Visualizing Exercise Hidden in Everyday Activity

by

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Submitted to the Program in Media Arts and Sciences,
School of Architecture and Planning,
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Master of Science in Media Arts and Sciences
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Abstract

Obesity in the United States has reached epidemic proportions and inactivity is a key factor in this health problem. One difficulty in promoting an active lifestyle is the idea that getting enough "exercise" means jogging, going to the gym, or riding an exercise bike for half an hour every day. While these activities are helpful, they can be daunting for an inactive person and difficult to plan into a busy schedule. Alternatively, many regular activities such as using stairs or walking to work can also provide healthy exercise. To bring attention to the exercise present in everyday activities, I created visualizations of full-time measurements of heart rate. These visualizations were designed to improve a person's sense of control over physical fitness. They show how everyday activities can accumulate into significant amounts of exercise. I conducted a pilot test of this device on a small number of subjects. These tests indicate that feedback of all-day heart rate measurements may lead to changes in beliefs about exercise.
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Thank you to my teachers Brian, John, Roz, Anna, and Ted. I hope to make good of the time and energy you have invested in me. Thanks Vadim for all your time and hardware! Thanks to all my yoga teachers who taught me the pleasure of falling down. Thanks to Google for allowing me to forget everything and just find out again later.

Thank you Slowly, you were my carrot on a string!
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Obesity in the United States has reached epidemic proportions, related to an estimated 300,000 deaths every year (Karra, 1999; Mokdad et al., 2001). One key factor in this health problem is inactivity. An estimated 25% of all adults are never physically active, and an additional 35% are not active on a regular basis (Phillips et al., 1996). This thesis aims to address this problem by using daily records of heart rate to direct attention towards the connection between lifestyle and fitness.

One difficulty in encouraging an active lifestyle is the belief that "exercise" must be a high-intensity workout separated from other activities (Macera et al., 2000). Actually, simple exercise such as a short brisk walk or using the stairs can lead to significant health improvements including improved mood, added muscle strength, and reduced risk of cardiovascular disease (Boreham et al., 2000; DeBusk et al., 1990; Donnelly et al., 2000; Hansen et al., 2001; Schmidt et al., 2001; Woolf-May et al., 1999). Furthermore, adherence to such short bouts of exercise is higher than prolonged exercise partly because it is more easily incorporated into daily practice (Jakicic et al., 1995; Jakicic et al., 1999).
visualizing all day records of exertion, I want to show exercise accumulated from every day activities such as short brisk walks or stair climbing. Presenting this information back to the user may increase a sense of control over health and fitness by connecting these everyday activities to overall exercise amounts.

Albert Bandura's theory of self-efficacy describes how people act primarily on their beliefs of their own capabilities (Bandura, 1992). I will argue that Bandura's model outlines how feedback of daily exertion can increase an individual's sense of self-efficacy towards health and fitness. The eventual result of this self-efficacy increase could be an increase in daily activity.

This study uses full time recordings of ECG to record daily exertion levels of subjects. During exercise, heart rate is a fairly good predictor of exertion. With full time recordings however, other factors contribute to increases in heart rate such as emotional stress or arousal (Surgeon General, 1996). Combining motion-sensing accelerometers to heart rate recordings gives a much better assessment of exertion (Strath, 2002).

The project includes a pilot study where three subjects used the device for one or two days, and were then shown the visualizations from that time. Each subject was interviewed to assess any possible changes in attitudes or beliefs about exercise. The evaluation indicated a positive reaction and interest by all subjects, with varying signs of changes in beliefs. Given each individual's different experience, the results highlight the importance of treating each case individually. Devices and activities such as the one outlined in this project would likely be useful as part of personal health and lifestyle counseling.
In this chapter I will first describe the experiences and ideas that led me to choose this project for my thesis. This description puts the project in a context that I believe to be of real value. Second, I will describe the experience of wearing a heart rate recorder all the time while I built the first visualizations of the data coming from my own body. Developing software around my own heart rate data was an interesting experience. I was getting feedback from my body, and was able to sift through it, and do with it whatever I chose. I had never had access to health information where I had so much control. Normally, a doctor would interpret the information for me. Here I was able to use my skills with computation to tinker with whatever questions I found interesting.

**Prologue**

It was about a year ago that I first went to the gym. At 24 years old, I figured it was best to start good habits early rather than earning that late 20's gut and then desperately trying to burn it off while my hair starts falling out. On my first day at the gym they offered me a complemen-
tary fitness test. I touched my toes, lifted some weights and had my fat pinched and entered into a spreadsheet. At one point I did what I later learned to be a standardized fitness test. I stepped up and down on an aerobics step for a minute, and then measure my heart rate. I was surprised when the trainer told me that I was in good shape. I was particularly surprised because I had come to the gym to get in shape. I hadn't worked out in as long as I could remember. And every previous effort to start an exercise regimen ended shortly after. I always lost my zest for stinky lockers rooms, sore muscles, and the sheer discomfort of working out.

It wasn't too long before this stint at the gym waned as well. This time I did manage to keep a regular schedule of yoga classes. I never considered them "working out" but I figured it was better than nothing. I was still puzzled by how I managed to be in shape. I did have one suspicion though.

Living and going to college in a small city, I live a fairly active pedestrian lifestyle. I walk to and from school 15 minutes each way. I've always enjoyed it as a quiet buffer zone between two worlds. I suspected this walking kept me in shape. Though I quickly dismissed this idea as the fantasy of someone hoping to get out of real exercise.

Through my time at MIT, I continued to practice Yoga, and have developed a curiosity about the systems in my body. I am particularly interested in the connection between small day-to-day choices and how these choices effect my health and moreover the quality of just being alive. By "quality of being alive," I don't mean some ethereal or mysterious state; I mean my baseline. It's the difference between facing the day having slept 3 hours and having slept 10 hours. The former will feel horrible, and the latter is much more likely manageable. When I am dehydrated, under fed, or tired, the small trials of every day living appear larger.
When I am well rested, hydrated, and energized, I am at a solid baseline, and fewer difficulties "unhinge" me.

This kind of thinking initiated a line of questioning about how I could record the tiny, elusive, forgettable choices I make day to day, and then reflect on them all together later on. The trick with a lot of these tiny decisions is that they were long ago delegated to habit.

I remember walking home one day as an undergrad, and suddenly noticing how fast I was going. As an experiment I deliberately tried slowing down. I couldn't believe it! I was instantly more relaxed. I started noticing more of my surroundings. I was no longer rushing to meet an invisible deadline. Instead I had the sensation of having plenty of time to get there. This is not to say that I forever walked slowly after that day. In fact, I doubt I walked more than a few blocks before I lost track of my newfound peace and was off to races again. But after that day, I had a choice that I hadn't had before. I had never thought to walk any speed but the one my legs walked at. Now, if I think about it, I can intervene and change my pace deliberately to serve my needs. I am also not suggesting that everyone start walking at a turtles pace. In fact, I will suggest the opposite-- people should try to walk a faster sometimes to get more exercise. The significance of my experience was the creation of a choice. I saw a control knob that I didn't know was there.

I was lucky in this case because my walking "experiment" made a change that I could experience right away. Often, the impact of habit is over the long term but enacted in the short term. For example, the choice of whether to stop working and get a drink of water, to eat or not eat a snack, or to take the elevator or take the stairs. These small choices compounded over time could affect blood pressure, hydration, blood sugar, weight gain, fitness, and
many other important factors.

As a result of these ideas, I wanted to record these choices, and make them more visible in order to reveal hidden "control knobs" and their significance. I thought about measuring the outcome of all sorts of choices-- the distance I walk in a day, the total time I watch TV, or the color of my pee. With each of these measurements, the question comes up about the true value of that data. How complex of a system results in that outcome? What will rise out of the noise and have real bearing on my baseline?

