Web-Based Visualisations Supporting Rehabilitation of Heart Failure Patients by Promoting Behavioural Change

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Abstract

Heart failure is a major cause of death in the Western world and has a severe impact on the functioning status of individuals suffering from it. Self care management involves behaviour and lifestyle changes that reduce the negative effects of this chronic illness. We have developed web-based visualisations for educating patients and promoting behavioural change. The tool uses interactive web graphics to visualise relationships between lifestyle, symptoms, patient parameters and the disease. The goal is to empower and motivate patients to take more control of the disease management process. In contrast to many educational websites with interactive content our application utilises real patient parameters and it has been evaluated from a health psychology perspective.

Initial usability studies revealed difficulties with the platform independent design, but that overall the tool was perceived as educational and easy to use. A more detailed study explored the responses of Māori individuals with heart failure and their whānau to a patient education intervention using the tool. Semi-structured interviews, guided by the Common Sense Model of illness representations, demonstrate that the programme promotes knowledge and understanding of the illness and its associated symptoms and promotes protective behaviour.

Keywords: visualisation, web graphics, heart failure, chronic disease management, telehealth, behavioural change

1 Introduction

Cardiovascular diseases are a leading cause of death in New Zealand (Hay 2004) and the Western world (Lopez et al. 2006). Heart failure is a common chronic form of it. Previous research indicates that many heart failure patients have a poor understanding how their lifestyle influences their cardiac health and rehabilitation (Horowitz et al. 2004). Medication and changing lifestyle can help the patient to live a normal life, but many patients do not have a good understanding how they can control their disease due to the complex relationship between disease, medication, symptoms and lifestyle choices. As a result many patients do not adhere to rehabilitation procedures. Examples are reduced adherence in medication usage and adverse lifestyle choices such as smoking, lack of exercises, and a high-salt diet. This lengthens the rehabilitation process, increases the risk of another cardiac event, adds demands on health care staff, and overall increases health care costs (Horowitz et al. 2004).

In this paper we present and evaluate the use of visualisations of patient parameters for improving patients' understanding of their disease and increasing their level of control over the rehabilitation process.

Section 2 summarises important facts about heart failure impacting the design of our solution. Section 3 reviews the literature in this field and discusses related applications. Section 4 analyses the problem and derives design requirements. The design of our solution and implementation details are explained in sections 5 and 6. Section 7 presents a usability study and a detailed patient study demonstrating the effectiveness of our application. We conclude this paper in section 8 and give a short overview of future work.

2 Heart Failure

Heart failure is a cardiovascular disease characterised by the heart being unable to pump sufficient blood to meet the needs of the body (Fuster et al. 2008). The disease can result from any structural or functional cardiac disorder, which impairs the ability of the ventricle to fill with or eject blood (American College of Cardiology/American Heart Association Task Force on Practice Guidelines 2005). The term "congestive heart failure" is frequently used instead of "heart failure" because it often leads to fluid retention. But because not all individuals with heart failure complain of oedema at the time of initial or subsequent evaluation, the term "heart failure" is preferred (American College of Cardiology/American Heart Association Task Force on Practice Guidelines 2005). Almost any form of cardiac disease can produce heart failure, but the most common cause in Western society is coronary artery disease (Timmis & Mccormick 2003).

The impact of heart failure, due to its increasing prevalence, is viewed as a significant economic and societal burden (Masoudi et al. 2002). In 2006, the

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cost of heart failure in the USA was estimated at approximately \$29.6 billion (Doughty & White 2008).

2.1 Symptoms

Most symptoms of heart failure are caused by fluid retention and reduced oxygen supply. Symptoms caused by fluid retention, such as shortness of breath, weight gain and swelling in the feet or ankles, can be regulated by medication and reduced salt and fluid intake. Symptoms caused by reduced oxygen supply are confusion and fatigue and weakness, the latter two are especially prevalent during physical activity because of inadequate oxygen delivery to the muscles (Timmis & Mccormick 2003).

Symptoms can vary widely and the "Rotterdam study" showed that sixty percent of individuals with left ventricular systolic dysfunction did not have symptoms or signs of heart failure (Mosterd et al. 1999). Furthermore attempts to diagnose heart failure in the elderly population may be difficult as typical signs and symptoms may be masked (Masoudi et al. 2002).

2.2 Heart Failure Self Care

Heart failure self care refers to specific behaviours that individuals initiate and perform on their own behalf, with the intention of improving health, preventing disease or maintaining their well-being. Individuals with heart failure can assist the treatment process by taking medication, adhering to dietary requirements such as low sodium intake, exercise, restricting smoking and the intake of alcohol, and monitoring for signs and symptoms of heart failure (Lopez et al. 2006, Lee et al. 2009).

Guidelines on warning signs and management of heart failure have been published for patients and health care professionals (National Heart Foundation of New Zealand 2010). Significant parameters influencing heart conditions are age and gender, weight, blood pressure, pulse rate, exercise, alcohol, smoking and salt intake. All of these parameters can be recognised or measured by the individuals with heart failure and are hence useful for patient education and disease monitoring and management.

Four key barriers to heart failure self care have been identified: medication adherence, dietary adherence, symptom monitoring and decision making (Riegal et al. 2009). Comorbidities, such as diabetes, can make it difficult to follow dietary guidelines and monitor symptoms. Additional important factors are poor health literacy and problems with the healthcare system, which often neither encourages nor supports self care by individuals.

3 Literature Review

A growing body of evidence supports the illness cognition and behaviour processes delineated by the Common-Sense Model of self-regulation (Cameron & Leventhal 2003, Hagger & Orbell 2003). In particular, research supports the crucial roles of illness representations, or mental schema that include images as well as abstract beliefs about symptoms, consequences, and actions for managing the illness conditions. Mental images within an illness representation play a powerful role in shaping beliefs; enhancing a sense of coherence or understanding of one's condition; forming "IF-THEN" connections among symptom experiences, representational beliefs, and recommended actions; and motivating adherence to treatment (Cameron & Chan 2008). Using visual images in educational programmes can thus have a powerful impact on representational beliefs, coherence or understanding, and behavior. Pictures have been found to have longer lasting effects on memory than words (Gardner & Houston 1986) and their effects can be positive, such as encouraging the pursuit of goals, or negative, such as motivating avoidance behaviours (Bradley & Lang 1999). Embedding visual images within an appropriate narrative structure is therefore critical for ensuring that the images motivate behaviours as intended. A well known example of using images in the medical field to effectviely influence behaviour is the use of graphic warning labels on tobacco packs (Hammond et al. 2003). The Common-Sense Model served as the theoretical framework guiding the development of the Heart Mentor Programme.

