level for each patient case, (2) the follow-up task to identify differences in which risk factors were perceived to require follow-up due to display format, (3) the treatment decision task to examine whether the display format would lead participants to select treatment options that were more likely to agree with ATP-III and JNC-7 guidelines, and (4) the ranking task to determine if display types were to
allow participants to more accurately identify the risk factors that increase 10-year CVD risk the most.

4.2. Method

After discussion with some medically trained advisors, we were informed that these tasks would be too difficult for non-medically trained participants. They also informed us that it would take about 6 minutes for participants to complete all four tasks for each patient case and that we were likely to only get about an hour of participation time from each participant. These constraints limited the number of cases we could evaluate. However, some of these advisors were associated with an internal medicine residency program at a local urban hospital and invited us to conduct our research with their residents during one of their weekly training seminars. This provided us the opportunity to collect data from more than 20 medically trained participants over the course of a few hours rather than a single hour.

4.2.1. Participants

Twenty-three residents participated in the study. The mean age was 29.75 years ($SD = 4.22$ years, age range: 25 – 40 years). Twenty-one residents provided us with information regarding their gender. Of those that responded, 57% (12) indicated that they were female. Thirty-nine percent of participants self-identified race as “White,” 13% as “African American,” 34% as “Asian,” 4% as “Other,” and 10% did not respond. None identified as Hispanic or Latino. The mean year in residency was 2.19 years ($SD = 0.8$) of a 3-year program.
Residents were verbally informed by the researchers, as well as their residency program director, that they would not be required to participate in the study and that their individual results would not be shared with hospital faculty. However, the program director did encourage the residents to follow along as part of their educational experience, even if they did not want to submit their responses for research. All residents were provided with the opportunity to enter a drawing for an iPad® as a matter of goodwill and as a way to encourage participation in the study (although participation was not a condition of eligibility for the drawing). All residents entered the drawing for the iPad and all consented to include their results in our research study.

4.2.2. Materials

4.2.2.1. Stimulus Packets

Upon entrance to the seminar room, participants were handed an informed consent form and two packets of 8.5” × 11” inch white paper. The residents were instructed to review and sign the consent form if they wished to participate in the study and were further instructed not to look at either packet until given further notice. The first packet contained the stimulus materials containing the patient cases and the other packet contained the corresponding response forms.

Given our time constraint, we estimated that we would have time for twelve male patient cases. One half of the cases had data presented in the number line format while the other half contained data presented in the ecological display (which also included the number line format). All stimuli packets contained the
same 12 cases. The displays were all printed in color. All cases were male due to the fact that the software used to generate the cases only worked for males at the time. The stimulus presentation order had been randomized prior to administration in order to reduce the probability of patient pairs (to be discussed shortly) appearing sequentially. All packets presented cases in the same order.

Patient Pairs.

Given our intention to compare performance of different display types, and given the relatively few cases and participants, we opted for a repeated measures design. To reduce the potential of participants recognizing the case in the second condition, we created the twelve cases so that each had another similar case in the opposite condition. Each pair was matched in some respects but differed in others (see Table 6). This meant that we altered many of the risk factors of one patient a few points above or below its counterpart. Thus, no patient was exactly the same as another, but was similar enough to one another to allow for some comparisons. The primary factor to which we tried to match cases was the manner in which they should be treated according to the medical guidelines. For example, Patients 1 and 2 were not exactly the same age nor did they have the same systolic blood pressure, but both would likely require drug therapy according to the ATP-III guidelines for treating hyperlipidemia. Pair 3 was the exception to this rule and had different treatments for recommended treatment for systolic blood pressure.
### Table 6 Paired Stimulus Scenarios

<table>
<thead>
<tr>
<th>Pair #</th>
<th>CVD Risk</th>
<th>LDL</th>
<th>SBP</th>
<th>DBP</th>
<th>Context/Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Med</td>
<td>DT</td>
<td>DT</td>
<td>TLC</td>
<td>Patient could quit smoking to drop to NT for cholesterol</td>
</tr>
<tr>
<td>2</td>
<td>Low</td>
<td>NT</td>
<td>TLC</td>
<td>TLC</td>
<td>Patient had enough risk factors to have metabolic syndrome</td>
</tr>
<tr>
<td>3</td>
<td>Low</td>
<td>TLC</td>
<td>NT/TLC</td>
<td>TLC</td>
<td>Although patient has low LDL cholesterol that would not normally require treatment, their diabetes places them into the high risk area and requires TLC</td>
</tr>
<tr>
<td>4</td>
<td>Low</td>
<td>DT</td>
<td>DT</td>
<td>TLC</td>
<td>Patient has many treatment modifying risk factors that suggest TLC for cholesterol instead of NT if fewer factors were present</td>
</tr>
<tr>
<td>5</td>
<td>Med</td>
<td>DT</td>
<td>DT</td>
<td>DT</td>
<td>Patient with relatively good cholesterol levels, yet requires DT</td>
</tr>
<tr>
<td>6</td>
<td>High</td>
<td>TLC</td>
<td>TLC</td>
<td>TLC</td>
<td>Patient whose risk is mostly determined by age</td>
</tr>
</tbody>
</table>

*Note. In Pair 3, the treatment for SBP in the ecological condition is NT and TLC in the number line condition.*

*Response Forms.*

The packet of response forms was 13 pages long—twelve pages for recording responses for each case and one final page for collecting demographic data. An additional space for notes was provided if residents felt that certain decisions needed clarification or justification. A copy of this form may be found in Appendix A.

The next section will provide further details into these tasks and the measures used.
4.2.2.2. Performance Evaluation and Measures

Accuracy vs. Guideline Agreement.

Before we discuss the specific tasks from the response forms and performance measurement, we need to make a distinction between accuracy and guideline agreement. Accuracy is a loaded word—it carries a connotation of a comparison between a response to some objective answer or standard. We did not always have the benefit of a standard or guideline in this research. There were some cases where even though there were standards, there was some flexibility in them. For instance, one physician reported that they were completely confident in the medical decision that they were making for the patient, yet were fairly certain that their decision did not follow the ATP-III and JNC-7 guidelines and that the guideline was wrong for that specific patient.

Although it might be tempting to say that this physician was wrong and that the guidelines should be considered to be the objectively correct answer, it should be noted that both the ATP-III and JNC-7 guidelines both defer to the physician’s clinical judgment in all cases. Thus, instead of using the term accuracy to refer to the extent to which a participant followed the guidelines and possibly give the false impression that one graphical display allows one to make more “accurate” decisions, we will use the term, guideline agreement, to indicate that one display might be able to lead one to make decisions that are more likely to agree with the established guidelines. The difference is subtle, yet extremely important.
4.2.2.3. **The Tasks**

*Concern Task.*

There are many CVD risk factors that can be combined to create high 10-year risk, including cases where many factors appear to be relatively normal. This might lead to a sense that the patient is healthier than they might otherwise be. We wondered if the graphical presentation format of data might influence the impression of a patient’s health and increase or decrease a physician’s sense of concern for that patient.

The level of concern was recorded by having the participants indicate their concern on a 4-point scale found at the top of the response form. The possible answers were: (1) “Not concerned at all, seems to be in good health” (2) “A little concerned, there is some risk present” (3) “Quite concerned, there are several worrisome findings,” or (4) “Very concerned, there are significant worrisome findings.”

We did not have any specific hypotheses to test, but given the various risk levels and treatments that were recommended, we estimated that there would be some ordering to the concern expressed (see Table 7).

<table>
<thead>
<tr>
<th>Table 7 Expected Concern across Patient Pairs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concern</td>
</tr>
<tr>
<td>------------</td>
</tr>
<tr>
<td>Greatest</td>
</tr>
<tr>
<td>Middle</td>
</tr>
<tr>
<td>Least</td>
</tr>
</tbody>
</table>
Follow-Up Task.

The follow-up task required the resident to review a list of risk factors and indicate in a check box whether they felt that the particular risk factor should require some follow-up. The follow-up response was strictly dichotomous—either the factor was felt to require follow-up or not. Although there could have been many degrees of concern for any of the risk factors, we wanted to use a dichotomy as a means to find the “obvious” differences. This list of items to be considered included: total cholesterol, LDL cholesterol, HDL cholesterol, triglycerides, systolic blood pressure, diastolic blood pressure, diabetes, smoking, obesity, blood sugar, and metabolic syndrome.

With this task, we evaluated the agreement within residents’ responses for follow-up for each risk factor when using the two graphical displays. We compared the responses for each participant and tallied the number of times that the responses across both conditions differed using a sign test or binomial test paradigm. For instance, if a participant chose to follow-up on a risk factor in one graphical condition and not in the other, a tally mark would be made for the corresponding graphical condition. If the responses were similar across both conditions (either both indicated or not), no tally mark was made. The sum of tally marks across all participants was an indication of the agreement between the graphical conditions. A high tally is an indication of low agreement between the graphical displays and suggests that one display format leads to differences in the frequency at which participants endorse follow-up.
With the exception of believing that there would be low agreement for follow-up on metabolic syndrome in patient pair 3 (the only cases which met the metabolic syndrome criteria) due to the pentagonal shape for metabolic syndrome in the ecological display, we did not have a logical means for determining which factors or graphical format would lead to any potential differences.