These various recording options also bring up many logistical problems. What is possible to measure? Initially I thought about sensors in my home that indicated how much I slept, or how long I spent eating breakfast. What about the systems directly inside my body? It seemed the most interesting stuff might be measured right off my body. These options include heart rate, respiration, hydration, blood sugar, movement, and brain waves. Eventually though, I came back to my experience at the gym, and my suspicion about getting exercise from walking to school. Some searches in medical literature further heightened my interest. There is a body of research that argue the benefits of "short-bout" exercise. The overall argument is that while some improvements may be greater given long bout exercise, accumulated short bouts are still helpful and the importance for people to exercise at all outweighs the differences. Boreham et al. show improvements in cardiovascular health in previously sedentary women after a seven week stair climbing program (2000). DeBusk et al. find high adherence to multiple short bouts of exercise as well as significant increases in fitness over an 8 week study of healthy men (1990). Hansen et al. show improved moods after 10 minutes of moderate exercise and recommend 30 minutes a day of moderate exercise in multiple short bouts (2001). Schmidt et al. find three 10 minute
bouts of exercise equally effective as a single 30 minute bout in weight loss and increasing fitness during caloric restriction with overweight young women (2001). Woolf-May et al. state that while the best-case scenario for exercise is longer bouts, short bouts also lead to health improvements; they advocate short-bout exercise because it is more likely to be a successful health intervention (1999). Doctors are endorsing small activities through out the day, or "lifestyle activities" as a way get exercise. The choice became clear that I wanted to visualize exercise accumulated in the day in order to give someone a different way to control physical health.

Life On-Line

The process of developing the visualizations began with the need to have some data to look at. I used the electrocardiogram (ECG) feature of Vadim Gerasimov's "Every Sign of Life" board to constantly measure my heart rate activity (Gerasimov, 2001). This device provides large amounts of data storage and easy transfer using a compact flash card. Because of this, it is a better solution for constant heart rate recording than commercially available heart rate monitors (Polar, 2002; Fitsense, 2002). I did not look in to medical grade heart monitors.

For two weeks, I wore the device as much as I could. The device consists of a package about the size of a deck of cards. A plug with three wires coming out of it plugs into the device. The three wires lead to three metal snaps that snap to adhesive electrodes warn on the chest. In order to keep the device safe, I kept it always inside a small nylon pouch with a belt loop. When wearing pants with a belt, I wore the device on my belt. When wearing house pants I would wear a sweatshirt with pockets and tuck the device in a pocket. The wires are not long enough to put the device
Figure 2-3a
The author’s exertion mapped over two weeks. See Figure 2-3b for corresponding activity logs.
<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Activity</th>
</tr>
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<tbody>
<tr>
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<td>5:30 pm</td>
<td>walk to talk</td>
</tr>
<tr>
<td>04_05_02</td>
<td>6:00 pm</td>
<td>sit at talk</td>
</tr>
<tr>
<td>04_05_02</td>
<td>7:50 pm</td>
<td>walk to Emma’s</td>
</tr>
<tr>
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<td>10:30 pm</td>
<td>walk home</td>
</tr>
<tr>
<td>04_06_02</td>
<td>9:30 am</td>
<td>wake make coffee code all day</td>
</tr>
<tr>
<td>04_06_02</td>
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<td>run to meet Rahul- go to parties</td>
</tr>
<tr>
<td>04_07_02</td>
<td>12:00 pm</td>
<td>wake up</td>
</tr>
<tr>
<td>04_07_02</td>
<td>1:00 pm</td>
<td>double cap</td>
</tr>
<tr>
<td>04_07_02</td>
<td>4:00 pm</td>
<td>walk to yoga</td>
</tr>
<tr>
<td>04_08_02</td>
<td>10:00 pm</td>
<td>go to bed</td>
</tr>
<tr>
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<td>12:10 pm</td>
<td>wake up shower</td>
</tr>
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<td>1:02 pm</td>
<td>begin walk</td>
</tr>
<tr>
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<td>arrive at lab, take stairs</td>
</tr>
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<td>walk to lunch</td>
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<td>walk back</td>
</tr>
<tr>
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<td>take stairs</td>
</tr>
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<td>5:50 pm</td>
<td>walk home</td>
</tr>
<tr>
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<td>yoga begins</td>
</tr>
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<td>12:30 am</td>
</tr>
<tr>
<td>04_08_02</td>
<td>1:02 pm</td>
<td>1:55 pm</td>
</tr>
<tr>
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<td>walk to pizza place</td>
</tr>
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<td>1:35 pm</td>
<td>ride bike to school</td>
</tr>
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<td>04_09_02</td>
<td>11:55 am</td>
<td>walk vigorously to school</td>
</tr>
<tr>
<td>04_10_02</td>
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<td>walk to food truck</td>
</tr>
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<td>climb Stairs</td>
</tr>
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</tr>
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</tr>
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</tr>
<tr>
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<td>1:19 pm</td>
<td>max hear rate test in green bldg.</td>
</tr>
<tr>
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<td>run home</td>
</tr>
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<td>3:55 pm</td>
<td>back at home</td>
</tr>
<tr>
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<td>run to yoga</td>
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<td>trip to 1369 in car w/folks</td>
</tr>
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</tr>
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<td>climb stairs</td>
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<td>2:46 pm</td>
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<td>4:07 pm</td>
<td>climb stairs</td>
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<tr>
<td>04_16_02</td>
<td>6:21 pm</td>
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</tr>
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<td>run and walk to and from grocery</td>
</tr>
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<td>go to dinner at Emily and Rob’s</td>
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<td>04_19_02</td>
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<td>walk to school</td>
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<tr>
<td>04_19_02</td>
<td>1:17 pm</td>
<td>climb stairs</td>
</tr>
<tr>
<td>04_19_02</td>
<td>4:19 pm</td>
<td>give demo</td>
</tr>
<tr>
<td>04_19_02</td>
<td>11:08 pm</td>
<td>run to Rahul’s</td>
</tr>
<tr>
<td>04_19_02</td>
<td>9:30 am</td>
<td>woke up and went to sleep again till noon</td>
</tr>
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<td>walking to school</td>
</tr>
<tr>
<td>04_19_02</td>
<td>6:09 pm</td>
<td>walking home</td>
</tr>
</tbody>
</table>
in a pants pocket. Especially for women users, having the device strapped to a belt makes using the toilet difficult. You have to make a shirt hammock by holding the bottom edge of your shirt under your chin. Then the device will rest happily in the hammock until you are done on the toilet. During yoga, I strapped the device to my arm with an ace bandage. At night (I chose to wear it during sleep too), I let the device float freely in the bed when I slept. The data collecting stopped mostly when the batteries ran out while I slept, when the plug came undone from the device, or when I just needed to take a break.

This device allowed me to start collecting heart rate data from my own daily activities and download it to my computer. I developed the first visualizations using this data, and learned what to expect living with an ECG.

The first thing to say about living with an electrocardiogram is how this device interacts with the body. Three sticky electrodes on the chest act as mediator between you and the device. These electrodes leave circles of goop that collect lint, and itch. Over a few days the goop and lint will wear off and a thin red circle is left for at least a week. Anyone trying to conduct a major distribution of such a device will need to solve this problem first.

It took about four days before I didn't notice the device hanging on me anymore. Though, I never stopped lifting my shirt at parties when people asked me what I was up to. When the two weeks was over, I had grown so used to it, that I kind of missed it.

Figure 2-3 shows my heart rate over the two weeks I wore the device. First off, notice the wide range of total exercise times over the two weeks. Four days show total exercise amounts of less than 10 minutes, and six days have more than 40 minutes. The 5th, 13th, and 19th are low partly because the device wasn't recording for some of the day. But even within the times it was
on, I didn't do much. Monday the 15th is a good example of a day where I didn't leave the house except to drive with my parents to a coffee shop. I show two minutes of exercise for the whole day. It isn't on the record, but I think it was from cleaning up my room for when my parents swung by.