3.1 Web-based Educational Tools for Individuals with heart failure

A large variety of web-based resources exist for educating and supporting individuals with heart failure. The American Heart Association website uses videos to explain symptoms of heart failure and what to do when they get worse (American Heart Association Inc. 2010*b*). The associated "Heart Failure Media Library" contains images and Adobe Flash animations that explain heart failure related topics. The "Heart360$^{\text{TM}}$" site, powered by Microsoft's Health Vault, allows patients to manage health information, evaluate health parameters, and to obtain recommendations and reports for visiting their healthcare provider (American Heart Association Inc. 2010*a*).

The National Heart Foundation of New Zealand website delivers comprehensive information about the heart's function, how to prevent heart disease, how symptoms of heart failure are caused and how to do lifestyle changes (National Heart Foundation of New Zealand 2010). It uses predominantly text and 2D graphics. Brochures can be downloaded and targeted information for cardiac rehabilitation is available to enable individuals with heart failure to return to the most normal life possible after a cardiac event. This includes helping them to take control of their life and improving their quality of life by means of education, information, physical activities and social support.

While many educational websites have interactive content, the visualisations do not reflect patient parameters and hence there is little identification of patients with the visual content they perceive. Furthermore no evaluations of these sites' effectiveness exist.

3.2 Patient Specific Visualisations

To improve the rehabilitation of individuals with heart failure, Rubin et al. developed a tool with an embedded animated 3D heart model (Rubin et al. 2005). The 3D heart model is an adaption of a 3D finite element model of the mechanical and electrical behaviour of a porcine heart developed by the Bioengineering Institute of the University of Auckland (Hunter & Pullan 2002). The animated model is integrated into a web site using the ZINC plug-in and adapts to user input such as heart rate, state of the arteries (e.g., no plaque), and structure and number of capillaries. Changes to the heart, e.g., due to exercises and a healthy diet are illustrated by changes to the model, images, pop-up windows with explanations and videos. A disadvantage of the application is that it only runs in the Mozilla Firefox browser, because of the need of the ZINC plug-in.

Lee et al. used this model for studying various forms of heart disease education. The authors found that imagery content is superior to text-based content and leads to increased representational beliefs and mental imagery relating to heart disease, worry, and intentions at post-intervention (Lee et al. 2010). Increases in sense of coherence (understanding of heart disease) and worry were sustained after 1 month. The imagery contents also increased healthy diet efforts after 2 weeks.

This research builds on top of the above work and replaces the Finite Element heart model with a simplified polygonal model suitable for popular web graphics technologies. We also integrate a 2D body model and provide comprehensive inter- and intra-element communication to improve understandings of the complex causal relationships between symptoms, disease, medication and lifestyle.

4 Problem Analysis and Design Requirements

4.1 Requirement Analysis

The main purpose of our application is to educate and motivate the patient using visual content conveying the effect of lifestyle choices and the relationship between them and medication, symptoms and disease. The requirements for the application are divided into visualisation requirements, web-based requirements, interface requirements and structural requirements.

4.1.1 Visualisation Requirements

The visualisations must be easy to perceive, informative, and convey relationships between disease specific parameters, e.g., "If you take this medication, then these symptoms will be relieved". This might necessitate abstract and symbolic visualisations since many symptoms and medication effects do not have obvious physical manifestations. The patients acceptability of the animation plays a significant role (Bradlyn et al. 2003). Adding new associations can enhance message effectiveness (Lee et al. 2010). Most individuals with heart failure do not have a vivid or detailed picture of their hearts (Broadbent et al. 2004). To improve the perception the visualisation should be as simple as possible, while still looking professional, and retaining enough details to display functional and anatomical changes.

Most available medical brochures contain non-photorealistic images, which omit non-essential information and reduce the complexity of the content. Non-photorealistic visualisations can be more effective for communicating specific information than photographs or photorealistic visualisations (Strothotte & Schlechtweg 2002). The freedom to modify other parameters such as colour, texture, and highlighting details, allows us to visually convey health or illnesses. The heart model should be animated in order to emphasise its crucial pumping action. A 3D model is preferred because this improves patient identification with the model and makes perception of the pumping behaviour easier compared to using a 4-vessel cross section (ventricles and atria).

Section 2 demonstrated that many symptoms and medications affect other organs than the heart, and hence a whole body visualisation is necessary. In order to simplify perception of parameters, and because of users' familiarity with them, we prefer a schematic 2D frontal graphic of the body similar to illustrations in medical brochures or biology school books. Organs that play a decisive role in heart failure must be shown within the body visualisation and must be identifiable by the user.

4.1.2 Web-Based Requirements

To make the application easily accessible it must be web-based. The web application should provide a consistent experience with immediate responses and real-time interactions. In order to avoid problems due to latency and bandwidth (many users will have dial-up connections) client side computations should be used where possible. Other desirable features are scalability (for running on a PDA) and data base support.

Of particular importance is the choice of 2D and 3D graphics technologies. We used and extended an evaluation framework by Holmberg et al. (Holmberg 2006, Holmberg et al. 2006) and identified the following main requirements:

Technical Capabilities

Communication with servers is necessary for loading visualisations and accessing databases. Compressed communication is of low importance since the amount of transferred data is likely to be small. Encrypted communication is relevant for future work when real patient data will be collected and stored. For the 2D visualisation animations of geometry and visual attributes are essential. For the 3D visualisation we want to have texture mapping and real-time animation of heart geometry in order to display patient parameters and increase patients' identification with the model.

Community Support

The selected technologies should be platform independent, standardised and widely supported. Downloads and installation of plug-ins should be avoided and if necessary made as easy as possible. The application should be compatible across major browsers and operating systems to reach a wide range of audience. The cost and availability of development tools is important to ensure fast and cost-efficient development.