Treatment Decision Task.

We were interested in determining how residents would choose to treat the various risk factors associated with blood pressure and cholesterol. For this task, participants were given a matrix of risk factors and treatment decisions on the response form and were asked to indicate how they would choose to treat each risk factor by checking the corresponding box. The risk factors included: total cholesterol, LDL, HDL, triglycerides, SBP, DBP, smoking, diabetes, obesity, and blood sugar. The treatment options were: no treatment (NT), therapeutic lifestyle changes (TLC), and drug therapy (DT).

Although we asked about treatment decisions for many risk factors, we only focused on the treatment decisions for LDL cholesterol, SBP, and DBP because they were the only factors for which we had specific treatment guidelines. As with the follow-up task, we were measuring agreement. Guideline agreement was measured similarly as before, but responses within each graphical condition were first compared to the respective guidelines before being compared to the corresponding graphical condition. For example, if a resident chose an answer that did not agree with the guideline when using the number line but chose the answer that agreed with the guideline when using the ecological display, a tally mark was awarded to
the ecological display condition. Low agreement between the graphical conditions indicates that residents chose a particular treatment more frequently in one condition than the other and that the response was in agreement with the corresponding guideline. In other words, one graphical condition had greater guideline agreement.

Given the fact that we created the ecological display to help users to visually make the connection between the data and the guidelines, we hypothesized that the ecological display condition would lead to greater guideline agreement for LDL, SBP, and SBP.

*Ranking Task.*

One difficulty of an alphanumeric table or number line is that it is difficult to tell which risk factor has the greatest influence on a patient’s risk or, in other words, which is the most important to treat. The six factors identified in the Framingham model (i.e., total cholesterol, HDL, systolic blood pressure, age, and smoking status) were presented for each patient on the response form. The residents were asked to rank the risk factors for that specific patient case in terms of their severity as specified by the product of the risk factor level and its regression coefficient from the Framingham model.

Given the many risk factors that influence risk, we were interested in not only whether residents were able to more accurately identify the top risk factor but whether they could identify the top two and top three risk factors as well, regardless of order. The rationale was that a physician might be able to identify the top risk factors, but not necessarily in the precise order.
The top two and top three risk factor components were scored such that the precise order was irrelevant as long as the factors were included in the grouping. For example, if the top three risk factors were HDL, LDL, and Age and a resident ranked them as HDL, Age, and LDL, they would have correctly identified the top risk factor, but not the top two risk factors. However, the resident would still have correctly identified the top three risk factors. In theory, the task gets easier as more factors are added because the list of factors grows and order becomes less important.

We believed that because the ecological display provides the unique contribution of each factor in the display (i.e., the contribution bar chart), we hypothesized we would find that more residents would correctly identify the top risk factors when using the ecological display. For this measure, we simply used the count of participants who correctly identified the factors at each of the levels (i.e., the top, top two, and top three factors) rather than making agreement comparisons as with the other tasks.

4.2.2.4. Procedure

The study was conducted during the residents’ weekly seminar forum, which took place in a small auditorium-style classroom (seating capacity approximately 40) of a local urban hospital. After having been introduced by the resident program director, we used a PowerPoint presentation projected from an overhead projector to introduce the EID display to the participants and explained the task instructions by reading aloud from a script (see Appendix B). In the instructions, we asked the residents to work as quickly and accurately as possible, but noted that accuracy was
more important than finishing all cases. After the instructions, we allowed the residents additional time to review and sign the informed consent. Residents were also informed that they were free to leave at the conclusion of the study, but that we would have a presentation about ecological displays and data visualization at the conclusion of the study for those interested.

Once all residents had indicated that they were ready to begin, we instructed them to turn over the stimuli and response packets and begin the study. The study was self-paced, with an upper limit of three hours for completion. All residents finished all cases within 1 hour and 45 minutes.

### 4.3. Results

#### 4.3.1. Concern

The distribution of concern levels for each case is located within the table found in Error! Reference source not found. The mode of all concern levels for all cases was 2 (i.e., “A little concerned, there is some risk present”) with the exception of pair 5 (cases 9 & 10) which had a mode of 3 (i.e., “Quite concerned, there are several worrisome findings”). We believed that Pair 5 would be one of the Pairs with the highest levels of concern. This was the case, but we were surprised that Pair 5 only had a mode of 3. In fact, all of the scores seemed to be lower than we thought, particularly in light of the fact that nearly all cases were designed to require treatment. It would appear that with the exception of pair 5 having a mode of 3, there did not appear to be any meaningful differences in concern between display types or between patient cases.
Figure 14 Expressed Concern Levels Across Patient Pairs

### 4.3.2. Follow-Up

Other than metabolic agreement for metabolic syndrome for pair 3, we did not have any specific hypotheses to test with the follow-up task; we were simply interested in determining whether participants responded differently between the display types.

In the sign test paradigm, “successes” (x) are the number of times an event occurs in one condition but not in the other. In our case, a "success" represented the
event of a resident having chosen to follow-up using only the ecological display. The number of trials \( n \) represents the number of events that resulted in a tie or where a resident chose to follow-up (or not) in both conditions. As the number of ties increase, the trial size shrinks for each comparison. If there are many “successes” or “failures” (i.e., where follow-up was indicated only with the number line), then there is little agreement between the two displays and one display is more likely to have been used to indicate follow-up.

We used a two-tailed sign test (assuming a probability of 0.5) to calculate the agreement between the two displays. The fraction-like numbers in Table 8 represent this relationship with the number of follow-up indications with only the ecological display (i.e., “successes”) on the left and number of trials the right of the slash. The exact calculated probabilities are located beneath each fraction.

Due to the many instances where \( n \) was low (e.g., less than 6) or where \( x \) was approximately half of \( n \) (e.g., 4/8), we only performed seven binomial tests. Of the seven tests, five proved to be significant. However, of the five significant differences, two for Pair 3 should be discounted because they reflect differences in the TC and Triglyceride levels between the associated cases (i.e., higher values in one format) rather than differences due to graphical display.
<table>
<thead>
<tr>
<th>Pair</th>
<th>TC</th>
<th>LDL</th>
<th>HDL</th>
<th>Trig</th>
<th>SBP</th>
<th>DBP</th>
<th>DM</th>
<th>Smk</th>
<th>Obes</th>
<th>BS</th>
<th>MS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5/7</td>
<td>4/6</td>
<td>0/0</td>
<td>0/0</td>
<td>1/2</td>
<td>0/2</td>
<td>0/0</td>
<td>2/3</td>
<td>0/1</td>
<td>1/1</td>
<td>0/1</td>
</tr>
<tr>
<td>2</td>
<td>1/4</td>
<td>1/4</td>
<td>1/8</td>
<td>0/4</td>
<td>4/7</td>
<td>4/7</td>
<td>1/2</td>
<td>0/0</td>
<td>0/0</td>
<td>1/5</td>
<td>12/12</td>
</tr>
<tr>
<td></td>
<td>--</td>
<td>--</td>
<td>0.07</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>3</td>
<td>8/9</td>
<td>1/1</td>
<td>0/1</td>
<td>9/10</td>
<td>0/2</td>
<td>0/2</td>
<td>1/2</td>
<td>1/2</td>
<td>0/0</td>
<td>1/4</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>0.04*</td>
<td>--</td>
<td>--</td>
<td>.02*</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>2/2</td>
<td>0/1</td>
<td>3/4</td>
<td>0/0</td>
<td>6/6</td>
<td>7/9</td>
<td>0/0</td>
<td>0/1</td>
<td>0/0</td>
<td>0/0</td>
<td>2/2</td>
</tr>
<tr>
<td></td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>.03*</td>
<td>.18</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>5</td>
<td>1/4</td>
<td>1/2</td>
<td>0/2</td>
<td>0/0</td>
<td>0/2</td>
<td>0/6</td>
<td>1/1</td>
<td>1/1</td>
<td>3/3</td>
<td>2/2</td>
<td>4/5</td>
</tr>
<tr>
<td></td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>6</td>
<td>4/7</td>
<td>5/7</td>
<td>2/3</td>
<td>1/2</td>
<td>4/6</td>
<td>4/6</td>
<td>0/1</td>
<td>0/1</td>
<td>2/3</td>
<td>3/4</td>
<td>1/2</td>
</tr>
<tr>
<td></td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

**Note:** The top row of each Pair is a pair of numbers divided by a slash; the number to the left is the number of "successes" (i.e., x) and the number to the right is the number of trials (i.e., n). The number on the bottom row for each pair is the probability of achieving x or more successes out of n trials. The slightly greyed exact probabilities are the values that cannot be explained by differences in the cases.