It appears from the visualization that the days when I walk to school and home I get between about 15 or 30 minutes of exercise such as on the 8th and 10th. Some days I tried jogging to school to increase my levels of hard exercise, such as on the 11th and 12th. On the 11th, I ran to school and to the pizza place and got 22 minutes of hard exercise (43 minutes total). On the 12th I ran to school and home, but the monitor ran out of batteries right before I ran home; this day showed 15 minutes of hard exercise.

The days where my exercise totals were over 40 minutes almost always included two trips from the house. On both the 12th and 18th I reached totals over an hour, and on both days I walked to school and walked or jogged to a friend's house at night. On Saturday the 6th I was almost completely inactive all day, but ran to meet a friend and then walked with him about a mile to go to some parties. In the end this totaled about 38 minutes of exercise. While I had suspected the walk to school as contributing to exercise, I had never thought about being social at night as good exercise. When I get exercise "by accident" it goes easily unnoticed.

Another interesting feature is on Tuesday the 9th when I rode my bike to school. This gave me 6 minutes of hard exercise, and 12 minutes total for the day, not quite as much as a brisk walk or a slow jog to school. Over time, even with the errors of only using heart rate, I can develop an understanding of how much exercise my common activities offer me. My exercise amounts depend on factors such as my distance from common destinations, my usual walking pace, how fast I ride my bike, and how many flights
of stairs I must climb to get to my apartment or my office. By measuring the exertion amount for these activities, I can develop a "vocabulary" of every day exercise. This new knowledge allows me to estimate my exercise amount without wearing a monitor.

It is important to note that many of the discoveries I made about my exercise came in writing this chapter. Close inspection of the visualization and reflecting on the information led me to build new beliefs about exercise present in my daily practice. These visualizations should not stand alone. The user should use these tools in the context of some kind of organized reflection. I did not think to outline such reflection for this project, but I did try and ask many questions to the subjects in order to reveal as many discoveries as possible. One option for a deployment of a device with visualizations such as this would be to use it within one-on-one health counseling with a professional such as a doctor, nutritionist, or therapist. Another option would be to create a worksheet that had questions designed to promote discoveries.

My experience using the ECG and creating visualizations from that data was an interesting one. I resolved questions about how much exercise I actually got from common activities. I am particularly happy to discover that if I maintain a pedestrian lifestyle and walk most places, I should have a fairly easy time staying in shape. Whether it is done best with this device or not, I believe that many people could improve their lives both physically and mentally by finding fitness and exercise in their everyday activities.
In this chapter I will examine related research and theory behind visualizing all day heart rate. Measuring heart rate with a portable sensor system began in 1949 when Montana physician Norman J. Holter built a 75-pound backpack that transmitted an electrocardiogram over radio (Holter, 1949 cited in Jenins, 2002). Since then the "Holter Monitor," a device that records 24 hour ECG to tape or digital media, has become a ubiquitous device in medicine. Primarily, doctors use this device to monitor and diagnose cardiac patients. Immediate feedback of heart rate is commercially available through companies such as Polar and Fitsense (Polar, 2002; Fitsense, 2002). These companies make devices that transmit heart rate to a wrist watch so users can reach target heart rate levels during exercise.

All day measures of heart rate can be used to estimate exertion, but other factors such as emotional stress can lead to increases in heart rate that can be misunderstood as exertion (Moody, 1992). Recently, to account for this inaccuracy, Strath et al. have shown that a combined heart rate and motion sensor can provide accurate free-living measures of exertion (Strath, 2001; Strath, 2002). Just as
some research looks to isolate exercise, other research looks to isolate emotional response from physiology sensors. Picard and Healey set forth a system for measuring emotion and affect which can be used to measure factors such as stress and anxiety (Picard & Healey, 1997). Recent research has used pedometers to measure exercise and recommended exercise amounts as a number of steps per day (Wilde et al., 2001). The pedometer research is similar to this project because it describes using an all-day physiology measure as a means of encouraging exercise. Other current research focuses on treating diabetes with visualizations of health practice using glucose monitor data and photographs (Frost & Smith, 2002).

The goal of my research is to strengthen a person's belief in their ability to live a healthy active lifestyle. This is based on Bandura's theory of self-efficacy, the idea that people act according to beliefs about their own capabilities (Bandura, 1992). In health intervention research, self-efficacy has been shown to be an important variable in the adoption of good health practices (DeVellis & DeVellis, 2001).

Before addressing the specifics of Bandura's theory, I will establish two assumptions. The first assumption is that people believe that exercise is a beneficial activity. Without the belief that exercise has some positive effect, there is no motivation to try the activity. The overwhelming agreement from all health professionals is that some form of exercise is a beneficial practice (Surgeon General, 1996). People can believe that exercise is beneficial but also believe that they are incapable of doing it themselves. Consider the question, "Should I exercise?" I might believe exercise is beneficial, but reply, "No" because of a belief that it would be impossible for me to do so (Bandura, 1992).
The second assumption is that short bout exercise can improve health. Accumulation of short bout exercise has been shown to improve mood, increase muscle strength, and reduce risk for cardiovascular disease (Boreham et al., 2000; DeBusk et al., 1990; Donnelly et al., 2000; Hansen et al., 2001; Schmidt et al., 2001; Woolf-May et al., 1999). Short bout exercise consists of activities such as stair climbing and brisk walks. Long bout exercise commonly consists of activities such as a long walk, a jog, or a workout at the gym. Short bout activity is important because it can be part of everyday activities such as mowing the lawn, walking in the mall, walking to work, or using the stairs at the office. These kinds of activities, conducted with fervor and energy, can accumulate over a day into significant amounts of exercise. Because of this, short bout exercise creates an exciting potential for people to live healthy lives in ways they had not believed possible before.

According to Bandura, self-efficacy regulates human behavior through four major processes--cognitive, motivational, affective, and selection (Bandura, 1992). Cognitive processes involve an individual's thoughts and ideas, for example, whether a certain act is possible or not. Motivational processes involve 1) interpreting events that have already occurred; 2) Evaluating the expected outcomes of taking certain actions; and 3) setting goals for future actions (Bandura, 1992). Affective processes are the ability to control one's own thoughts, affect, and actions (Bandura, 1992). Lastly, selection processes are how an individual chooses an environment. For example, if I am trying to quit smoking, I might avoid a bar where people smoke. The theoretical impact of the heart rate visualizations is through influencing three of these processes--cognitive, motivational, and affective.
**Cognitive**

The cognitive influence is to change formal and informal knowledge of what activities constitute "exercise". "Exercise" needs to be redefined to constitute everyday activities. Visualizations showing an increase in short bouts of activity along with the experience of increased energy and greater physical capability could lead to the belief that short bouts of exercise improve health. The advice of a doctor or friend may also convince someone of the benefit of short bout exercise. The heart rate recordings could then further support that advice. Over time, concepts about an inability to "workout" can be left to the side because a person can get enough exercise without ever having to "workout" or be "in shape."

Most people already perform some short bout exercises every day, only probably not enough. Actually accomplishing a task is the most powerful way to create a strong sense of efficacy (Bandura, 1986, 1988, cited in Bandura, 1992). Walking and stair climbing are activities that nearly everyone has already mastered. Because it is a common requirement, few people can believe it is impossible to walk up a flight of stairs or walk a short distance. The cognitive change can thus be described as changing "exercise" from a difficult activity that one is unable to do into a collection of small activities that one already does regularly.

**Motivational**

According to the theory of self-efficacy, motivators come in three varieties: Causal attribution, outcome expectancy, and cognized goals (Bandura, 1992). Causal attribution is how people interpret events that already happened to them. Consider a man who hasn't exercised in years who tries to go for a 10-minute jog. Afterwards he is winded and his muscles are sore. If he has a high
sense of self-efficacy, he will probably feel good about these signs, interpreting them as the result of a healthy challenge for his body. If he has a low sense of self-efficacy, these factors might tell him that he is too out of shape to be doing such activities (DeVellis & DeVellis, 2001). One of the benefits of short bout exercise is that it can be somewhat "invisible." A woman walking with vigor between stores in a mall is still shopping, even though her body is getting exercise. This can help to avoid the potential for negative interpretations. Further, there isn't a mentality of pushing oneself beyond comfortable limits in everyday activities. The "no pain, no gain" attitudes traditionally associated with getting in shape is much more likely to give someone reason to have a bad interpretation.