Interactivity

Interaction is important to emphasise the relationships between disease, symptoms and lifestyle, e.g., to demonstrate changes in patient conditions for different lifestyle choices. The 3D heart model should be rotatable in order to appreciate its function and the effects of stress. The 2D body visualisation should support selection of organs and display more information about them and their role in heart failure.

Script support is essential to work predominantly on the client computer, and support should be provided for creating new content and inserting it into the existing scene. Inter-element communication is essential when the web application uses different technologies.

Application Specific

Native graphical structures are good but not essential. It must be possible for the 2D visualisation technology to create a "complex" graphics like a body shape. Hence, the option to use parametric curves is beneficial. The chosen 3D visualisation technology should support loading and animating 3D models.

4.1.3 Structural Requirements

In order to communicate logical "IF-THEN" statements that connect concepts, experiences or beliefs it is helpful to represent them as "narrative" (Meadows 2006). The narrative provides a structure, helps retaining attention, enhances or recalls memories (Simpson & Barker March 2007), and enables the user to identify with story characters (Kolko 2010). Furthermore, the narrative can project into the future and emphasise options and choices.

To create such a narrative the key relationships between components have to be identified by capturing dependencies. It is important to consider appropriate start and end points and to display data in the most relevant context. The connections between in- and output must be apparent so that users easily understand the meaning of the content and where to navigate from there.

4.1.4 Interface Requirements

The user interface should be designed like an interactive storyboard in order to support the narrative, facilitate navigation, and increase impact on patient behaviour. Various other supporting media can be considered to convey messages. For example, we want to use videos to demonstrate positive lifestyle choices such as patient specific exercises. The media integration should improve usability and intensify conveyed messages. Explanatory text is essential for parameters which can not be visualised (e.g., likelihood of disease) or to prevent ambiguities (Lee et al. 2010). Sound can also convey health or illness (e.g. heart rate, breathing, coughing). The tone or volume can be changed to reflect patient conditions.

4.1.5 Functional Requirements

The application should, inform, motivate and empower the patient. "Inform" means answering common questions such as

- What is heart failure?
- What are the Symptoms of heart failure?
- What are the causes of these symptoms?
- How can lifestyle influence the condition?

"Motivate" means increasing adherence, e.g., using medication, and encouraging users to follow rehabilitation procedures such as diets and exercises. "Empower" means that patients recognise their ability to influence their condition and improve symptoms. This is possible with lifestyle changes such as reduced salt and alcohol intake, more exercise and quitting smoking. Furthermore patients can assist doctors by being proactive and looking out for warning signs such as swellings and sudden weight increase.

From consultations with cardiologists and guidelines for patients and health care professionals (National Heart Foundation of New Zealand 2010) we identified the following parameters relevant for heart failure diagnosis, monitoring and rehabilitation.

- Age and Gender influence the risk of developing heart failure. These risk factors can not be controlled by the patient and hence are not significant for the intended goals of the visualisation.
- Rapid weight gain can be a sign of a worsening heart condition. Since weight is also an important measure of diet and lifestyle, this input parameter is essential.
- Blood pressure data is of limited use for our application since few patients in New Zealand have the necessary monitoring equipment.

Patient parameter	Visual representation
weight	body contour
fluid retention	enlarged body contour
fluid in the lung	blue lung
swollen feet	enlarged feet contour
reduced blood circulation	transparency of arteries increases farther from heart
confusion	thought balloon with symbols
fatigue	thought baloon with "zzz"
weak posture	hanging shoulder and head

Table 1: Visualisation of patient parameters.

- The pulse is easy to measure and visualise, but care must be taken that no wrong conclusions are drawn by pulse rate changes due to other factors such as stress and physical activity.
- In order to improve patient outcomes we want to promote physical activities. Hence, exercise is an essential parameter.
- Alcohol intake is an important component of patient behaviour and requires monitoring and control.
- Heart failure patients are strongly advised to quit smoking and hence this parameter needs monitoring.
- Patients' salt intake is a significant parameter in heart failure (high blood pressure), but is difficult and inconvenient to measure quantitatively. Preliminary interviews suggested that recording the number of fast food meals and snacks consumed would be unreliable due to forgetfulness and different interpretations (what is a "snack"?). We hence use a qualitative measure by recording whether patients add extra salt to their food.

5 Design

5.1 Visualisations

Based on the identified symptoms and affected organs, the most relevant components of the 2D body visualisation are the heart, the lung, the arteries and the body contour. Table 1 explains how different patient parameters are displayed. When displaying conditions it is important to first show a healthy body or the current situation for comparison. Changes to the 3D heart model include changes in the heart beat rate and enlargement to indicate cardiac remodelling when load is increased (high blood pressure).

5.2 Structure and Content

A major design aspect of the application is to visually represent key relationships between symptoms, patient behaviour and the disease. Based on the previously discussed information the following tables were developed. Table 2 presents symptoms and the corresponding patient parameters represented in the body visualisation. Table 3 presents patient behaviours (lifestyle choices) and the affected patient parameters.

As discussed in subsection 4.1.3 a clearly structured narrative is crucial for the effectiveness of the application. We choose a linear structure which is centered around the 2D body and 3D heart visualisation. Text is predominantly displayed in the text section of the web page as indicated in figure 6. More detailed explanations are displayed in pop-up windows. This simplifies the linear structure and gives the user the option to skip detailed explanations.

Symptom	Patient parameter
breathlessness	lung, circulation
weight gain	weight, circulation
swollen feet	swollen feet, circulation
fatigue	weak posture, fatigue, circulation
confusion	confusion, circulation
weakness	weak posture , circulation

Table 2: Mapping of symptoms to patient parameters.

Behaviour	Patient parameter
high calorie diet	weight
exercise	weight, circulation
salt intake	swollen feet, weight, circulation
smoking	lungs, circulation
alcohol intake	lungs, weight, circulation

Table 3: Mapping of patient behaviours (lifestyle choices) to patient parameters.

The narrative starts with an explanation of symptoms of heart failure. This is followed by information about weight monitoring since this is one of the most essential measures for patients to observe. The patients should understand that rapid weight gain in a couple of days has to be reported to their healthcare provider. Explanations to weight and diet related items, such as exercise and salt intake, are followed by information about smoking and alcohol intake. The narrative ends with information about cardiac rehabilitation.