There was low agreement for Pair 2 on HDL, where more residents chose to endorse follow-up while using the number line display, but this difference only approached significance \((p = .07, \text{two-tailed})\). However the primary finding for Pair 2 is the low agreement for follow-up on metabolic syndrome, where residents were significantly more likely to only follow-up when using the ecological format \((p = .0004)\). This is not surprising given that the ecological display makes a point to highlight this syndrome with red text and a pentagon shape while the number line does not share such features.

More residents chose to follow-up only on SBP using the ecological display for Pair 4 \((p = .03)\), but we are unsure of the reason for this. More residents only
chose to follow-up on DBP using the number line display for Pair 5 \( (p = .03) \), but we are also unsure of the reason for this.

Over all, performance was rather similar for follow-up between the display types. This similarity is reflected in low number of meaningful significant differences and in the fact that of the 66 potential tests (6 cases \( \times \) 11 risk factors), there were only three instances where \( n \) was greater than 9. In other words, only about 5% of the comparisons had 9 or more participants chose different answers between graphical conditions.

### 4.3.3. Guideline Agreement

When reviewing the data, we noted that many participants chose to indicate both TLC and DT for some patients. Given the fact that the medical guidelines always recommend prescribing TLC along with DT, we coded these instances strictly as DT. We hypothesized that the ecological display would lead to greater agreement with the ATP-III and JNC-7 guidelines. We used a one-tailed binomial test (assuming a probability of 0.5) to test the difference between the number of cases where participants only chose to agree with the guidelines with the ecological display for each patient pair. Table 9 contains the results for each test. There were only six significant differences and all of them favored the ecological format. However, two of the significant differences (SBP and DBP for Pair 3) were an artifact of the different risk level values, rather than due to the display (i.e., the blood pressures were borderline for one condition and not the other). Twenty-two percent of all binomial tests resulted in support for our hypothesis that the ecological display would lead to greater guideline agreement.
Table 9  Guideline Agreement for the Ecological Display by Patient Pair

<table>
<thead>
<tr>
<th>Pair</th>
<th>LDL k/n</th>
<th>p(X ≥ k)</th>
<th>SBP k/n</th>
<th>p(X ≥ k)</th>
<th>DBP k/n</th>
<th>p(X ≥ k)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10/12</td>
<td>0.02*</td>
<td>4/7</td>
<td>0.50</td>
<td>3/7</td>
<td>0.77</td>
</tr>
<tr>
<td>2</td>
<td>7/8</td>
<td>0.04*</td>
<td>3/6</td>
<td>0.66</td>
<td>2/5</td>
<td>0.81</td>
</tr>
<tr>
<td>3</td>
<td>4/7</td>
<td>0.5</td>
<td>14/14</td>
<td>0.001**</td>
<td>14/15</td>
<td>0.001**</td>
</tr>
<tr>
<td>4</td>
<td>7/7</td>
<td>0.007**</td>
<td>3/5</td>
<td>0.5</td>
<td>4/7</td>
<td>0.5</td>
</tr>
<tr>
<td>5</td>
<td>5/6</td>
<td>0.11</td>
<td>0/1</td>
<td>1</td>
<td>0/3</td>
<td>0.125</td>
</tr>
<tr>
<td>6</td>
<td>4/6</td>
<td>0.35</td>
<td>6/6</td>
<td>0.02*</td>
<td>4/6</td>
<td>0.34</td>
</tr>
</tbody>
</table>

4.3.4. Ranking

We created six graphs to examine any patterns that might have emerged in the ranking responses (see Figure 15, Figure 16, Figure 17, Figure 18, Figure 19, & Figure 20). These graphs plot the number of residents who correctly identify the top one, top two, and top three risk factors that increase 10-year CVD risk for the corresponding patient case in each Pair. For instance, in Figure 15, twenty-one residents identified the top risk factor using the number line display and 18 identified the top factor when using the ecological display. Fourteen residents then identified the top two risk factors (in any either order) and 15 identified the top three risk factors (in any order) when using the number line format. The implication of these results would suggest that the top risk factor was easy to identify using the number line display but the second and third risk factors were more difficult to identify.

On the other hand, when using the ecological display, most residents identified the top risk factor (although fewer than when using the number line), but confused the second most detrimental risk factor with the third most detrimental
risk factor. This is likely because it is easier to identify the top risk factors in general than it is to identify the specific order of those risk factors.

As a whole, these results provide insight into the difficulty of identifying the top risk factors regardless of display type. Only in two Pairs (1 & 3) did more than 15 residents correctly identify the top risk factor. The other four Pairs tended to have identification rates less than 60% for identifying the top risk factor.

Sometimes residents were able to identify the top (one-, two-, or three) risk factors more easily when using the ecological display and sometimes it was more difficult. We are not sure why these results are so conflicting, particularly in case of the ecological display, which provides users with a graphical means to evaluate the influence of each risk factor.

![Figure 15 Number of Correct Identifications by Number of Factors and Display Type for Patient Pair 1](image-url)
Figure 16 Number of Correct Identifications by Number of Factors and Display Type for Patient Pair 2

Figure 17 Number of Correct Identifications by Number of Factors and Display Type for Patient Pair 3
Figure 18 Number of Correct Identifications by Number of Factors and Display Type for Patient Pair 4

Figure 19 Number of Correct Identifications by Number of Factors and Display Type for Patient Pair 5
4.4. Discussion

With the exception of guideline agreement, our results were not what we had expected. We imagined that there would be greater levels of concern expressed for these patients than what was indicated, particularly in the cases of patients with 10-year risk levels of 20% or more or those who should be on drug therapies for both hypertension and hyperlipidemia. Perhaps we needed a scale with a greater range to capture some of the nuances that we may not have been able to capture, such as possible interactions of risk levels and treatment options.

In terms of follow-up, although we had no formal hypotheses, it was no surprise to find that more residents endorsed follow-up on metabolic syndrome for Pair 3, particularly for the fact that the ecological display practically spells out this syndrome for the user and the number line does not. Given that Pair 3 was the only Pair that had cases with metabolic syndrome, we would like to try and replicate this finding in future research. This would particularly be important because these
results might be spurious in the same way that we suspect that the other two significant differences might be, given that we do not have a ready explanation for them like we do for metabolic syndrome. Further research is certainly needed to determine if these are real or spurious differences and why they occur or not.

We also found support for the ecological display as a means to increase guideline agreement. Not every test proved to provide a significant difference between the two formats, but every significant difference supported the ecological display.

The ranking task results were also surprising in that so few residents could correctly identify the top risk factors in any order. Even with the contribution bar chart in the ecological display to provide the correct answers, many failed to identify the correct factors. The pattern of correct identifications was not even consistent among cases or Pairs. We are not sure what to make of these results and should be the subject of future research.

We believe that there are at least three factors that influenced the results. First, we believe that our participants may not have had enough training or familiarity to take advantage of or trust the ecological display. Given the fact that some answers are given to the user (e.g., metabolic syndrome, the unique contribution of each risk factor), we are not sure why participants failed to utilize these resources. Either way, we believe that more training and familiarity would go a long way to improve performance when using the ecological display.

The second factor is that of the stimulus presentation method for the ecological display. We believe that one of the compelling aspects of the ecological
display is the ability to make changes in the display and see the dynamic changes made in real time. We suspect that the static paper displays did not allow the residents to benefit from these abilities.

The third factor to consider is whether we actually captured the essence of the detection, evaluation, and treatment task for hypertension and hyperlipidemia. Although our medically trained advisors reviewed our tasks, we still may not have been asking the questions that are most meaningful or would allow the ecological display to demonstrate its strengths.

We are aware of a number of limitations with our research and its design. One question we cannot answer is whether either the number line or ecological displays are better than the alphanumeric display. We did not incorporate the alphanumeric display because we estimated that we would not be able to run enough trials with participants to collect a meaningful sample size due to potential time limits with physicians. We chose the number line for two reasons. First, many of our medical advisors believed that anything would be better than the alphanumeric format. Second, using the number line format against the ecological display would allow us to compare a configural display (the ecological display) to a separable display.

Second, all of our participants were evaluated simultaneously and had the cases presented to them in the same order. We could not control for environmental distractions or for any order effects. We initially planned to randomize the case presentation order and meet with participants individually, but when the last minute opportunity arose to conduct the research with 23 participants at one time,
we made as many adjustments to the study as we could, but trade-offs had to be made. In the end we could not control for order effects or environmental distractions, but we benefited from having a larger sample size and more cases to evaluate than we might otherwise would have.

Third, while we believe that insufficient training played a part in some of the responses, there was another issue with the treatment responses. This was that we were not able to differentiate between those who knew the guidelines and disagreed with the treatment and those who did not agree with the guideline because they did not know the guideline recommendation and chose differently.