The second type of motivator is "outcome expectancy," what people expect to get out of changing their habits and behavior. I already assumed that a person sees some form of exercise as beneficial. In addition, the visualization reflects an outcome that is difficult to perceive without an aid. Again, a walk in the mall is still shopping. In using regular behaviors to increase fitness, there is a possibility to not notice how these activities accumulate into exercise. Because of this, visualizing accumulated exercise throughout the day can increase the perceivable outcome. An increased outcome can increase the motivation to reach it. The visualization functions much like a penny jar. Throw in some coins at the end of every day and at the end of the year there is a surprising amount of money. Without the jar to accumulate the coins, the value of coins is easily overlooked.

The third motivator is "goal setting," where a person sets out an explicit challenge. This is a particularly important asset of recording heart activity. The heart rate visualizations can be used to both create challenges and confirm their attainment. For
example, after noticing that on Sundays that I normally get only 5 minutes of exercise in the day, I might set a small goal by deciding to walk to get the Sunday paper instead of drive. Then, I could use the visualizations later to confirm that my walk added 20 minutes of exercise to every Sunday. This process, self-evaluation, begins with using the visualizations to assess the current status. This assessment creates a base from which reasonable goals can be set. Lastly, future performances can be evaluated against this goal. In this case, the individual goes about another day of life while trying to park a little farther from the store and take the stairs more often than the elevator. Self-evaluation requires both sides of a comparison, the setting of the standard, and means of knowing one's performance level. Simply having a goal without knowing how one is doing, or knowing one's progress without having a goal has no lasting motivational effect (Bandura & Cervone, 1983; Becker, 1978; Strang et al., 1978, cited in Bandura, 1992). The combination of these two heightens motivation substantially (Bandura, 1992).

The heart rate recordings offer opportunities for comparison. Measuring activity amounts in the day allows the user to set auxiliary goals around exercise while maintaining the regular goals of a day's chores and business. People can set goals, easy to difficult, using their own knowledge of what works best for them. These decisions can also be made with counsel of someone who understands the type of goal setting that the individual will respond to best. In either case, the measurement can aid in the key practice of choosing goals and in comparing performance to goals.

**Affective**

The last intervention into the mechanisms of self-efficacy is in affective processes, how a person controls thought, affect, and
action (Bandura, 1997, cited in DeVellis & DeVellis, 2001). This intervention concerns directing thoughts, in other words, affecting the stimuli that a person attends to (DeVellis & DeVellis, 2001). There are two means of directing the attention of the user. The first is through the activity of recording heart rate all day. By explicitly participating in this activity, users may be more likely to attend to their hearts, or their level of exertion, throughout the day. By directing the users attention towards exertion levels throughout the day, I hope to increase one's belief in the ability to control these exertion levels. This control is possible through decisions such as choosing to take the stairs or adjusting the speed of walking. This direction of attention is supported further with the feedback from visualizations that reflect the user's choices.

The visualizations themselves also reflect an attentional intervention by highlighting the times of exercise with bright red and yellow colors. Times of exercise are the most prevalent features of the visualization. Again, this is aimed at increasing self-efficacy through showing users their ability to control how much exercise they get from every day activity.

Although the influence of self-efficacy is broken down into separate components, there are many interrelations between these processes. In the same way, the interventions will create an impact through their sum as well as alone. For example, a change in understanding that stair climbing counts as exercise might lead a woman to set a goal of climbing the stairs to her office twice a day.

A user with a strong sense of self-efficacy will likely make more changes faster using this tool than a person with a smaller sense of self-efficacy. In either case, the recording and visualization of heart rate may increase individuals' beliefs that they can control their body, fitness, and health through small changes in
everyday activities. This process works through changing understanding of how one can get physical activity, by providing measurement and feedback of how much exercise a person gets, and by directing the user's attention towards their exertion levels in the day.
Figure 4-1
Data collection, translation, and manipulation by stage.
This chapter documents how to make meaningful pictures out of tiny electrical signals in the body. The process begins with data from a digital electrocardiogram (ECG). It is then run through a series of software scripts. Finally, the software constructs an image that shows the total number of minutes where the heart was above a certain level during the day, and a color-coded map of heart rate over the day. Before describing this process, it should be established that this description of extracting data from an ECG is to document a fast and adequate means of collecting heart rate using the materials at hand. Research in medical sensing and correlating exertion data with sensor data is beyond the scope of this project.

**Hardware**

Three electrodes collect data by measuring very small electrical signals from the surface of the chest. These signals are caused by electrical potentials that trigger the muscles of the heart (McGill, 2002). Each electrode consists of an adhesive circle with a conductive gel in the middle. This gel provides a medium to transmit signals
from the skin to a wire that connects to the hardware.

The hardware is the "Every Sign of Life" (ESL) board designed by Vadim Gerasimov (Gerasimov, 2001). This board amplifies the tiny signals from the chest and converts them to digital signals for storage. The analog to digital converter samples the analog signal 250 times a second, with a 10 bit accuracy (each sample gets a value between 0 and 1023). The samples are written to a compact flash card plugged into the ESL board and amount to 27 megabytes of data every day (24 hours/day * 60 minutes/hour * 60 seconds/minute * 250 samples/second * 10 bits/sample). The ESL board can run for nearly 24 hours on four rechargeable NIMH AAA batteries. The data on the card includes a time and date stamp that can be extracted later.

After a period of data collection, the user removes the compact flash card from the ESL board and loads the data onto a computer. Data processing software, as described in the following section, prepares the data for the visualizations.

**Software**

This section describes a series of basic mathematics that filter, translate, and reconstruct the data collected with the ESL board. Figure 4-1 outlines this process. Each arrow in the diagram represents a script written in Python, an interpreted programming language (Python, 2002). Each script reads in a file and creates a new file using information from the first. There are six kinds of files, or six ways the data from the heart is represented: raw Data, BPM Data, Daily Data, Smoothed Data, HRR Data, and Summary Data. After all of the stages of translation have been completed, there are nine files that contain all the data collected from the body in some way. This process allows each stage of translation to be fully "exposed," available for inspection or graphing. There are
graphs of much of this data, but these are not all part of the user experience. The visualizations are designed to be simple and share only the data needed to know how much exercise is accomplished in a day, and when it occurs.

Stage 1- Raw Data

The data is transferred from the compact flash card into the computer and stored as a list of values between 0 and 1023 in a text file. The file contains the list of values written by the ESL board. These values represent voltages that the ESL board read in 250 times each second. The file size tends to about 3 megabytes per hour recording. As a text file, it is not compact, but it is easy to read. The values tend to range between 100 and 700. For each heartbeat though, a few values will appear over 900. These values...
correspond to measured voltages on the chest, but they are not a meaningful unit in this case. The meaning lies in the frequency of heartbeats.

There is one raw data file for every time the ESL reader is turned on. This can contain data from a few seconds to an entire day. The name of the file is related to the time that the recording begins. For example 04.13.02h15m59s45raw.txt is the file that started on April 13 2002, at 15:59:45. The specific time of any value in the file is determined based upon its place within the file and the starting time of that file. Because the raw data is written 250 per second, exactly 4 milliseconds pass between each data sample. The blue line in figure 4-6 illustrates an ECG signal as recorded by the ESL board.