6 Implementation

6.1 Technology Choices

Web graphics technologies were evaluated using the framework presented in (Holmberg 2006) and the requirements summarised in section 4.1.2. For the 2D visualisation both Adobe Flash and SVG were identified as possible solutions. At the start of this research Adobe Flash needed a plug-in, whereas SVG only needed one for the Internet Explorer and all other major browser were natively supported. Further advantages are the text based nature of SVG and free tools for graphical editing, such as Inkscape (Inkscape 2010). We hence decided to use SVG for the 2D body graphics.

For the 3D content JOGL was chosen and embedded using a Java applet. The technology is a Java binding of the popular OpenGL API which facilitates the integration and animation of different 3D model formats. It allows the use of vertex and fragment shaders for rendering and animation and Java applets are supported by all major browsers. JOGL does not need to be installed on the client computer such as Java3D. Eclipse is used as development tool.

Besides the visualisation technologies, HTML, CSS and PHP are used to create the user interface. JavaScript is applied for the client side scripting, because both technologies have the ability to work with it. The Document Object Model (DOM) offers the access to elements of the SVG and the Java applet, so that user input through the user interface can influence the visualisations.

6.2 2D Visualisation

Figure 1 (a) shows the healthy body contour with the arteries, the lung and the heart. Each element is described in SVG with a <path>-tag which characterises a Bézier curve and its style (colour, opacity,

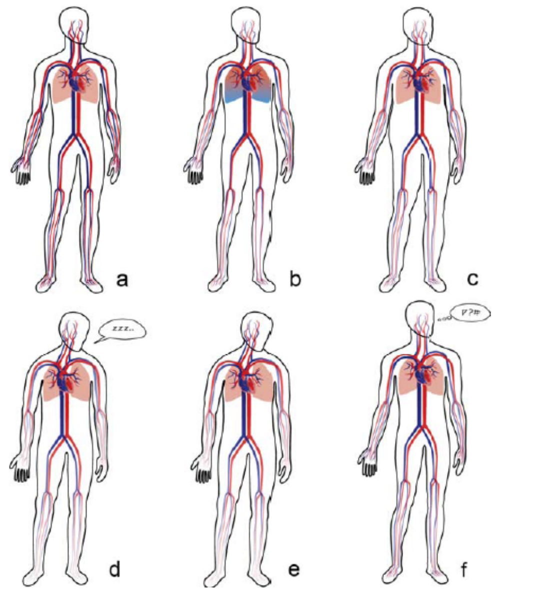

Figure 1: Body visualisations. a: healthy, b: breathlessness, c: weight gain, d: fatigue, e: weakness, f: confusion.

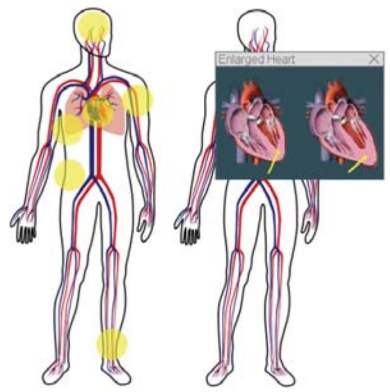

Figure 2: Highlighted body regions (left) and SVG pop-up window within the body graphic (right).

etc.). The arteries and veins are represented in red and blue to indicate oxygen rich and poor blood, respectively. The lung is pinkish in the normal state and becomes blueish when fluid build-up is represented. Insufficient blood supply to the body is indicated by increasing the transparency of arteries with increasing distance from the heart.

6.2.1 Intra-Element Interaction

SVG supports four animation elements which are defined in the SMIL Animation specification (W3C 2010):

- `<animate>` allows scalar attribute animation over time
- `<set>` sets a value of an attribute for a specified duration
- `<animateMotion>` moves an element along a motion path
- `<animateColor>` modifies the colour value of particular attributes or properties over time

The animation can be activated through a mouse click, mouse motion or keyboard input. Since browser support of these functionalities is limited we use JavaScript to animate and interact with the graphics.

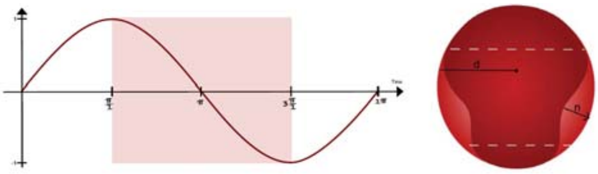

Figure 3: Section of a sine curve used to animate the model in order to simulate non linear deformation during a heart beat (left) and a schematic representation of the resulting deformation (right).

Intra-element interaction is used to highlight specific areas of the body (yellow dots in figure 2) when the mouse moves over them. A click opens a small window using an SVG Window Object (Andreas Neumann and Andre M. Winter 2010) and a JPEG image is loaded by creating a new SVG element.

6.2.2 Inter-Element Communication

Inter-element interaction describes the communication between SVG and other elements of the application. The user input is integrated via a HTML form. With every input a JavaScript function is called to change the SVG graphics using access via the Document Object Model. The body contour, for example, is modified through

```
svgdoc.getElementById(body).setAttribute(d,x)
```

The SVG document is searched for the element "body" and the path attribute 'd' is changed into the new value 'x'. The modified contour is illustrated in parts (c)-(e) of figure 1. In a similar way it is possible to edit the colour of the SVG element. For example, for the lung in figure 1 (b) a colour gradient is used when the symptom "breathlessness" is chosen.

6.3 3D Heart Model

JOGL is supported since Java Runtime Environment version 1.4.2. The JNLPAppletLauncher downloads native code on the fly and allows the use of JOGL via an applet without the need to be signed or an additional installation of software on the client computers. The user will receive a security dialog to accept the certificate for the JLNPAppletLauncher.

The applet reacts to user input through a JavaScript function call. The JavaScript function can call functions in the Java application via DOM:

```
document.getElementById("HeartApplet").
            getSubApplet().function();
```

This ability to use JavaScript and to call functions enables loading new content in response to user input. MAYSCRIPT has to be named in the <applet>-tag to give access to the JavaScript of the web page. JOGL does not natively support loading of 3D models, but there are some implementations of OBJ file loader for Java. We modifed one from (Andrew Davison 2010) to work within applets.