Given the exploratory nature of this work, we tried to maximize the variation in the cases we presented to our participants, while preserving some aspects, in order to try to come to a sense of which questions might be important. To this end, we created patient pairs. However, due to the number of risk factors and their interactions, small differences (even just a few points) in the risk factors meant that we could not compare cases to each other or control for the various risk factor levels.

However, in spite of the weaknesses, we believe that this study has provided a useful starting place for future research and has provided us with some more refined research questions. As we mentioned, we were concerned about the inability for participants to fully engage with the ecological display in this study, so we chose to follow up with an additional study to compensate.
5. DYNAMIC DISPLAY EVALUATION & USABILITY INTERVIEWS

5.1. Overview

The second part of this dissertation research consists of quantitative and qualitative components. The quantitative component builds on the evaluation of the ecological and number line displays during the previous study by having participants use an interactive version of the ecological display in order to provide users with a better sense of the domain dynamics. The qualitative component included observations and interviews and focused exclusively on the ecological display in order to provide us with a better understanding of potential usability and usefulness issues.

5.2. General Method

5.2.1. Participants

Five participants were involved in this study. Two were faculty physicians with nearly 30 years of experience; one was associated with a department of family medicine and the other was associated with a department of internal medicine. Two participants were completing their residency in a family medicine/psychiatry program; one was a first year resident, the other was a fourth year resident. The
final participant was not a physician, but a registered nurse who had more than 20 years of patient education experience. Ages were not collected. Three participants were female and two were male.

The nurse completed only one patient case during the quantitative evaluation and therefore had her data excluded for that portion. However, she had many valuable insights during the qualitative portion and her data was included there.

Participants were personal contacts of the author or of the medically trained advisors associated with this research and were associated with two Ohio medical schools. Although sampling was primarily a matter of convenience, attempts were made to obtain participants across a range of experience. Seven participants were originally recruited, but two were not able to participate due to scheduling conflicts.

The study and interviews were conducted at each participant’s workplace within a quiet office. Although the doors were closed, we could not eliminate all distractions due to the nature of our participants’ work. We informed all participants that they would have their name entered into a drawing for an iPad® in exchange for their participation.

The Wright State University Institutional Review Board approved this research.

5.3. Part 1: Interactive Ecological Display Evaluation

There were two purposes of the quantitative evaluation. First, we believed that a major benefit of the ecological display was that it would allow the physician to engage in “what-if” experiments with patient data, allowing them to visualize how
changes influenced the recommended treatment. We believed that this ability would increase the frequency of making treatment decisions that agreed with the respective guidelines when using the ecological display. To evaluate this hypothesis, we had our participants complete a simplified version of the DET task used in the previous study. In the simplified task, we also provided 12 trials (also from six patient pairs) to the participants, but only asked participants to prescribe a treatment instead of also deciding which factors to follow-up on or rank risk factor severity.

Second, we believed that graphically representing the ATP-III and JNC-7 guidelines in the ecological display format would increase the physician’s confidence in how well their prescribed treatment agreed with the respective guidelines. This does not imply that the recommended guidelines are the correct answers, but simply whether the participant felt that their decision matched that of the respective guidelines.

5.3.1. Method

5.3.1.1. Materials and Procedure

We used twelve electronic images to present the patient data in the present evaluation. As with the previous study, patients were classified into six Patient Pairs, with half of the trials being in the ecological condition and the other half in the number line condition. Unfortunately, there was an error with the naming convention used that led to the accidental use of dissimilar patients in one the pairs,
so we had to discard the data from one pair and left us with five Pairs. These five scenarios are outlined in Table 10.

We presented the stimuli to the participants with a laptop computer with a 16" monitor (with a screen resolution of 1600×900 pixels) that used the Windows 7 operating system. We used Techsmith's Morae (version 3.2) to capture video of the computer screen as the participant interacts with the displays. Morae also allowed us to record both the participants' faces and the audio dialog using the computer's integrated video camera and microphone. A portable computer mouse was also provided for greater convenience.

The displays used in the number line cases measured 535×840 pixels and were not interactive. They were presented to the physician using Windows Photo Viewer®. For the ecological display condition, participants used the ecological display software program that we developed. This software was simply an interactive version of the ecological format used in the previous study that allowed users to manipulated the various risk factor levels in order to effect change in the display. The ecological displays measured 1420×840 pixels in dimension. Stimulus presentation order was not randomized because we were worried that full randomization may have left us without any completed pairs to use for comparison because of the low number of participants and did not know how many trials each participant could complete in their allotted time.
In the task instructions, we asked participants to prescribe and verbalize their treatment decision for both cholesterol and blood pressure for each trial. As with the previous study, the treatment options were no treatment (NT), therapeutic lifestyle changes (TLC), or drug therapy (DT). We avoided interrupting the participants when possible; only interrupting for clarification.

<table>
<thead>
<tr>
<th>Pair #</th>
<th>Cholesterol Tx</th>
<th>SBP Tx</th>
<th>Context/Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>DT</td>
<td>DT</td>
<td>Patients could quit smoking to move from DT for cholesterol to NT</td>
</tr>
<tr>
<td>2</td>
<td>NT</td>
<td>TLC</td>
<td>Patients had enough risk factors to have metabolic syndrome</td>
</tr>
<tr>
<td>3</td>
<td>TLC</td>
<td>NT</td>
<td>Although patients have low LDL cholesterol that would not normally require treatment, their diabetes places them into the high risk area and requires TLC</td>
</tr>
<tr>
<td>4</td>
<td>TLC</td>
<td>NT</td>
<td>Patients have many treatment modifying risk factors that suggest TLC for cholesterol instead of NT if fewer factors were present</td>
</tr>
<tr>
<td>5</td>
<td>TLC</td>
<td>TLC</td>
<td>Patients with high 10-year risk due primarily to age</td>
</tr>
</tbody>
</table>
5.3.1.2. Measures

Guideline Agreement.

We had two measures for guideline agreement, one for ATP-III and one for JNC-7. Given the small sample size, we defined guideline agreement as the number of participant responses that matched the guideline recommended treatments for each condition (hypertension and hyperlipidemia) for each patient trial.

Guideline Confidence.

We measured guideline confidence for both ATP-III and JNC-7 guidelines. To measure confidence, we asked participants to rate how confident they were that their decision matched that of the respective guideline on a 7-point scale (1 = Not at all confident and 7 = Extremely confident). If a participant failed to mention the rating before moving on to the next trial, we briefly interrupted the new trial and reminded them to provide ratings for the previous trial.

5.3.1.3. Procedure

Once we had made contact with our medically trained participants, we arranged to meet with them in their respective offices. Upon arrival, we provided a brief overview of the study and provided an informed consent form from which we obtained their written consent. While participants reviewed and signed the consent form, we set up the laptop computer on a desk in an area that the participant designated.

After obtaining participants’ consent, we opened up a sample number line trial for the participant to view while we read from a script detailing the task
instructions (see Appendix C) and describing how to interact with Windows Photo Viewer® to advance through the number line trials. We also informed participants that they would be able to review their answers at the end of the block.

In that our appointments with the physicians were limited to 60 minutes, we wanted to ensure that we had time to collect data from the DET task for both graphical conditions as well as an interview. To ensure that there was time left for the interview, we had to limit the time spent on the DET task. We limited the time allotment for each graphical condition to about 10 minutes. With the addition of the instructions, consent review, and set-up, the total duration of the DET task was about 30 minutes. However, these times are approximate because the purpose of the time limit was to allow us some time for the interview, not timing how long it took to complete a trial. If a participant was in the middle of a trial after 10 minutes had elapsed, they were allowed to finish the current trial before we moved on. This process also meant that some participants did not finish every trial.

Once the participant had finished the last trial, we opened a sample ecological display and read from a script that described the task instructions and provided an introduction to the ecological display. As with the number line block, we informed participants that they would be able to review their answers at the conclusion of the block and that they would be able to interact with the display as we read through the task instructions. We also instructed participants on how to interact with the Windows 7 operating system to view and close each instance of the ecological display program in order to navigate through the ecological block of cases.
5.3.2. Simplified DET Task Results

Given the few data points for the DET task, we have opted to provide the data here in lieu of formal analyses (see Table 11).

For Patient Pair 1, all four participants made decisions in agreement with the ATP-III guidelines and 3 of 4 participants agreed with the JNC-7 guidelines when using the ecological display while not making any decisions in agreement with the number line display. Display type seemed to have little effect for the other Patient Pairs as demonstrated by the similarity in scores between the display types (e.g., 0 vs. 1 for ATP-III or 4 vs. 3 for JNC-7 in Patient Pair 2).