**Stage 2- BPM Data**

Heart Rate, measured in beats per minute (BPM), reflects physical exertion. Heart rate also reflects other events such as emotional stress and inaccuracies present in any ECG hardware (Surgeon General, 1996; Moody, 1992). This project began with the assumption that heart rate would be close enough to exertion to experiment with giving people feedback about exercise in the day. The evaluation will describe experiences with this inaccuracy as well as potential uses that use it advantageously.

The raw data files are analyzed to determine the number of heartbeats per minute (BPM). There are multiple techniques for doing this. One very simple approach is to read in the raw data and count the number of times the values cross a threshold value, such as 900. This signal peak, also called the R-wave, corresponds to a moment where much of the heart muscle contracts (McGill, 2002). This is the beat that can be felt with a hand over the heart. In addition to looking for threshold crossing, the algorithm also as-
sures that 70 samples pass before counting another beat to prevent double counting single beats and to reduce susceptibility to noise (spikes in the voltages than aren't heart beats). Waiting 70 samples assumes a heart rate slower than 215 beats per minute:

for every 15000 values in the raw file (one minute of values):
    if value > 900:
        if I haven't seen a high value within 70 values:
            then count one more beat in the minute

The problem with this simple technique is that the peak values at each heart beat vary according to unpredictable factors, such as placement of the electrodes and dryness of the skin.

In figure 4-6, the peak values of the blue ECG signal move up and down. Breathing causes this beat-to-beat change in peak voltage (Moody, 1985). Breathing contracts and expands the chest that in turn moves the electrodes closer and farther from the heart. This causes small variations in peak voltage for each beat. These factors make a single threshold value a poor means of counting heartbeats.

To improve this reading, I created a simple falling threshold algorithm. The falling threshold is shown as the purple line in figure 4-6. This algorithm still counts the number of time the ECG signal crosses the threshold, but in this case, the threshold falls between each crossing. With each beat, the threshold is lifted back up to the peak value. Pushing the threshold only as high as the current peak value accounts for long-term variation. For example, if the
values are peaking at 700, the threshold will climb only that high instead of waiting for values of 900 that will never come. The falling threshold accounts for short-term changes in the peak value. It can catch short peaks between tall ones. For tall peaks, it just hits them "in the side" and gets lifted up. The threshold cannot fall too fast or else it will count small peaks or just "hit the ground." Fast heart rates require faster falling, and slower heart rates need slower falling. This is especially true because when heart rate is high, it is often accompanied by heavy breathing which causes the peak variation from beat to beat to be substantial. The rate of falling is controlled by the by the number of heartbeats counted in the last 10 seconds.

The threshold falls by a value $s$ each time a new value is read from the raw file (one for every 4 ms) where $s = b \times A - C$ where $b =$ beats in last 10 seconds, and constants $A = 0.21$ and $C = 1.2$. This linear function was made from guess and check on a variety of different samples of ECG. It slows the fall for slow heart rate, and speeds it for fast heart rates.

Lastly, if the sink falls below 0 (meaning the falling threshold would actually rise up) then it gets reset to 0.5. This safety prevents the algorithm from breaking after reading in some bad data, for example if an electrode got unplugged temporarily. This would lead to no beats getting counted, and sink end up as -1.2. For this research, this technique is simple and has enough reliability.

**Stage 3- Group the data by day**

At this point, we have used the files in the raw Data folder to fill the BPM data folder. The files still correlate to groups of consecutive data samples, one file for every time the device was turned on. Now the files are recombined so that there is a single
file for each day. This is done by reading through each BPM file in chronological order, and writing its values to the proper "daily file." Unlike the previous files, the data is no longer consecutive, so each BPM value is assigned to a minute of the day, a value between 0 and 1439. Therefore, each Daily file contains no more

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**Figure 4-9**
Smoothed BPM stage

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**Figure 4-10**
Raw heart rate plotted over time

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**Figure 4-11**
Smoothed heart rate plotted over time
than 1440 value pairs (the minute and the BPM for that minute),
one for each minute in the day. These files are named for the day
such as "04_13_02.txt."

**Stage 4a- Smoothing the data**

Figure 4-10 shows a graph of BPM data for one day. This
graph shows every minute-to-minute oscillation in heart rate.
These oscillations, when viewed over a day, create a hectic graph.
One way to simplify this data is to smooth it out. For ten itera-
tions, each value is updated to a weighted average with its two
neighbors-- 0.5 times the center value plus 0.25 times each side
value. This process pulls down peaks, lifts lows, and makes the
data a lot smoother. The result is shown in figure 4-11. With ten
iterations, many short events basically disappear and overall trends
appear more clearly. Erasing short amounts of high heart rate is
a poor way to reveal short bouts of exercise. On the other hand,
the smoothed view is a means to look at overall trends of a day.
While finding trends was not an original goal, there are potential
discoveries that subjects could make from viewing trends in heart
rate over a day.

**Stage 4b- Percent Heart Rate Reserve**

Percent heart rate reserve (HRR) is a measure of exertion
relative to the individual (Surgeon General, 1996). Every person
has a maximum and resting heart rate. Resting heart rate ranges
between 50 and 80 BPM; Maximum heart rate can be estimated as
220 - age (Surgeon General, 1996). Resting heart rate is normally
measured just after waking up or after sitting in a relaxed state for
5 or 10 minutes.

The range between minimum and maximum heart rate is
the heart rate reserve. HRR is the description of a heart rate as a
percentage of that reserve. For example, with a resting heart rate of 60, and a maximum heart rate of 180, a heart rate of 150 is using 75% of the reserve (HRR of 75%). This measure is particularly useful for this project because it is a measurement relative to the individual. If I am working at 50% HRR, I am using half of my fitness capability. This is also how many exercise recommendations are specified. An example is the 1995 American College of Sports Medicine guidelines for initiating cardiovascular exercise. They recommend 12 - 15 minutes of exercise 3 - 5 times a week at 40% to 85% HRR (Surgeon General, 1996).

The conversion from the daily files to the HRR files is a simple conversion where every minute of BPM data is rewritten in HRR form. Each subject has a small file with resting heart rate and age. Resting heart rate can either be given by the user if known, or read as a minimum BPM measured from the collected data. Each new HRR measure equals \( \frac{\text{BPM measure} - \text{Resting HR}}{\text{Max HR} - \text{Resting HR}} \). The data remains stores as a pair of values per line, the first value is the minute (0 - 1439) and the second value is the HRR (0 - 100). Again, any time where data was not recorded is left out of the file.

**Stage 5- Summary**

Creating the summary is the final step before making the visualizations. The summary groups similar HRR values together, and then creates blocks of time where the values remain in the same range. The ranges are grouped together according to an unofficial but common word description of HRR ranges-- very light (under 25% HRR), light (under 45% HRR), moderate (under 65% HRR), hard (under 85% HRR), and very hard (over 85% HRR) (Surgeon General, 1996).

Each minute of HRR data is assigned to its group. All
values under 25% are in "very light" and so on. Then, consecutive minutes in same exertion group create blocks of time. Each block is described with a number 0 through 4 that describes the group (very light to very hard). Along with this group number, the block has the start minute (0 - 1439) and block length in minutes. Each line in the file contains these three numbers, group, start, and length. This description of the day is easily converted into the image representation of exercise in the day. Rectangles can be drawn for each line in the file and colored according their group.

The summary script also keeps two running totals as it compiles the blocks of time. One is the total number of minutes of moderate exercise, and the other is minutes of hard and very hard exercise. These will be used in the visualization along with the time blocks.

In the case where the user kept activity logs, those are added into the summary file as well. The logs are stored as a file with a time and data stamp followed by a text string. This string is whatever note the user took at that time. One solution to make this transition easier is to use a palm pilot for field notes so that the file can be loaded in directly from the palm instead of transcribed from
Stage 6- Data Visualizations

The data visualizations are implemented in Flash MX. Flash is an authoring environment for building dynamic on-line content. In this case, Flash is acting to build visualizations of the data files created in Python. The data files are imported into Flash and the images are built according to actionScript code embedded in the Flash movie.