6.3.1 Heart Animation

In order to simulate the heart deformation we analysed a heart model obtained from computed tomography images (Wünsche & Young 2003). The hearts motion is best described as wringing motion. The heart surface seems to have the strongest perceived deformation around the center section and towards the apex. We approximate this motion by displacing the surface of a polygonal 3D heart model using the function

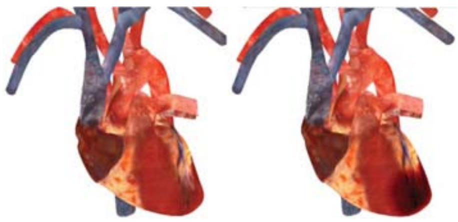

Figure 4: Heart model without (left) and with (right) multitexturing to indicate an infarcted region.

$$\hat{v} = v + n\sin(\alpha)a|\sin(time)|$$

where n is the surface normal at the vertex v and a is a scale factor. The sine function with the time argument varies between 0 and 1, which corresponds to the maximum contraction and expansion of the heart. The second sine function with the parameter α has the effect that the displacement depends on the position with respect to the centroid of the heart. The displacement is zero for vertices above and below the white lines in figure 3 (right) and is maximal at the centre section of the model. The vertex displacement formula is efficiently implemented as a vertex shader using GLSL (OpenGL Shading Language) and has no measurable effect on rendering speed.

6.3.2 Texture Mapping

Multitexturing is used to create an infarct region as illustrated in figure 4. The shader computes new texels by subtracting the infarction texture from the heart texture (see figure 4). Note that in reality infarcted and healthy tissue are visually indistinguishable. The visualisation symbolises heart damage caused by bad life style choices.

6.4 User Interface

The user interface consists of three panels: one for visualising the body, one for the heart, and one for user input and navigation. The user input consists of HTML form elements such as text entry and selection lists. Input values change the body and heart visualisation via JavaScript functions.

Before the application starts a page with an SVG and a Java applet is shown to test whether appropriate plug-ins are installed. Links to the appropriate downloads are provided (see figure 5). The first page of the application shows visualisations of a healthy heart and body. The drop-down box for selecting symptoms is initially set to "healthy".

7 Results

7.1 Usability Study

The usability of the application was tested using a web-based survey of technical and user interface aspects (Fischer 2009). A total of 23 participants from Germany and New Zealand took part in the survey. 16 participants (nine females and seven males) completed the survey and 7 did not because of technical difficulties. Twelve participants were between 20 and 30 years old, three participants between 30 and 40 years old, and one was in the 40-60 age group. Half of the participants were native English speakers. Only one person was not a university student, the remaining participants studied psychology (8), computer science (4), medicine (1), and other fields (2).

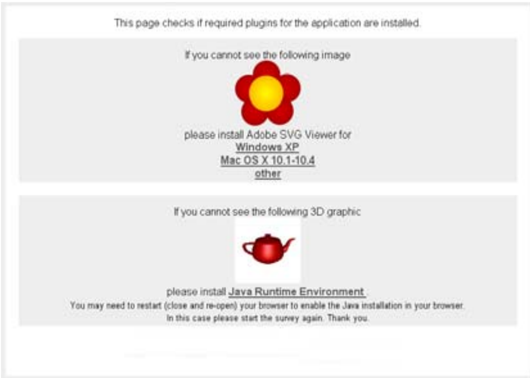

Figure 5: Test and download page for required plug-ins.

7.1.1 Technical Aspect

Technical problems were predominantly dependent on the Operating System. The 12 participants, who used Windows XP finished the whole survey. Half of them used Mozilla Firefox 3 and did not need a plug-in for SVG. The other half used Internet Explorer 7 and had to install the plug-in. Five of the 12 participants could not see the Java applet, but it worked after installing the Java Runtime Environment. “Not my computer” was the only reason mentioned for not install the SVG Viewer or the Java Runtime Environment.

During the development we became aware that Windows Vista and Internet Explorer did not support the Adobe SVG Viewer. As a result 5 of 8 Windows Vista users did not complete the survey since they could not see the body graphics.

One participant used Linux and Firefox 3. The SVG visualisation worked fine, but the Java Runtime Environment could not be installed because of lacking administrator privileges. Two participants using Mac OS X and Safari did not complete the survey, because the Java applet was not working after installation of the Java Runtime Environment.

7.1.2 User Interface Aspect

All but two of the participants found interaction with the 2D body graphics “easy” or “very easy”. The two participants who disagreed did not recognise that the graphics was interactive. All but one participant were satisfied with the heart and body model and had no difficulties understanding them. Most users were satisfied with the written messages in the text boxes, but 3 participants would have preferred a more “entertaining” text. Further suggestions were to replace/extend information in the visualisation with a quiz to make it more interesting, to visualise smoking and alcohol consumption more explicitly, and to make navigation options visually more obvious. Participants who could see the visualisations perceived the application as moderately informative, and those without problems using it enjoyed the experience (Fischer 2009).

7.2 Clinical Study

In order to evaluate the effectiveness of the application a study was conducted with Māori heart failure patients. Heart failure is a major health issue for Māori (Ministry of Health, 2010; Riddell, 2005; Robson & Harris, 2007) since the heart failure mortality rate is approximately three times that of non-Māori (Māori Health (2010)). In addition, Māori are five and a half times more likely to be hospitalised with heart failure than non-Māori (Māori Health, 2010).

However, Māori have been resolute in resolving their state of health, incorporated key legislation, and developed models of health that resonate with their cultural values. The negative state of Māori health may be offset by the majority of health conditions (chronic illnesses and risky lifestyles) that are preventable and manageable. As such, this allows an opportunity for patient education intervention that acknowledges Māori cultural values and concepts, which must be taken into account when examining the effects of our application.

7.2.1 Study Design

The study was conducted using semi-structured interviews. Participants were Māori individuals diagnosed with heart failure who attended the Manukau Super Clinic, Manukau or whañau of the Māori individuals with heart failure. Exclusion criteria to participation were cognitive impairment, age of less than 18 years and a non-Māori ethnic identity. Te Reo Māori (the Māori language) was spoken as appropriate with the participants. Eighteen potential participants who met the exclusion and inclusion criteria were invited to participate in the study. Four potential participants declined due to failing health or other commitments. Eight Māori individuals with heart failure and six of their whañau members of the Māori individuals with heart failure participated in the study.