Guideline confidence was high across all Patient Pairs. Almost all participants reported confidence scores of 6 or 7. Only participant S3 (30+ years of experience) chose confidence scores other 6 or 7. In Table 11, we have highlighted participant all of S3’s Confidence scores below 6 in gray. Note that with the exception of the ecological display for Patient Pair 1, all responses less than 6 are for the number line condition. We wonder if this participant was better “calibrated” than the others, given that there seemed to be some measure of overconfidence for all participants given the lower levels of guideline agreement.
Table 11 Guideline Agreement and Confidence Tables

<table>
<thead>
<tr>
<th>Pair</th>
<th>Participant</th>
<th>Guideline Agreement</th>
<th>Guideline Confidence</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>ATP-III (3) JNC-7 (3)</td>
<td>ATP-III JNC-7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NL ECO NL ECO</td>
<td>NL ECO NL ECO</td>
</tr>
<tr>
<td>1</td>
<td>S1</td>
<td>2 3 2 3</td>
<td>7 7 7 7</td>
</tr>
<tr>
<td></td>
<td>S2</td>
<td>2 3 2 3</td>
<td>6 7 7 7</td>
</tr>
<tr>
<td></td>
<td>S3</td>
<td>1 3 1 2</td>
<td>5 7 5 5</td>
</tr>
<tr>
<td></td>
<td>S4</td>
<td>2 3 1 3</td>
<td>6 6 6 6</td>
</tr>
<tr>
<td></td>
<td>Agreement</td>
<td>0 4 0 3</td>
<td></td>
</tr>
</tbody>
</table>

|      |             | ATP-III (1) JNC-7 (2) | ATP-III JNC-7         |
|      |             | NL ECO NL ECO        | NL ECO NL ECO        |
| 2    | S1          | 2 2 2 2              | 7 7 7 7              |
|      | S2          | 2 1 2 1              | 6 6 6 6              |
|      | S3          | 3 2 2 2              | 3 7 5 7              |
|      | S4          | 2 2 2 2              | 6 6 6 6              |
|      | Agreement   | 0 1 4 3              |                      |

|      |             | ATP-III (2) JNC-7 (2) | ATP-III JNC-7         |
|      |             | NL ECO NL ECO        | NL ECO NL ECO        |
| 3    | S1          | 2 2 2 2              | 7 7 7 7              |
|      | S2          | 3 2 3 2              | 6 6 7 7              |
|      | S3          | 2 2 2 2              | 4 6 7 7              |
|      | S4          | -- -- -- --          | -- -- -- --          |
|      | Agreement   | 2 3 2 3              |                      |

|      |             | ATP-III (2) JNC-7 (1) | ATP-III JNC-7         |
|      |             | NL ECO NL ECO        | NL ECO NL ECO        |
| 4    | S1          | 3 3 3 2              | 7 7 7 7              |
|      | S2          | 3 2 3 3              | 6 6 7 7              |
|      | S3          | 2 2 2 2              | 2 6 7 7              |
|      | S4          | -- -- -- --          | -- -- -- --          |
|      | Agreement   | 1 2 0 0              |                      |

|      |             | ATP-III (2) JNC-7 (2) | ATP-III JNC-7         |
|      |             | NL ECO NL ECO        | NL ECO NL ECO        |
| 5    | S1          | 3 3 3 3              | 7 7 7 7              |
|      | S2          | 3 3 3 3              | 6 6 7 7              |
|      | S3          | -- -- -- --          | -- -- -- --          |
|      | S4          | -- -- -- --          | -- -- -- --          |
|      | Agreement   | 0 0 0 0              |                      |

Total Guideline Agreement 3 9 6 9

Note: Guideline treatment recommendations are in parentheses in the LDL Tx and BP Tx column headings; 1=No Treatment, 2=Therapeutic Lifestyle Change, 3=Drug Therapy.
5.4. Part 2: Ecological Display Usage

The second objective of this study was to investigate issues of use and usability of the ecological display. To meet this objective, we observed participants’ usage and interactions with the ecological display as well as conducted semi-structured interviews about their experiences with it.

5.4.1. Method

5.4.1.1. Observations

During the quantitative portion of this study, we recorded participant interactions with the screen capturing software. Two researchers reviewed the resultant audio/video data and coded the participants’ usage behavior. Usage was measured as the number of times that participants either referred to directly or used the mouse to interact with the various graphical elements of the ecological display (i.e., the number line, risk function curve, contribution bar chart, blood pressure bar chart, treatment option matrix, and pentagons) while they completed the DET task for each of the ecological display trials.

In that the number line element contained so many data elements and played such a significant role in the DET process, we divided it into four smaller areas for coding purposes. These areas were the top section (which includes the yes/no switches for dichotomous variables along with the age number line), the cholesterol area, the blood pressure area, and the risk value. Any time a participant navigated (verbally or with the mouse) among these areas, we assigned a point to the number line element tally. According to this coding scheme, participants used the number
line at least three times every case (once for the dichotomous variables and age, once for cholesterol, and once for blood pressure).

Discrepancies between the researchers were reviewed until consensus was reached. However, there were a few cases in nearly every trial where coding was impossible for verbal remarks. For instance, when addressing 10-year risk, many participants made a comment along the lines of, “the patient’s risk is higher than I would like” without verbally reporting or using the mouse to indicate which source of data was used. Without accurate coding for these few cases, we are likely underestimating actual usage.

5.4.1.2. Interviews

Upon conclusion of the simplified DET task, we presented all five participants with one final ecological display and began the short semi-structured interview. We used three standard probes in these interviews to supplement and enhance our understanding of usability issues related to the ecological display. These were: (1) What do you think is confusing about the ecological display? Is it something that training could resolve? (2) What features would you like to see implemented or removed and why? and (3) Would you use the ecological display in your practice? Why or why not?

All interviews lasted between 15 and 30 minutes. Once the interview section had been concluded, we thanked the participants for their time and debriefed them about the purpose of the study.
5.4.2. Results

5.4.2.1. Graphic Element Usage

Overall, the number line component had the most use ($GM = 6.74$, $SD = 3.44$; see Figure 21), followed by the treatment option matrix ($GM = 1.53$, $SD = 1.64$), JNC-7 bar chart ($GM = 1$, $SD = 1.28$), function curve ($GM = 0.79$, $SD = 0.97$), pentagons ($GM = 0.42$, $SD = 0.94$), and contribution graph ($GM = 0.21$, $SD = 0.7$). Taken together, the number line component was used, on average, roughly 1.6 times more often than everything else combined.

Although the number line component had the most usage, the JNC-7 bar chart and ATP-III treatment option matrix were also used at least once on average for each trial. The pentagons were little used, but the contribution graph was used even less frequently. In some respects, this surprised us in that we believed that the unique contribution of each factor would be important.
5.4.2.2. Observations and Interview Responses

In response to the question about confusion with the ecological display, one faculty physician stated that, “you need to be walked through [the ecological display], but once you are walked through it, it’s pretty clear. [...] Like anything else computerized, you have to get used to looking at it. It’s really pretty clear.” All five participants indicated that the ecological display was confusing at first glance but that some instruction and experience with it made it simple to use.
The sense of confusion from the ecological display came from a number of sources. Perhaps unsurprisingly, all the graphical elements received a comment or observation at some point. In that every element was implicated as a potential source of confusion, we will present the results of the responses and observations starting with the number line area, then the function curve, blood pressure bar chart, treatment option matrix, and ending with the pentagons.

*Number Line Area.*

None of the participants mentioned the data-input number lines specifically during the interview, but some did ask for clarification during the simplified DET task. Two physicians asked once for clarification about how to read the graphical switches for dichotomous variables (e.g., smoking) once; the nurse asked three times.

There were some mixed responses to the coloration of the number line bars and the colors used to indicate the risk factors themselves. Two physicians mentioned that they felt the colors should be even brighter. Three physicians mentioned that they liked the color schemes and felt that it helped distinguish the risk factors from each other. However, the nurse kept referring to the colors as “grey” and reported difficulty distinguishing between smoking, age, and diabetes statuses.

Only one of the physicians mentioned the potential problem associated with red-green color blindness. Two participants mentioned that they felt the red-yellow-green coloration was helpful.
There were complaints about the abbreviated labels such as “FamHx,” “>110mg, and “>100mg.” The label for fasting blood glucose (i.e., >110mg) was brought up by all participants at least once, either to verify what it was or if the metric was supposed to be noted as “>110 mg/dL.”

*Function Curve.*

The function curve did not elicit any specific complaints, but there were two comments about it being intimidating without training. There was a sense of usefulness of this component, particularly when seeing the difference that toggling smoking status has. One physician felt that the ability to see the change in risk that smoking cessation could have was important for the patient to see. He stated, “[…] I think the real beauty of something like this is that I’m cutting [the patient’s] risk from 9.6 to 5. That’s hugely dramatic with just the click of a button. […] I think that might convince a patient or two.”

*Contribution Bar Graph.*

One physician noted that it was difficult to notice or distinguish between risk factors when the contribution of one risk factor is only a few pixels wide and is placed next to another risk factor that shares a color or luminosity with the first. For instance, a contribution of total cholesterol (dark blue) only 2 pixels might be lost if placed next to contribution of systolic blood pressure (dark purple) that is 30 pixels in width.