The first question the data visualization must answer is, "How much exercise did I get today?" Figure 4-15 shows the visualization. Along the top of the visualization is a row of values. The values in yellow indicate the total amount of "moderate" exercise in minutes, the values in red indicate the total amount of "hard" exercise and harder. Very hard exercise infrequent enough that it can be grouped with hard for these day totals. The value in black outline is the total amount of exercise in minutes. This row is designed to answer the first question, "How much?" This value is used for setting goals and for comparing performance to goals. Given a goal of 20 minutes a day for example, the user can quickly see what days the goal was reached, and what days it wasn't. If the user wants more information, each day has a "map" of heart rate over the 24 hours of the day.

The map is built directly from the time blocks in the summary file. It shows when the exercise occurred and at what level. The triangular markers down the side of each day indicate notes. In a dynamic version, clicking the markers brings up the note. In the paper version, numbered triangle match an accompanying numbered list of notes. The notes should help correlate specific activities with heart response as well as give hints for the user to remember events that may have been undocumented. The color bars alone can help to spot trends in days and weeks. These color values are
based on ranges of HRR described in making the summary.

In the key on the left edge of the graph, these ranges are described in heart rate values. This connects the color ranges back to the original beat per minute heart rate measurements. Users can also measure BPM with a finger on the neck counting pulses in ten seconds and multiplying that value by six. An ECG is not necessary to measure BPM for one minute. Giving context back to BPM makes the visualization useful after the ECG is gone. Users can measure heart rate and know whether their current activity counts as exercise. They can also find activities in the visualization with similar exertion rates to the current. These ranges could add meaning to an easy low-tech health measure.

What I have described so far is the visualizations used with subjects. After trying these visualizations with the subjects, I received feedback on the design and made changes to the visualizations.

One question that arises is what counts as exercise. In the first version, I counted a single minute in a certain range as exercise. A very short event such as a sneeze or lifting a heavy object and putting it down will probably not make a minute appear as exercise. If the heart is beating at a lower level for the rest of the minute, it will keep the minute average low. On the other hand, how short can a short-bout of exercise be? I chose one minute because I wanted people to see short events too. These have the potential of getting extended into longer more meaningful bouts of 3 or 5 minutes. This could also make users feel more confident about their lifestyle than they should. Given the goals of the users, and how much encouragement they need, this minimum exercise duration should be adjustable.

This sequence of steps outlines a condensation and filtering of large amounts of sensor data into a concise image. The software
extracts pertinent heart rate data from the ECG signal, organizes it into days, translates it into the relative measure of percent heart rate reserve, groups the data into time blocks, and finally makes an image from the time blocks. In addition, the software creates a smoothed version of the data over a day. This condensation of data creates a feedback mechanism to support short bout exercise during the day.

**Visual Reform**

After creating and testing the initial set of visualizations, it became clear that I needed to advance the visual display of this information. First, according to basic principles of color in visualizations, my initial color choice can cause visual discomfort because it
combines high chroma spectrally extreme colors (Marcus, 1995). I addressed this problem by creating a new color palette for my first visualization (figure 4-16). I chose colors by using the technique of selecting them from a photograph (Kobayashi, 1999). I used an outdoor image from a popular shoe company in hopes of tapping into the visual vocabulary of athletics advertising.

Early in this project, I wanted to represent heart rate using radial plots (figures 4-17 & 4-18). In a radial plot, the location of each point is given by a radius and an angle. In this case, time controls the angle and heart rate controls the radius at that angle. To help explain this visualization, I created a graphical explanation of translating a linear to radial plot (figure 4-19). I chose radial plots to encapsulate each day in a single shape. I highlight exertion levels using color gradients. This visualization is a sketch only and does not have exact correlations between colors and heart rate measures.

Unfortunately, in practice these plots were disappointing. The first problem is that it is difficult to read exertion levels in activities that take place over midnight. At this point in the radial
plot the time scale jumps 24 hours back. An event crossing over midnight must be read from two sequential radial plots.

Another problem is that when using angle to represent time, it is much like an analog clock. In this case, we have 24 hours instead of 12 hours which creates a confusion when reading the plot. Each plot could be split into two 12 hour plots, but this would create another discontinuity at noon in addition to the one at midnight. Another difficulty with radial plots is that one of the most prominent features is missing data. These big pieces of pie cut from the graph distract the eye. I had not considered missing data when I first thought of these graphs.

Radial plots share their last difficulty with the vertical bar plot. Both of these plots show the entire day. Thirty minutes of exercise appears very small on a 24 hour scale. One of my main goals for this project was to accommodate individuals with very
Figure 4-19
The stacking block visualization.
low-self-efficacy. In these cases, getting even a few minutes of exercise could be an important event. If a minute appears as a tiny dash or blip, this is not going to incite a great feeling of accomplishment.

Another problem with both the radial and bar type visualizations is that there is no way to explicitly set goals and compare performance. Goal setting is one of the most important aspects of the theory behind this project, so this would be a valuable addition to a visualization.

In response to these problems of scale and goal setting, I created a third visualization. In this visualization every bout of exercise appears as a block in a stack. Each day is a stack of blocks. Each block is sized proportionally to the number of minutes in the exercise bout. In this visualization, each bout of exercise must be at least two minutes long and of at least moderate difficulty (at least 45% HRR). The vertical bar visualization needed only one minute to count as exercise, and distinguished between exertion levels.

One week of data is shown in the stacking block visualization in figure 4-20. In addition to a week of days, the current “high score,” or best day of exercise so far is shown to the left in blue. This personal best measure can help encourage the user to go beyond it. It can also act to “congratulate” the user and not let such success go forgotten.

A slate blue shelf indicates the current daily goal for total minutes of exercise. This goal level can be changed over time. In the week shown here, the goal begins at 20 minutes of exercise per day and increases to 30 minutes. Minutes beyond the goal are highlighted in red to draw attention to times when users exceed their goals. Again, I am trying to draw attention to successes. The goal shelf also acts to create an empty space underneath which implies the emptiness of a goal not met. By creating a sense of
volume, the three dimensional style of the visualization helps to show emptiness better than just white space in a two dimensional graph. The explicit goal level also acts as a log of goal-setting. This record is a means of looking at a history of goals next to a history of performance. Past goals contextualize performance in a way that recording only exercise can not.

In the block stacking visualization, the 24 hour time scale of the other two graphs is gone. With this change, I did not want to lose the ability to answer the question of when exercise occurs. To accommodate this need, I show time in two ways. First, each block is labeled with the time when the exercise bout began. Second, a white mark at the bottom of each block is positioned according to this time. The far left is the beginning of the day, and the far right is the end of the day. This time marker allows users to take a quick look at when they are getting exercise and see how it is distributed over the day.

In creating this final graph I thought about this visualization in a clinical setting between a patient and counselor. My aim was to make something simple and encouraging. I also looked at the shortfalls of the previous visualizations in this context. I have shown how this final visualization allows goal setting, makes small changes more prominent, and highlights successes. For these reasons, I believe this to be the best visualization to meet the goals of this project.
To evaluate the practical potential of showing individuals their own heart rate, I conducted a pilot study where three individuals wore the device for one or two days. This chapter consists of three case studies describing the data collected and interviews with the participants while looking at the data. The interviews were conducted in an open exploratory fashion. As an initial exploration with this kind of visualization, I was looking for unexpected results as much as I was attempting to verify the theory behind the activity. In this chapter, I show the first version of the visualizations just as the subjects used.

**Subject B: male, age 27**

Subject B wore the ECG recorder on two nonconsecutive days. Though it was requested, he did not keep a log of his activity. This is a realistic outcome of this kind of research as many people would likely forget or simply choose not to record explicit data. This study is an opportunity to understand the difference in effectiveness with and without activity logs.