The use of semi-structured interviews has been suggested as the appropriate technique for health research among different cultural groups (Bowling 1997). An advantage of this approach is that more complex issues can be probed and answers clarified in a more relaxed environment. It is therefore more successful in enhancing in-depth discussion. Face to face interaction also supports ’he kanohi kitea’ people meeting personally, so that trust in the relationship between the researcher and participants can be built.

Since many participants did not have a computer and/or Internet access the interviewer conducted the studies with a laptop containing an installation of the Heart Mentor application (see figure 6).

A brief introduction informed the participant that the Heart Mentor Programme was a ten minute programme with images of the heart and body, and information about heart failure. The programme was accessed as directed by the text and audio media to the completion of the programme. Information details requested by the programme were fictional or supplied information from either the interviewer or participant. The option was offered to the participant to operate the programme, if not the interviewer would take direction from the participant, for example, to view information again or to make changes to informational details. Participants then viewed the heart imagery programme. During the presentation of the programme, dialogue was encouraged from the participant by natural verbal prompts from the interviewer, such as, “let’s go back to that, shall we?” or “shall we put that in?”. After the completion of the programme, questions explored the participant’s responses to the imagery programme. At the end of the session all participants received a koha (gift) in appreciation of their participation.

Ethics approval was obtained from the Northern Y Regional Ethics Committee for a period of 1 year, from 31 July 2009 until 31 July 2010 (Ref: NTY/09/05/045). Further approval was from the Māori Research Review Committee Counties Manukau District Health Board (Ref: July_ap_03) and Counties Manukau District Health Board (Ref: 750) as the study was situated within the Counties Manaukau District Health Board authority.

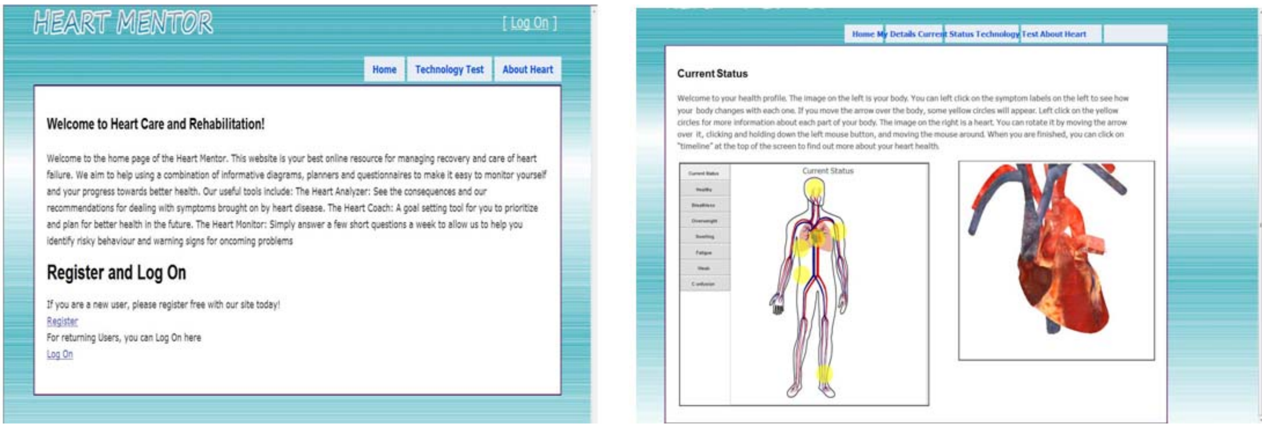

Figure 6: The Heart Mentor "Welcome" page (left) and the interactive "Current Status" page (right).

7.2.2 Heart Imagery Programme Questions

The key themes to the heart imagery programme questions were, whether and how the programme added to knowledge about the heart condition and enhanced coherence in heart failure representations. These questions addressed two areas: The quality of the programme itself and understanding of the role of adherence to treatments in managing heart failure. Questions about the programme centred on whether information increased understanding of the heart condition, associated symptoms and its perceived benefits. One question about the programme was technical, in that the participant was asked about the ease and simplicity in operating the programme. Changes in understanding about treatment and symptom management were assessed by the adherence questions. An additional question, exploring possible gains in knowledge and understanding of the participants' heart condition, probed for willingness to recommend the heart imagery programme to others, "Do you think this programme should be easily available to yourself and your whānau?". More detailed information is found in (Morunga 2010).

7.2.3 Evaluation of Participant Responses

The Heart Mentor programme depicts graphic images of the body and the heart. For that reason, prior to the demonstration of the heart imagery programme, the interviewer verified with the Māori participants that this was acceptable to them. As all participants agreed the demonstration of the heart imagery programme proceeded. Thirteen of the participants viewed and commented on the heart imagery programme.

Gaining *matauranga* (knowledge) and understanding information from the heart imagery programme was of great benefit to the participants. Most participants relished the opportunity to read and discuss sections of the programme.

Of the Heart Mentor programme featured pages, the "Current Status" page in figure 6 evoked the most comments due to the graphic sections on 'symptoms' and 'image of the heart'. The program text "The image on the left is your body", was quickly responded to by the participants as in, "is that really my body?" The interviewer explained that recording in the "My Symptoms" section tick boxes of the "My Details" page would provide the information for the image of the body. Some participants asked that the programme go back to the"My Symptoms" section to tick other boxes to verify the body image changes.

All the participants found the beating heart and the ability to rotate it very engaging. The interviewer was continuously instructed to "move the heart around . . . that way . . . the other way". Most questions were about "is that my heart beating?", "why is it red and blue?", and "is it (the heart) really that size?" The interviewer answered some of the questions and again advised the participants to talk with their doctors. One participant stated she was "fascinated by the beating and can't take my eyes off the heart". The images of the heart, body, circles and labels, all the information, had helped them to understand the symptoms of their heart condition better, or that they now recognised the symptoms of their whānau members. One individual with heart failure had gained some new understanding about blood flow in relation to the body's ability to function.

"*those parts in yellow. That was interesting, that. I don't know if I can explain it, yeah, all I can say was it was interesting to see why certain parts of the body doesn't function properly because of the blood flow, not getting much blood flow into it. That's about all I picked up on that, the reason why they can become dysfunctional.*"

However, another individual with heart failure was distressed by the symptom information but expressed the intention to be more vigilant in the future to his symptoms.