None of the participants had complaints about how the contribution bars align with each other (i.e., the base of the top bar begins at the top of the bottom bar.
instead of both originating in opposite directions from the y-axis), which is one issue we expected to hear about. However, this may have been because we explained the relationship in the instructions.

**Blood Pressure Bar.**

The nurse asked for clarification on the colors used in the bar. This makes sense in that this bar uses not only the red-yellow-green color scheme to indicate severity and treatment options, but it adds orange into the color scheme as well. There are two DT options for blood pressure in the JNC-7 guidelines and we used red for the most severe case and orange for the less severe case. Given that orange is a mixture of both red and yellow; we can see how the color orange may send a mixed message.

One of the residents did not immediately understand that the bars were scaled according to the severity and treatment recommendation (e.g., the green portion of graph field representing values for both SBP and DBP that were values that did not require treatment) rather than being scaled numerically. When we explained the logic to him, he indicated a preference for the severity/treatment scaling over the strictly numeric scaling after all.

**Treatment Option Matrix.**

The only issue mentioned or observed with the TOM was when one physician suggested that the colored regions have labels directly placed on them or to have a descriptive label pop up on the mouse-over interaction.
Pentagons.

One resident liked the pentagons, but reported that, “having the metabolic syndrome and the risk factors [there] is kind of busy. Maybe you could click on [that area] separately...click on it and have a box come up [...] cuz it’s a little busy.” One faculty physician stated that she “would remove the two pentagons because they have not helped [her] at all.” There were no other quotations about the pentagons directly, but we did observe one resident expressing surprise at noticing that one of the trials met the criteria for metabolic syndrome and had not realized that fact before he had looked at the pentagons.

Overall.

All participants indicated that they would like to use the display in their practices, however, not all wanted the ecological display to be the format in which test results were initially presented. Two of the physicians indicated that they wanted the test results returned to them from the laboratory in ecological format initially, one faculty physician wanted results presented in the traditional alphanumeric format, and one resident wanted results presented in the number line format. In spite of the mixed preferences, all participants felt that the ecological display would be helpful to at least have easily accessible for “the complex patients.” A few physicians mentioned that although they would like to use (or have available) the ecological display, it would be necessary for the patients’ data to be automatically populated (i.e., from an electronic medical record) into the display for them to use it for decision-making purposes. Its use for decision-making was contingent upon whether they had to enter the data manually or not.
One commonly reported reason for using the ecological display was the ability to see the Framingham model, ATP-III, and JNC-7 guidelines presented in a visual format. Everyone made at least one positive comment on how the ecological display reduced the need to “try and remember the guidelines.” As one resident reported, the ecological display would “speed things up” for him because he would not “have to think of the guidelines in his head.” Another resident agreed on this point, and added that this format would “force people to use evidence-based practice.”

All participants also mentioned that the ecological display would be a helpful tool for patient education, particularly for the ability to make adjustments with the data and see real-time changes. As one enthusiastic faculty physician put it,

“I like the ability to show the patient the impact of the changes that we’re trying to make. Lovely for motivating patients. [...] This is powerful for a patient—they can actually see what they are doing. You’re giving the patient something. [...] This makes it easy and easy is really important. [...] It’s nice to have something simple and graphic in front of you to say [to the patient], ‘You’re doing the right thing,’ or ‘this is what we’re recommending’. Right now EMRs are designed to deal with billing as opposed to helping us take care of patients. This [the ecological display] helps you take care of patients.”
5.5. Discussion

5.5.1. DET Task

Taken as a whole, we believe the results from the quantitative portion hint at a possible effect for the ecological display leading to greater agreement with the published guidelines. The link between display and guideline confidence seems a little weaker than that of agreement. Guideline confidence was particularly puzzling between JNC-7 confidence and JNC-7 guideline agreement for Pairs 4 and 5 (both display conditions) because in spite of the maximum confidence ratings, none of the participants actually chose a treatment in agreement with the JNC-7 guidelines.

When using the ecological display, participants followed the ATP-III guidelines in four of the five patient pairs. For the JNC-7 guidelines, participants followed the guidelines with the ecological display in three of the five patient pairs. Obviously the sample size limits the conclusions that we could draw from these results, but the results at least offer a basis for warranting additional research. As a pilot study, the ecological display seems promising.

We should also emphasize that even if additional future research were to support greater guideline agreement, it would not necessarily indicate superiority for the ecological display for the reason that some physicians felt that their treatment was best for the patient regardless of what the guidelines suggested. Following the guidelines does not necessarily equate to doing what is best for the patient. Determining whether the ecological display influences physicians to follow guidelines at the expense of what is best for the patient makes for an important
future research topic, but is certainly outside of what we were able to accomplish at this time.

In terms of guideline confidence, participants expressed greater confidence that their treatment decisions matched the ATP-III guidelines in four of five patient pairs, yet only once for the JNC-7 guidelines. However, it should be noted that for the JNC-7 guidelines, participants’ responses for three of the five patient pairs were tied. This is not so surprising given the degree of difference in steps required. The JNC-7 guidelines were much simpler in that they did not contain any information that was not already contained in the threshold levels used to delineate the severity levels, whereas the ATP-III guidelines required a 9-step process.

The same limitations apply to the results of the guideline confidence as for the guideline agreement. Future research is certainly needed, but we are not sure that asking about the confidence that their answer matches the guideline is the best question after all. This again returns back to the issue of whether the guidelines are the best thing for patients. A physician may feel very confident that their response does not match that of the guideline but feel very confident that they are making the best decision over all.

5.5.2. Interview and Observations

Aggregated together, all graphical display elements were used at some point. We interpret this to mean that although there are some mixed feelings about some of the graphical elements, each element could be a useful source of information for users. However, it should be noted that these results do not necessarily negate the less frequently used elements because we have reason to believe that they are a
result of the task, not of their inherent usefulness. We had participants complete a simplified DET task, which means that we asked participants to make a decision about treatment, not to reason about their decisions. We assumed that the reasoning process would have been inherent in the decision making process, but this may not be the case. One medically trained advisor admitted that she thought of the reasoning process as separate from the treatment decision-making process. If this were true, then future research would likely find that the less frequently used graphical elements (e.g., the function curve, contribution bar graph, and pentagons) would become more frequently used. In terms of

5.5.3. Weaknesses

We recognize that we had to make some trade-offs that left us with some drawbacks with this present study. First, our sample size was not large enough to provide meaningful statistical information. Although we cannot make any declarations of statistical significance, we believe that there is some evidence to warrant further research. Second, in order to get participants to finish enough trials (due to the time constraint) across both conditions, we had to standardize the presentation order. This meant that we gave up the benefit of randomization, but on the other hand, we were able to make comparisons within each Patient Pair.
6. SUMMARY

6.1. Study Overview

The purpose of this dissertation research was to evaluate the usefulness and usability of an ecological display developed to aid providers in the detection, evaluation, and treatment of cardiovascular disease. In order to accomplish this, we used both quantitative and qualitative methods with physicians of varying degrees of experience. Our primary purpose of carrying out this research was exploratory in nature rather than designed to test any specific hypotheses. In this, we believe that we have made some observations from the data that warrant further research.

First, when the cases in a Patient Pair met the criteria for metabolic syndrome, participants were significantly more likely to only indicate the need for follow-up when using the ecological display than the number line display. These findings are not too surprising given the fact that the ecological display provides the answer using the pentagon display along with some text.

Second, there was a trend for the ecological display to lead to greater guideline agreement than with the number line display. However, this pattern was only a trend, which was curious in light of the fact that the answer was figuratively spelled out for the user. We suspect that a lack of familiarity and training partially contributed to these findings, but we are unsure if certain risk factors or even a general disagreement with the guidelines contributed as well. Perhaps combining
multiple CVD risk models, such as the Framingham and Reynolds risk models along with the ATP-III guidelines would lead to suggested treatments that physicians would be more likely to agree with.

Third, we originally planned on comparing the number line format to the ecological format because our initial inclination was that any display format would have been better than the traditional alphanumerical format. We believe that it would be worthwhile to go back and revisit our initial assumption, especially in the light of having obtained fewer significant differences in every measure than we had expected.

Fourth, the ranking results were mixed. We are not sure why this is the case in spite of the fact that the answers were also figuratively spelled out for the participants. There was a sense from our advisors and participants that determining the most important risk factors for the patient was important, so we would like to refine our method and try again. For instance, we think that creating pairs that are matched according to the severity of risk factors instead of the treatment option would be a good start.

Although we had some mixed results overall, we believe that we have made an important first step in bringing forth an ecological display that physicians find useful and usable. Although our display certainly requires further work before “releasing it into the wild,” our partners and participants have received it with enthusiasm and support, indicating to us that we are on the right track.
6.2. **Ecological Interface Design**

For us, the major lesson from McGregor & Slovic (1986) is that graphical displays are only as good as the semantic mapping they have with their respective ecologies. Not only must a user be able to make sense of the display, but the display must also be a good representation of the domain in order to equate meaning with interpretation. Representing the domain well requires a conscientious effort to research the domain to discover the laws and constraints of the domain.