The subject was able to remember some of his
Figure 5-1
Subject B heart rate visualization
activities and piece them together using the visualization. On the morning of the 12th, the subject woke up, walked to the subway, and rode it to catch the 7:30am train to another city. This morning activity appears on the graph as well as the calm of riding the 7:30 train for one hour. The subject arrived at his destination at 8:30 and began walking in the city. He was looking for a coffee shop and wandering up and down hilly streets. Here we can see a definitive increase in his activity level as he walks around the city.

In this case, we face an interesting situation as the subject was facing some "major issues" in a long term relationship that were coming to the surface that day. This was causing the subject a lot of stress and worry over the day. He was walking around and having emotional stress at the same time. In a situation such as this, it is unclear whether adding motion sensors to the activity recorder would clarify the cause of high heart rate. Sensors would sense movement and could explain the high heart rate as due to physical exertion only. There is a blurring between emotional and physical causes for high heart rate. Here, the subject is nervous and walking around trying to relax and find some coffee. This is not an unusual thing to do, to walk and worry. One might also worry and pace or fidget, or be angry and throw a tantrum. Human behavior is full of physically expressed emotion. Measuring exercise with heart rate relies on separating physical causes of high heart rate with mental causes. In practice, drawing the line can be very difficult.

Wednesday the 17th was a more typical day for the subject. He shows 52 minutes of exercise over the day. This exercise is interspersed throughout the day in two to five minute bouts of moderate exercise. The subject was pleased to see this result. He realized from this that one important factor for his health was that he lives on the 5th floor of a building with no elevator. This means
he gets a solid bout of stair climbing every time he goes home. In addition, he lives on the campus where he goes to school. This means that he frequently returns home for meals, forgotten items, and daily chores. This is an excellent example of how a person's living environment can affect his health. In addition to the pedestrian lifestyle of a student going between classes on a campus, the subject has five flights of stairs to work out his heart every day. The 17th is freckled with short bouts of exercise because of this lifestyle. No bouts are over seven minutes, yet subject B accumulated 52 minutes of exercise in the day.

From this visualization the subject gained an unexpected appreciation of his top floor room in an old building. This new understanding of his staircase supports the theory that this device and visualization can influence an individual's beliefs about exercise and daily practice.

The subject did not feel the need to set any new goals. This may reflect a drawback in the system. Before realizing the value of his regular stair climb, subject B may have added more exercise to his life because he never "works out." After a change in beliefs, he may be less likely to get as much exercise as he did before. This was a potentially unfortunate effect of giving this feedback. It stresses the importance that this attitude towards exercise should not be seen as a final goal, but one on the way towards even greater levels of fitness.

The subject also did not report any difference in his attention while wearing the device. On both days he mostly ignored the device, addressing the issues of his regular life. As he reported, "I pretty much ignored it." Wearing the device didn't seem to influence the subject's attention; in other words, he reported no influence on his affective process.

Subject B provided some unexpected results because he
has a lifestyle where he is forced to get short bout exercise. While he remains in this living situation, he will continue to benefit from this environmental factor. When he moves to another place, perhaps he will replace this forced exercise with another activity. Perhaps he will choose to live somewhere where he has to take the stairs again. This would suggest an influence in the fourth process of Bandura's self-efficacy theory, selection process, how we chose where to be. I ignored this aspect of the theory because I could not think how this device or the visualizations could ever effect how a person chose an environment. In the case of this subject, there is a plausible story where he would choose an environment to maintain his forced exercise regimen.

**Subject C: female, age 32**

The subject was presented with this activity log and visualization of two days. Her first response to the data was to start matching activities with exertion levels. "I guess walking becomes moderate," she said right away. The subject saw her walking showing up as yellow regions. "What is hard?" she asks as she looks for red regions in the graph. She continues to connect certain activities with an exercise level. "Looks like using the stairs in my house looks like light, not moderate." This process reveals the potential changing cognitive models. The subject speaks about building connections between exercise amounts and activities common to her day. The drawback is the potential for false conclusions. Heart rate can vary throughout the day on its own. Heart rate response to low-intensity activities has been shown to be particularly variable (Surgeon General, 1996). More data would help this potential problem as well as hardware that relies on more sensors and reflects physical exertion more accurately.
Figure 5-6
Subject C heart rate visualization
The subject described how at 4:00 pm on Friday a conference started where she couldn't find a chair. Over the two-hour conference there is an increase from "very light" to "light" exertion. This coincides with her explanation that she was getting increasingly uncomfortable and shifty having to stand up for the two hours. This heart rate response could be from increased shiftiness, an increase in mental agitation, or both. It is difficult to distinguish between the mental and physical causes for high heart rate when they are closely related.

Noticing the red areas beginning at 10:15 AM on Monday without any corresponding notes in the exercise log, the subject recalled an upsetting e-mail received around that time. She was agitated for a while that morning, debating for whether and how to respond to the mail. This is a case where the heart record shows psychological stress. On the one hand it is an error, an example of the system's inability to distinguish physical exertion from stress. On the other hand, this disparity provoked an interesting discussion. She commented, "I never thought about how emotions could set off my heart in that way. If I had known in the moment that I..."
was reacting so severely for something so not worth it." The heart response gave a weight to the stress reaction that made an impression on the subject. This impression may affect her beliefs about the cost of stress in her life. Her body paid an unexpected price by her reaction to the e-mail. The subject reiterates that instead of just her mind, "It's my body also suffering for these annoyances, which are not worth it. The magnitude of the event is not worth it. To get all worked up." While this is not a change in understanding of exercise, it is a change in an understanding of stress. This indicates a potential use for aiding stress reduction.

After the 1045 walk to the post office, the subject's heart rate returned to the lower range where it was before the e-mail. This exposed the possibility that the short walk helped the subject relax. With more evidence such as this, short-bout exercise could appear not only to provide long term fitness related health benefits, but also short term emotional benefits.

After reflecting on the heart rate response to the stressful e-mail, the subject commented that she would like to wear the device during a therapy session. She wanted to use her heart rate as a measure of stress while she spoke with her therapist. She wanted to review her heart rate along with an audio recording of the session. She thought that this could provide an opportunity to reflect after the session on her emotional response to certain topics in the conversation.

Another interesting comment during this interview was, "I can not escape from it." As a user of the device myself, I understood this reaction. There is a sensation of being under constant light surveillance. This response reminded me of my own feeling that I was "on stage." This perception is to some extent a reality as well. Especially as recording techniques improve through augmenting the ECG, this kind of recording can provide a lot of
information about one's habits and behavior. Unlike more thorough recording devices such as video cameras, this data is easily condensed into a meaningful summary. Weeks of data can be viewed on a few pages. In its current state using only ECG, it remains difficult to make conclusions about behavior. This idea suggests that subjects may find more accurate measures invasive or too overwhelming. Decisive empirical evidence of my own practices may conflict significantly with my beliefs about my practices.

There were also comments directly related to fitness as well. The subject remarked, "I think I should exercise more. Look at all those blues. That is not acceptable to my standards," and "I feel like I am very sedentary." This is evidence supporting the claim that visualizations can support self-evaluation, the measurement of performance, and setting goals based on that performance. In this case the subject noticed periods of sedentary states and said how she was going to try to walk around more during work to break up those periods. Here she set explicit goals. Unfortunately, the evaluation period did not include a follow up period to measure performance with these new goals. This evidence certainly suggests that a long-term study looking for actual behavior change could produce exciting results.

The visualization also generated questions from the subject about explanations for trends. She was surprised to see her heart rate in the morning lower overall then in the evening. The morning shows less yellow and light blue. This question remained unanswered. These visualizations could lead patients to approach their doctors with questions.

After noticing this trend from the summary visualization, we looked at the smoothed BPM over time graph for the subject's first day. This graph shows an increase in heart rate after lunch by about 20 BPM for the rest of the day. The subject was surprised
by this fact, and again noticed how her heart rate was higher in the evening. She wondered if anxieties had built up over the day. She was confused by this because she felt more tired at the day's end than its beginning, yet her heart rate was higher. We had no explanations for these observations. A detailed view of heart rate without a person to interpret it may lead only to confusion and misunderstanding. In this way, the simple colored bars may provide a better experience than the more detailed graphs. The simple graph shows less, but more features are explainable.