"*That's scary eh? Yeah, I know what to look for, you know the weakness, all the weakness, like the breathing, and your body blowing up, coming up to a heart attack.*"

With added knowledge and understanding there can be improved management of the individual with heart failure's illness. The following responses typify comments from the participants.

A whānau participant expresses her relief at gaining further understanding about the individual with heart failure's illness to manage a specific area of concern.

"*We truly know how to, what is happening inside his heart, and why he's getting all these symptoms. In the 2 years that we've been dealing with this illness, it's so good to have it summarised up so that we know how to care for ourselves better. You know the next thing I think we need to do is have a strict heart diet.*"

Whānau members were pleased about identifying the individual with heart failure's symptoms and understanding more about the illness.

"*Yeah, yes, I understand it a little bit more. Because he used to be breathless too and he used to tell me that his doctor said that he has an enlarged heart.*"

"*Yeah I think, like I don't think, you know having seen it, it makes me understand his illness better.... His puku, his swelling and stuff like that, that's made that a bit clearer. And we identified with all those symptoms eh?*"

As the following whānau participant implies the information added to their existing knowledge and, also, corrected a misconception.

"*I mean we know that she's got a heart condition, but we don't know what it affects and what it entails. But I think to see why she actually has to do that and why the body's doing that, yeah, that's interesting. Because I didn't know that involved too much of the heart. I thought that was because of the smoking over all these years. So, yeah, I didn't realise it was the heart condition, why the lungs were filling. We knew that the fluid on the lungs wasn't good for her heart though. We understood that. Yeah, so that's good.*"

An individual with heart failure was enthusiastic about his improved understanding and possible strategies to manage the illness.

"*it's new information and I just got to watch my eating, watch my drinking, listen to my body and, yeah, learn to eat more healthier, healthier food.*"

An unexpected benefit can be recognition of symptoms that were undiagnosed. One whānau participant recognised a symptom that was troubling her. To clarify, following is selected text from the heart imagery programme that preceded the following comment, "You may notice some swelling in your abdomen, legs and feet. You will see that these areas of the body are now bigger. Swelling occurs, because blood doesn't flow as quickly around your body, so fluid can build up in tissues and veins."

"*Now I understand why my legs always swelled up. But I always had that for, even though I was skinny, you know, I still get swelling in the ankles. Well not now, I'm not skinny anymore. But I thought it was just the hereditary from my dad.*"

The complete interview findings are presented in (Morunga 2010). In summary the heart imagery computer-based programme is placed as the mechanism through which knowledge and understanding of the illness and its symptoms are enhanced. This can alleviate emotional distress that the participant may be experiencing. For example, one individual with heart failure was anxious as to why he had to take a specific medicine and undertook behaviours to avoid taking this medicine. Knowledge and understanding about the illness and more specifically, the medicine's purpose to treat a symptom can alleviate the distress and influence self-management of the illness and the symptoms.

The Heart Mentor's graphics encouraged a greater sense of coherence between the symptoms and the condition, and thus enabled a strengthening of knowledge and understanding of the illness and the symptoms. This encouraged the endorsement by the participants to make available and accessible the programme to whānau and other individuals with heart failure so as to increase their knowledge and understanding of the illness and its symptoms. Thus, enhanced knowledge and understanding of the illness and its symptoms can motivate protective action, such as, for the individual with heart failure to improve self-management of the illness and the symptoms, and for the whānau participant to be supportive of the individual with heart failure's self-management of the illness and the associated symptoms.

8 Conclusion and Future Work

The Heart Mentor is a novel application supporting the heart rehabilitation process through behavioural change. This is achieved by combining educational content with an interactive 2D body and 3D heart model reflecting patient parameters.

The usability study proved that the lack of web graphic standards and the rapid changes in software and hardware made platform independence difficult to achieve. In particular SVG proved to be an unfortunate design decision due to Adobe support ceasing since Windows Vista. We are currently testing Adobe Flash and Silverlight for 2D graphics and Web3D and Silverlight for 3D graphics.

Several users did not notice that the 3D heart model is interactive and only started to rotate it after they were prompted to do so. We hence believe that more audio support is necessary to guide users through the application and to demonstrate disease and patient parameters (e.g., a dry cough versus a "normal" cough).

The heart imagery programme promotes knowledge and understanding of the illness and its associated symptoms. The sub-themes were (1) Emotional distress is alleviated by knowledge and understanding of the illness and its symptoms; (2) Text contents and imagery contents of graphics encourage knowledge and understanding of the illness and its symptoms and (3) Availability and accessibility of the heart imagery programme fosters shared knowledge and understanding of the illness and its symptoms. Overall, the study revealed that the patient education programme enhanced representational coherence of heart failure and its management held by Māori individuals with heart failure and their whānau, therefore, motivating engagement in protective behaviours.

We are currently extending the Heart Mentor application to further empower patients to take charge of their own health. This will be achieved by adding social networking components for providing social support and opportunities for sharing with peers (patient groups). We also are developing interactive tools for creating *action plans* which allow patients to define and monitor goals.

Results so far have been encouraging and we strive to make our application accessible to a wider population group in the future.

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References

American College of Cardiology/American Heart Association Task Force on Practice Guidelines (2005), 'ACC/AHA 2005 Guideline Update for the Diagnosis and Management of Chronic Heart Failure in the Adult'. URL: `http://circ.ahajournals.org/cgi/content/full/112/12/e154`.

American Heart Association Inc. (2010*a*), 'Heart360^{TM}'. URL: `https://www.heart360.org`.

American Heart Association Inc. (2010*b*), 'Homepage'. URL: `http://www.americanheart.org`.

Andreas Neumann and Andre M. Winter (2010), 'SVG Window Object'. URL: `http://www.carto.net/papers/svg/gui/Window`.

Andrew Davison (2010), 'Pro Java 6 3D Game Development'. URL: `http://fivedots.coe.psu.ac.th/~ad/jg2/`.

Bowling, A., ed. (1997), *Research Methods in Health: Investigating Health and Health Services*, Open University Press.

Bradley, M. M. & Lang, P. J. (1999), 'Fearfulness and affective evaluations of pictures', *Motivation and Emotion* **23**(1), 1–13.