What we have tried to accomplish with our display is similar to that which has been done in domains as varied as aviation (Amelink, Mulder, van Passen, & Flach, 2005), power production (Schaefer, Little, Copper, & Easter, 1987; Woods, Wise, & Hanes, 1981; Bennett, Payne, Calcaterra, & Nittoli, 2000), process control (Bennett, Nagy, & Flach, 1997), military command & control (Bennett, Posey, & Shattuck, 2008), and even fictional literature search (Petjersen, 1992). However, one major difference between our work and that of the aforementioned work is that we have chosen to use a correlational model as a functional constraint (i.e., the Framingham risk model) rather than conceptual models (Pejtersen, 1992) or physical systems described by (partial-) differential equations (Amelink, Mulder, van Passen, & Flach, 2005, Bennett, Nagy, & Flach, 1997).

While there is nothing in the ecological interface design principles that precludes the use of correlational models, we are unaware of their use in existing work. We hope that our use of a correlational model will serve as an additional tool in the ecological interface designer’s toolbox. Furthermore, we suspect the use of correlational models may have pedagogical value because many in the human
factors (and similar disciplines) are more familiar with correlational models than they are of physical systems based on differential equations.

In our search for domain constraints, we had to rely upon the medical science to tell us what was important. We assume that medical science has improved since medieval times and that our current models of risk are far more accurate and efficacious than what could be divined from astrology and planetary motion, but validity of current medical models in the hands of those researchers. Our job has not been to refine the medical science or create new models of risk, but to use existing knowledge to develop a display capable of presenting the complexities of the domain models to healthcare providers. We believe that the positive response to our display from our participants indicates that we may be on the right track, but we hope that we have not simply created a display that is marginally better than the manuals used by medieval doctors. The success of any ecological display used in healthcare will always depend on the quality of the models it represents.

6.3. Future Design

Although we believe that we are on the right track with our display, there are still a number of design issues that we think should be addressed. The first, and possibly the most obvious, is the need to address the issue of color in light of potential problems for those with color blindness. We agree that our display should be more usable to those who are color blind, particularly red-green blindness, because those colors are prominently used throughout. However, we would hate to lose the red-yellow-green/bad-warning-good cultural convention by eliminating
them. However, we think that redundantly coding them with a texture or pattern may be a potential solution.

Second, there were a number of complaints about the pentagons. At the same time, a number of participants requested additional data, such as body mass index, height, and weight. Given the suggestions and complaints, we wonder if we would be better off removing the pentagon and replacing it with other data or another graphical element. Regardless, additional research is needed in this area.

Third, we have two bars for systolic and diastolic blood pressure. There are bars in the number line portion of the display as well as beneath the contribution bar graph. From the systolic blood pressure contribution of the contribution bars are a set of splayed lines that connect to the JNC-7 bars. On one hand, these lines make an explicit connection between the risk model and the JNC-7 guidelines, but we believe they do the job rather inelegantly. We wonder if the splayed lines are necessary. Another aspect to consider is whether we need two sets of bars for blood pressure. There is nothing contained in one set that is not in the other. The only difference is that the bars in the JNC-7 area are scaled according to severity rather than numerically. We could potentially eliminate one set of bars and keep them on the same severity scale, which would free up some additional space for additional information.

Fourth, there are also a number of factors that are dichotomously measured in our display (e.g., waist circumference, fasting glucose, etc.) that our participants have suggested to be displayed continuously on number lines. We agree that this
would be a welcome addition to the display, even though the precise measurements are not used in the Framingham risk model or criteria for metabolic syndrome.

Fifth, we have not addressed changes over time and historical data. While this is a limitation of any number line or bar chart, not just our display, it still remains an issue on how to (or if we should) represent multiple readings for the various risk factors and outputs (e.g., 10-year risk levels and treatment options). However, all of this raises the larger issue as to the scope of this display.

Although we agree with our participants and medical advisors about the inclusion of additional data, we recognize the fact that we run the risk of trying to display too much at once if we add any more to it. Data overload was one of the problems we tried to address by creating this display in the first place. Creeping featurism is a problem we want to avoid.

The future scope of this display will be determined by the development track it lands in. On one hand, if this display were to be a stand-alone product (e.g., as an iPad® app), then we would need to consider the inclusion of additional information more closely because we do not want to leave our practitioners without the data that they need. On the other hand, if this display were included in an EMR system that was connected to a database of all patient data, then the need to include the data in the display is less important because it would still be available in the system for reference.
6.4. Concluding Remarks

As we mentioned earlier, we were not interested in creating a display from which experts and specialists could extract new models of cardiovascular disease and risk, but rather providing users with a quick entry into the decision making process with the medical guidelines as the starting point rather than as the endpoint.

We would also like to re-emphasize that while we attempted to make our display easy to use, some of our participants struggled with it (although some may have just disagreed with the guidelines). This should not be taken as evidence that our display is “user-hostile,” but rather that we are asking medically trained physicians to complete a difficult task in the face of ambiguity in that the “correct” treatment for the patient does not necessarily have to correspond with the guidelines and some participants wished for additional data. However, this goes back to one of the misconceptions that people often have about ecological interface design. The point is not to create a simple interface. The point is to provide an interface that allows people to see, reason about, and interact with the ecology rather than the interface per se. Complex domains require sophisticated displays in order to capture the meaningful aspects of the domain. If a display is too simple, it runs the risk of trivializing the domain and becomes useless (or harmful) when the display cannot adequately represent the complexity of the domain. The law of requisite variety (Ashby, 1958) must always be respected for a display to remain successful. This may translate into the creation of a display that is sophisticated enough that may, depending upon the complexity of the domain, require training.
We hope that our display will have the opportunity to become refined after this initial development process and become something that people will use, regardless of a standalone product or as an integrated function of an EMR system. Whether or not this display is implemented as a professional tool, we hope that it at least serves as inspiration to designers to move beyond the dyadic world of colors, shading, and font sizes and move into a triadic world of representing medical science and guidelines.
APPENDIX A

Data Collection Packet Sample

1.) How concerned are you about this patient’s health based on these results?

_______ Not concerned at all, seems to be in good health
_______ A little concerned, there is some risk present
_______ Quite concerned, there are several worrisome findings
_______ Very concerned, there are significant worrisome findings

2.) Place a check mark next to the cardiovascular risk factors that you would address with the patient:

☐ Total Cholesterol  ☐ Smoking
☐ LDL Cholesterol  ☐ Obesity
☐ HDL Cholesterol  ☐ Blood Sugar
☐ Triglycerides  ☐ Metabolic Syndrome
☐ Systolic BP
☐ Diastolic BP
☐ Diabetes

3.) How would you treat the following risk factors in this patient? (Check corresponding box)

<table>
<thead>
<tr>
<th>Risk Factors</th>
<th>No Treatment</th>
<th>Lifestyle Change</th>
<th>Drug Therapy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Cholesterol</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>LDL</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>HDL</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Triglycerides</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Systolic BP</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Diastolic BP</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Smoking</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Diabetes</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Obesity</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Blood Sugar</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>
4.) Rank the following CVD risk factors in order of severity for this patient by placing a number next to each risk factor (1 = increases CVD risk the most to 6 = increases CVD risk the least; use each rank number only once):

<table>
<thead>
<tr>
<th>Risk Factor</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Cholesterol</td>
<td></td>
</tr>
<tr>
<td>HDL Cholesterol</td>
<td></td>
</tr>
<tr>
<td>Systolic BP</td>
<td></td>
</tr>
<tr>
<td>Diabetes</td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td></td>
</tr>
<tr>
<td>Smoking Status</td>
<td></td>
</tr>
</tbody>
</table>

Additional Notes:

-------------------------------------

**Demographic Information**

Gender:  ___M  ___F

Age:__________

Residency Specialization:__________________________

Year in Residency Training:____________

What is your race?
  ___ White
  ___ African-American
  ___ American Indian or Alaska Native
  ___ Asian
  ___ Pacific Islander
  ___ Some other race or mixed (please specify):__________________________

Ethnicity:
  Are you Hispanic or Latino?  ___Yes  ___No
APPENDIX B

Script for Static Display Evaluation

Thank you for coming today. We appreciate Drs. [X] and [Y] for letting us come and meet with you. The purpose of our visit is two fold; first, we want to share some of our work with you in the field of graphical display design, particularly in ways of displaying patient information. Secondly, we are here to solicit feedback from you in terms of our work and how this display influences decision-making. To this end, we have provided you with a test and ask for your participation in our research.