Finally, when asked if she would wear the device again for her own use, she replied, "If the electrodes didn't itch, and it wasn't such a fuss when I used the bathroom, then I would wear it all the time. It's interesting." This is a promising final note. With ergonomic improvements, the experience was good enough to warrant repeating.
Subject D: female, age 24

Subject D began wearing the ECG recorder on Friday the 19th and removed it at 5:30 the next day. The device recorded constantly except for when the batteries died while the subject was asleep. Subject D presents a different slice of life than the other two subjects because she did not wear the device during a weekday, but instead wore it on a Friday night when she went out to dinner, and on the next Saturday where she ran errands and did laundry.

On Friday night subject D walked to dinner and back home. She did not write this event in her event log, but it shows up cleanly as two distinct journeys. It appears as 16 minutes of exercise total. The next day the subject spent about four hours attending to chores--doing her laundry, bringing donations to the Salvation Army, getting coffee, and going to the bank and post office. In total, the visualization shows 21 minutes of exercise on Saturday. Unfortunately, the subject’s ECG electrodes came unplugged for almost 30 minutes during the day. Some exertion was lost there.

The subject used her car to carry laundry and drive around town. She walked only between the bank, the coffee shop, and the post office, a few blocks total. She was lifting laundry and large boxes of stuff to donate at the Salvation army, but in total, these chores added up to only a few minutes more than the walk to and from the restaurant the night before. Hauling boxes to donate, and moving big bags of laundry felt like a lot of work. The subject was surprised that these activities did not count as more exercise. She also had trouble discerning any particular connections between her chores and her heart response. When there are many activities close together as in this case, it is difficult to connect specific activities with exertion levels.

Subject D already participates in regular exercise. She runs
Figure 5-11
Subject D: heart rate visualization
a few times a week on a treadmill, practices yoga, and rides her bike to work. She is already very conscious of her health. By using her commute to work as an example of how she gets exercise, she shows us that she understands other means of getting exercise in addition to her explicit fitness practices (yoga and running). This subject was the least affected by the device and visualizations in terms of any apparent cognitive change, new goals. She did find the device interesting, but she was curious specifically how much exercise came from her activities. She imagined its value more to clarify and solidify the connection between exertion and activity rather than break new ground.

In terms of directing attention, subject D already checks her pulse about once a day. She checks periodically to know her resting heart rate. She also checks when she works out to make sure she is reaching her target exertion levels. Lastly, she will check her pulse if she ever feels particularly anxious as a way of "checking in" with her body. She already pays attention to her heart, and she is aware of the connection between emotional state and heart rate. In this way, the device did not provoke an affective change or a change in attention.

She was more interested in the device as a measure of emotional state than of physical state. This agreed with the interest subject C
had in using this device to measure heart response in therapy. Subject D explained more about the emotional activity of the day than the physical. She dropped her boyfriend off with the laundry, and was running around doing her other errands. She explained how she wanted to get back to help with the laundry as quickly as possible and was feeling rushed as she went about her activities. This fairly low level of emotional intensity did not to appear in these visualizations. Though, there is a high density of "light" activity instead of "very light" over the subject's period of doing chores, but that could easily be from her physical activity as well.

Subject D represents people who have the least to learn from this device and visualizations. Her awareness of heart rate is already present, and she already thinks about exercise as part of daily practice. She would use the device to clarify her understanding of exercise from her daily activities. For example, she mentioned how she would like to know how much exercise she got from riding her bike to and from work. Could she stay healthy from that alone?

Lastly, one of the most significant features of the device for this subject was dealing with the wires. The subject explained that the wires and the device were difficult for a woman because there is no way to comfortably route the electrode wires from above the breasts down to the device on the belt. Both women in the study complained of ergonomic issues, and these are clearly factors that must be dealt with to conduct further research. Frustrations and discomfort could lead many people to reject the device altogether.

Three different subjects tried this device and used the visualizations. Each case presents a unique set of interests and issues. Subject B realized the health impact of his apartment location. He did not show any change in motivational process or
affective process. He did however show the possibility that this experience could affect his "selection process," how he chooses an environment. Subject C revealed possible influences in the cognitive, motivational, and affective processes. She showed the most evidence that the theoretical base for this project has merit. Subject D did not reveal much influence from the activity in any of the self-efficacy processes. She was however interested in the information the device provided.

This evaluation revealed many unexpected results and potential new roads to follow with this research. It suggests the potential for heart rate feedback to encourage behavioral change. Subject C outlined an informal short-bout exercise goal after seeing long periods of no activity in her day. This informal goal was the closest any subject came to enacting change during the evaluation. I believe from my experience using the heart rate visualizations, and from watching others try it and talk about it, that this activity has the potential to get more people living active lifestyles, and feeling much better for it.
This thesis proposes the use of an all-day measurement of exercise to encourage short-bout exercise in everyday living. This encouragement comes through interventions into the mechanisms of self-efficacy. Visualizing all-day measurements of heart rate may show someone how small decisions made during the day can accumulate into significant amounts of exercise. It also gives someone a measure that may be used to set goals such as total minutes of exercise in a day. Individuals could then compare performance to goals. Finally, wearing the measurement device may lead someone to pay more attention to exertion found in daily practice.

Three case studies tested whether these proposed influences would occur in practice. Results depended largely on the specific situation of the person. Factors such as previous beliefs and current life practices seemed to affect the impact of the device. These results indicate that this type of intervention may be effective but that results will vary according to the individual. These experiences with the device also highlight the importance of reflection and interpretation as part of the experience. Users must go
through some kind of analytic process in order to benefit from the device. This inquiry could happen with only the individual, but it would likely work best if used in a one-on-one counselor patient setting. Counselors could use their understanding of the patient’s beliefs and practices in order to guide the user. Guidance could include asking questions and helping the patient set effective goals.

This project also led to ideas for future work that could further explore the potential for improving health with exertion measures. While the ultimate goal of this project is to increase exercise, the heart rate response to emotional stress also suggests that visualizations could be used to reduce stress as well. Research in hypertension has established the importance of stress reduction in treatment (Albright, 1991; Davis, 2002; Egan, 1983; Ginsberg, 1990; Johnston, 1985; Kondwani, 2001). With motion sensing used to separate physical exertion from other causes of high heart rate, visualizations could highlight non-physical causes of heart rate increase. These visualizations could be used to better understand causes of stress, and promote changes towards reducing stress.

There are also other ways to promote short-bout exercise with an exertion recorder. In particular, a handheld device could prompt the user to define common activities and mark the start and end of the activity as it is happening. After multiple rounds the device would have an accurate picture of the exercise associated with the activity. For example, over a week I could indicate then I was walking to work. This would develop a picture of how much exercise my trip to work gives me. Over time with multiple activities, an individual would have a “vocabulary” of common exercise activities. A computer could use this set of activities to generate recommendations of various ways to combine them to get enough
exercise in a day. One value of this method is that it generates content that could be useful after the measurement device is removed.

Another means of promoting exercise leverages social connections of the user. In this case, the data is shared not only with the participant, but also another person such as a close loved one. This sharing could increase motivation to add exercise to daily practice. Pairings of groups of people all using the device could also share data. This could promote discussion of exercise techniques and increase motivation through competition or an increased sense of accountability.

Many factors in modern society contribute to reduced physical activity. People used to get exercise from daily living. Automobiles, elevators, and sedentary jobs have done away with much of that. In order to combat this change in everyday health practice, people need to change their habits to no longer use the path of least resistance. “Getting there most easily” must sometimes become “getting there and living healthy.” In this thesis I have proposed using visualizations of heart activity recorded over daily living to promote this change. As wristwatches help us to be on time, an exercise monitor could help us to be fit.
Bibliography