Bradlyn, A. S., Beale, I. L. & Kato, P. M. (2003), 'Psychoeducational interventions with pediatric cancer patients: Part I. patient information and knowledge', *Journal of Child and Family Studies* **12**, 257–277.

Broadbent, E., Petrie, K. J., Ellis, C. J., Ying, J. & Gamble, G. (2004), 'A picture of healthmyocardial infarction patients' drawings of their hearts and subsequent disability: A longitudinal study', *Journal of Psychosomatic Research* **57**, 583–587.

Cameron, L. D. & Chan, C. K. Y. (2008), 'Designing health communications: Harnessing the power of affect, imagery, and self-regulation', *Social and Personality Psychology Compass* **2**, 262–283.

Cameron, L. D. & Leventhal, H., eds (2003), *The Self-Regulation of Health and Illness Behaviour*, Routledge.

Doughty, R. N. & White, H. D. (2008), Epidemiology of heart failure, *in* R. R. Baliga, B. Pitt & M. M. Givertz, eds, 'Management of Heart Failure', Springer, London, pp. 1–11.

Fischer, S. (2009), Web-based simulation for heart failure management and care, Master's thesis, University of Koblenz-Landau, Germany.

Fuster, V., O'Rourke, R. A., Walsh, R. A. & Poole-Wilson, P., eds (2008), *Hurst's The Heart*, 12^{th} edn, McGraw-Hill Companies, Inc.

Gardner, M. P. & Houston, M. J. (1986), 'The effects of verbal and visual components of retail communications', *Journal of Retailing* **62**(1), 64–78.

Hagger, M. S. & Orbell, S. (2003), 'A meta-analytical review of the common-sense model of illness representations', *Psychology & Health* **18**(2), 141–184.

Hammond, D., Fong, G. T., McDonald, P. W., Cameron, R. & Brown, K. S. (2003), 'Impact of the graphic canadian warning labels on adult smoking behaviour', *Tobacco Control* **12**(4), 391–395.

Hay, D. R. (2004), Cardiovascular disease in New Zealand, NHF report no. 82, National Heart Foundation of New Zealand. URL: `http://www.heartfoundation.org.nz/files/NHF6949\%20TechReport82.pdf`.

Holmberg, N. (2006), A framework for interactive web-based visualization, Master's thesis, Dept. of Computer Science, University of Auckland.

Holmberg, N., Wünsche, B. C. & Tempero, E. (2006), A framework for interactive web-based visualization, *in* 'Proc. of Seventh Australasian User Interface Conference (AUIC 2006)', pp. 137–144.

Horowitz, C. R., Rein, S. B. & Leventhal, H. (2004), 'A story of maladies, misconceptions and mishaps: effective management of heart failure', *Social Science & Medicine* **58**(3), 631–643.

Hunter, P. J. & Pullan, A. J. (2002), 'New developments in the Auckland heart model', *International Journal of Bioelectromagnetism - Special Issue on Electrocardiology and Neurophysiology* **4**(2), 47–50.

Inkscape (2010), 'Homepage'. URL: `http://www.inkscape.org/`.

Kolko, J., ed. (2010), *Pause & Effect: The Art of Interactive Narrative*, Morgan Kaufmann.

Lee, C. S., Tkacs, N. C. & Riegel, B. (2009), 'The influence of heart failure self-care on health outcomes: hypothetical cardioprotective mechanisms', *Journal of Cardiovascular Nursing* **24**(3), 179–187.

Lee, T., Cameron, L., Wünsche, B. & Stevens, C. (2010), 'A randomized trial of computer-based communications using imagery and text information to alter representations of heart disease risk and motivate protective behaviour', *British Journal of Health Psychololgy* .

Lopez, A. D., Mathers, C. D., Ezzati, M., Jamison, D. T. & Murray, C. J. L., eds (2006), *Global Burden of Disease and Risk Factors*, Oxford Press and The World Bank. URL: `http://files.dcp2.org/pdf/GBD/GBD.pdf`.

Masoudi, F. A., Havranek, E. P. & Krumholz, H. M. (2002), 'The burden of chronic congestive heart failure in older persons: magnitude and implications for policy and research', *Heart Failure Reviews* **7**, 9–16.

Meadows, M. S., ed. (2006), *Pause & Effect: The Art of Interactive Narrative*, Indiana, USA, New Riders.

Morunga, E. R. (2010), Māori, heart failure and a computer-based heart imagery programme, Master's thesis, University of Auckland, New Zealand.

Mosterd, A., Hoes, A. W., Bruyne, M. C., Deckers, J. W., Linker, D. T., Hofman, A. et al. (1999), 'Prevalence of heart failure and left ventricular dysfunction in the general population - the Rotterdam study', *European Heart Journal* **20**, 447–455.

National Heart Foundation of New Zealand (2010), 'Homepage'. URL: `http://www.heartfoundation.org.nz`.

Riegal, B., Moser, D. K., Anker, S. D., Appel, L. J., Dunbar, S. B., Grady, K. L. et al. (2009), 'State of the science: Promoting self-care in persons with heart failure: A scientific statement from the american heart association', *Circulation - Journal of the American Heart Association* **120**, 1141–1163.

Rubin, J., Wünsche, B. C., Cameron, L. & Stevens, C. (2005), Animation and modelling of cardiac performance for patient monitoring, *in* 'Proceedings of IVCNZ '05', pp. 476–481.

Simpson, A. & Barker, P. (March 2007), 'The persistence of memory: using narrative picturing to co-operatively explore life stories in qualitative inquiry', *Nursing Inquiry* **14**, 35–41.

Strothotte, T. & Schlechtweg, S. (2002), *Non-Photorealistic Computer Graphics: Modeling, Rendering and Animation*, Morgan Kaufmann.

Timmis, A. & Mccormick, T., eds (2003), *Heart Failure*, Churchill Livingstone.

W3C (2010), 'SMIL Animation - W3C Recommendation 04-September-2001'. URL: `http://www.w3.org/TR/smil-animation/`.

Wünsche, B. C. & Young, A. A. (2003), 'The visualization and measurement of left ventricular deformation using finite element models', *Journal of Visual Languages and Computing - Special Issue on Biomedical Visualization for Bioinformatics* **14**(4), 299–326.