In front of you, you should find a packet of paper. The top is a letter of informed consent for this research. As many of you may know, participation in any research is voluntary. If you choose not to participate, you may find this to be an interesting exercise anyway and we encourage you to follow along even if you decide not to return your responses to us. We will not share your personal information or results with any faculty. If you are interested, we will be happy to provide you with the group results when we finish analyzing the data. Regardless of whether or not you choose to participate in the experiment, the last page of the packet has a section where you can enter into a drawing for an iPad. Please take a few moments to decide whether you want to participate and review the informed consent document. Once we have your consent, we will proceed with the task instructions.

You are to imagine that you have added a new male patient to your practice yesterday. During your examination, you ordered a lipid panel for this patient. You were also able to have some of the patient’s medical information transferred over from his previous physician. Today, the results have returned from the lab and it is now time to review them and make a decision about how to proceed.

We will provide you with this patient data in a moment once we have completed explaining the task instructions. This patient information will be provided to you as a packet of papers. Each page represents one patient. There are 12 pages representing 12 different male patients. Your task will be to view this data and make decisions about treatment. Once you have made a decision, please move on to the next patient and do not go back to review data or change your answers from previous patients.

You will have access to the following medical data:

- If he has existing heart disease (i.e., clinical CHD, symptomatic carotid artery disease, PAD, abdominal aortic aneurysm)
- If there is a family history of CHD (i.e., 1st degree relative with CHD; male < 55 or female < 65)
- If the waist circumference is greater than 40 inches or 102 cm
- If fasting blood glucose is \( \geq 110 \text{ mg/dL} \)
- If he was previously diagnosed with diabetes mellitus
- If the patient smokes
- Age
- Cholesterol levels
  - Total Cholesterol, HDL, LDL, and triglycerides
- If he is currently on antihypertensive medication (Y/N)
- Blood pressure
  - Systolic and diastolic
- 10-year risk for cardiovascular disease (Framingham Model)

After reviewing this data, you will need to answer a number of questions found in the packets that we have provided underneath the informed consent page. There is an answer sheet for each patient. When you get to question 4, you are to rank order the severity of each risk factor for this particular patient by assigning it a number from 1 to 6, where 1 means it increases that patient's risk the most and 6 means it increases it the least. Use each number only once. None of the risk factors should share a number. If you feel that you need to explain any of your answers or believe that you would do something other than the options we have provided, please feel free to use the additional notes section at the bottom and feel free to write on the back of the page if need be. Please answer these questions to the best of your ability.

You will be shown the patient data in two different graphical formats. We will now briefly introduce these formats to you. As you can see, there are two numbers here. Number 1 represents the data as presented in a number line format. Some of the risk factors are dichotomous. These are: existing heart disease, family history (fam Hx), waist circumference above 40 inches, blood sugar above 110 mg/dL, diabetes, smoking, and antihypertensive medication (noted as Tx). You will only see what is on the left-hand side.

Number 2 represents what is known as an ecological interface or display. It is made up of section 1, or the number line format, as well as the three other sections. The first represents the mathematical function used for calculating 10-year CVD risk according to the Framingham model and a contribution bar chart graphic demonstrating the unique contribution of each risk factor to 10-year risk. The bottom bar graph represents the risk factors that increase risk for this patient while the top bar represents the factors that decrease risk for this patient. The line projected off the top bar meets with the Framingham function and indicates the 10-year risk. The lateral projection line takes us to the next area of the display, or the area representing the ATP-III guidelines. The multicolored box represents the decision rules advised by the ATP-III as a function of 10 year risk and LDL cholesterol. Red represents the region associated with drug therapy, yellow with therapeutic lifestyle changes, and green with no treatment. According to the ATP-3 guidelines, existing HD and diabetes will automatically place a patient in the high-risk region, even though the calculated risk may be lower. This is represented by extending the line up from LDL to place a point in the high risk region.

The pentagons underneath simply keep track of the number of treatment modifying risk factors and the number of factors that contribute to metabolic syndrome. As these conditions are met, these segments of each pentagon will fill up until they meet their thresholds and will turn red to indicate that enough factors are present to modify goals and treatment or that the patient may have metabolic syndrome.
The last area in this display represents the jnc-7 guidelines. Green represents health, yellow represents prehypertension, orange represents stage 1 hypertension, and red represents stage 2 hypertension.

Again, there are 12 answer sheets that correspond to 12 different patients—hence 12 trials. The data from each patient trial will be in one of two graphical formats. Please answer to the best of your abilities, make notes if you need to, and please do not go back to review previous cases or change your answers. Are there any questions?
APPENDIX C

CVD Risk Display Usability Protocol:
Dynamic Display Evaluation & Interview

1. Obtain consent to record video and audio
2. Read General Instructions
   i. *I will provide you with data from two sets of patients. Please evaluate the data and make a decision regarding treatment for these patients’ cardiovascular health. You will have 10 minutes to review each set of patients. At the end of both sets, you will get a chance to go back and review any of the patients that you have already examined and have a chance to change your answers.*
   ii. *As you review the data from each patient, please speak your thoughts out loud as if you were explaining your reasoning and decisions to a medical student or resident. Additionally, we would like you to provide a ranking of how confident you feel that your decision matches that of the JNC-7 and ATP-III guidelines. This ranking is on a scale from 1 to 7, where 1 is “not at all confident” to 7 being “completely confident.”*

3. Number line Format
   a. Read instructions
      i. *You are to imagine that you have added six new male patients to your practice yesterday. You ordered lipid panels for these patients as part of the examinations. You were also able to have some of the patients’ medical information transferred over from their previous physicians. Today, the results have returned from the lab and it is now time to review them and make decisions about how to proceed.*
   b. Give example number line format
      i. *This is patient data presented in a number line format. ExtHD means existing heart disease, which in this case means clinical CHD, symptomatic carotid artery disease, PAD, or abdominal aortic aneurysm. FamHx is family history of coronary heart disease, specifically meaning a 1st degree relative with CHD; male < 55 or female < 65. This is whether the waist circumference is greater than 40 inches or 102 cm. This is the fasting blood glucose level and whether it is greater than or equal to 110mg/dL. The reported blood pressure reflects the average pressure over many past readings. **Explain the rest.***
   c. You will have 10 minutes to review as many of these patients as possible. Please work as quickly and as accurately as possible. Do you have any questions?
   d. Allow 10 minutes for number line task completion
4. Ecological Display Format
   a. Read instructions
      i. *This portion will proceed exactly as the previous portion, where you will review the data from six different patients. Please continue to speak your thoughts out loud and rank the confidence in your answers.*
b. Give example of ecological format and demonstrate
   i. This is patient data presented in what is known as an ecological display, which means that attempts have been made to display the data within the context of the scientific evidence and treatment guidelines. This is an interactive display, so feel free to explore it by using the mouse as I explain the various components. The left hand side is the number line format from the previous task. You can click on the arrows and make adjustments to these values and have their effects displayed elsewhere in the interface. This part is a graphical representation of the Framingham model of cardiovascular risk. This is a contribution graphic for the risk factors and their influence on risk. The bottom bar is comprised of all of the risk factors that increase risk for this patient and the top bar is comprised of the factors that reduce risk for this patient. The colors in these bars correspond to the factors in the number line portion of the display. Clicking on the I icon will allow you to see each of these risk factors in terms of the most detrimental to the most beneficial for this patient. Clicking it again will return it back the contribution bars. If you project a line from the top bar up into the curve, you get the 10-year risk for this patient. If you project a horizontal line from this point, you end up in the ATP-III treatment options matrix. This matrix is a graphical representation of the ATP-III guidelines for treating cholesterol. If you find the patient’s LDL cholesterol level and draw a line up to intersect with the horizontal line from the 10-year risk, you create a set of coordinates in this matrix. If this point is in the red area, the ATP-III guidelines suggest drug therapy for treating cholesterol. If it falls in the yellow area, it suggests therapeutic lifestyle changes, and if it falls in the green, then no treatment for cholesterol is suggested. In this ATP-III area, there are also two pentagons. The first is a running total of factors that could constitute metabolic syndrome. The second is comprised of the factors that would modify treatment goals. If this turns red, then the treatment option matrix changes shape indicating the suggested treatment changes. The final area represents the JNC-7 guidelines for treating high blood pressure. This bar is scaled to the levels of severity. The green area is the healthy range, the yellow indicates prehypertension, the orange indicates Stage 1 hypertension, and the red represents Stage 2 hypertension.

c. You will have 10 minutes to review as many of these patients as possible. Again, please work as quickly and as accurately as possible. Do you have any questions?

d. Allow 10 minutes for ECO task completion

5. Free response
   a. Instructions
      i. Now that you have completed both tasks, you may go back and review any of the previous patients that you have reviewed.
      ii. If the physician goes back to review previous cases, then ask:
          1. What is it about this display that makes you want to revisit it?
          2. Would you change your confidence rating? To what?

6. Interview physician
   a. Would you use the ecological format in your practice?
   b. What do you think is confusing about the ecological display?
      i. Is it something that training could resolve?
   c. What features or information would you like to see implemented or removed? Why?
REFERENCES


doi:10.1207/s15327051hci0203_1


