DESIGN OF A HEART RATE MONITOR

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ABSTRACT

This project presents the optimal design of a health monitoring device worn during exercise--the body heart rate monitor. The product provides the time and duration of exercise session, heart rate of user, and calories burned during the session. The primary target market includes fitness enthusiasts, professional and armature runners and cyclists, and heart patients.

The objective from an engineering viewpoint was to minimize overall size and weight, resulting in an optimal size being 21 cm^3 and weight being 143 g. The objective from a microeconomics viewpoint was profit maximization, which yielded a maximum profit of $35,180,681.91 at a demand of 100,000 units sold. In the marketing model, survey results were used to determine user preference for product shape, size, orientation, and price. Using profit maximization, the results indicated that the preferred product has a rectangle shape, horizontal orientation, screen size of 4 cm by 6 cm, and the lowest possible price. The optimization results yielded a rectangle, horizontally oriented, 4 x 6 size, and a price of $214. The optimal solution provided a profit of $50,723,546 with a demand of 270,766 units sold.

The final aesthetic study revealed that the industrial design decisions made, according to "familiarity", "cohesiveness", and "complexity," corresponded to the users' preferences. The people surveyed preferred the most familiar, cohesive, and simple design. According to the marketing survey, the golden ratio for product dimensions was preferred, which affected engineering results by making the product larger.

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1. INTRODUCTION

1.1 The product design problem

The product that will be optimized in this project is a body monitor, used during exercise or training, that enables wireless, free-living data collection of body vital signs. The design of the product will include sensors that gather information about the body's heart rate, heat flow, and skin temperature. The product will be attached to the user's upper arm via an adjustable strap. The body of the product will have an output interface for the user interaction. There will also be a power button on the product. The product will get power from batteries that are charged with a power supply.

The overall design challenge will be to minimize the size and weight of the product. In addition, the product must be comfortable for the user and easy to understand. For user comfort reasons, a small size and weight will be less obtrusive to everyday, all day usage. A lower weight may limit breakage. In doing so, several tradeoffs will be made. When the size is minimized, functionality in the computerized element will be limited. In addition, small size will demand a smaller battery life. Small size also limits the screen size, which should be maximized for easy visibility. Demanding a small weight requires careful material selection and product design packaging.

Heart Rate Monitor Definition

The **Heart Rate Monitor** is like a coach that guides you through each workout. For endurance workouts, it paces you so you don't overdo it. For tempo runs, it keeps you on track. And for interval workouts, it makes sure you go hard enough and you recover when it's time. It can show you when you are dehydrating, or running out of nutrition, or not recovered from a previous day's workout. It allows you to analyze workouts and races so you can identify your weaknesses and turn them into strengths.

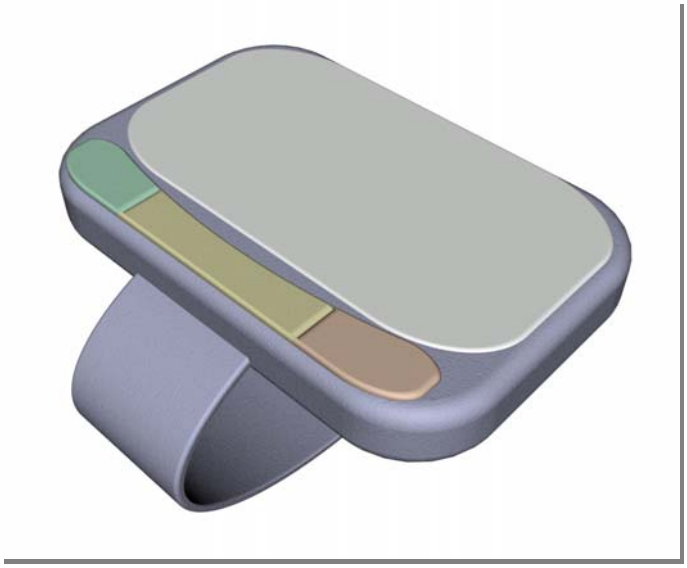


Figure 1.1 Conceptual drawing of a heart rate monitor

The current on-market heart rate monitors

It consists of a **watch** worn on your wrist, and a **transmitter** that you comfortably wear against your skin and around your chest. The transmitter picks up the signals of your heart, and sends them wirelessly to the watch you wear on your wrist. No wires, no taking your pulse and doing a multiplication equation.

Figure 1.2 Sample heart rate monitors on market

Usage of a heart rate monitor

By monitoring heart rate, the simple observation that the harder we exercise, the faster our heart beats is put to good use. Professional athletes and amateurs alike have for decades been relying on the information provided by their heart rate monitor for the following reasons:

- A heart rate monitor is like a rev counter, giving a precise measurement of exercise intensity.
- Training at your own ideal pace is made possible with a heart rate monitor.
- Direct measurement of heart rate during exercise is the most accurate way to gauge performance.
- Progress can be monitored and measured, increasing motivation.
- It maximizes the benefits of exercise in a limited amount of time.
- It introduces objective observation. Are you on the right track? Are you improving?
- It is a tool for regulating frequency and intensity of workouts.
- Because of the immediate feedback it provides, heart rate monitoring is an ideal training partner.

How it works

When you start training, your heart rate increases rapidly in according to the intensity of the training. In Heart Rate Monitors, the transmitter belt detects the electrocardiogram (ECG - the electric signal originating from your heart) and sends an electromagnetic signal to the wrist receiver where heart rate information appears.

The heart moves blood from the lungs (where the blood picks up oxygen) to the muscles (which burn the oxygen as fuel) and back to the lungs again. The harder the training, the more fuel the muscles need and the harder the heart has to work to pump oxygen-rich blood to the muscles. As you get fit, your heart is able to pump more blood with every beat. As a result, your heart doesn't have to beat as often to get the needed oxygen to your muscles, decreasing resting heart rate and exercise heart rate on all exertion levels.

1.2 Product development process

Decisions to be made in Design Phase

The decisions that can be made in the design phase are indicated in the green section in the process model. These are the governing constraints that regulate the overall design "shell".

They include the key decisions and variables as follows:

1) critical design elements (general length, width, thicknesses, list of parts in assembly, energy needs, power supply, battery size and output)
2) usability (comfortable strap materials, letter size, display location for easy viewing, display size, strap size, product body size according to anthropometrics)
3) visual appeal for market segment (overall dimensions, proportions, material suggestions, color suggestions)
4) human factors issues (screen legibility, different strap sizes, viewing problems)
5) innovative concepts (uniqueness in the market, screen functionality)
6) critical technologies (rechargeable batteries, battery charger attachment, wireless internet connection, display screen, sensor for heart rate and heat flow, power button)
7) technologically feasible ideas (discovered in brainstorm)
8) critical manufacturing issues (plastic housing and assembly)
9) # of ways that product improves user experience (softer strap, softer overall material, screen and functionality, no need for separate products)
10) product forms (golden ratio for overall body and display, new materials)
11) product function (heart rate, calories burned, time, metabolism, heat flow)
12) design details (display, button, adjustable strap, body, wireless connection)

The following process model is used for determining the values of input and output at each stage. The variables are noted in the diagram and the corresponding descriptions are given below.

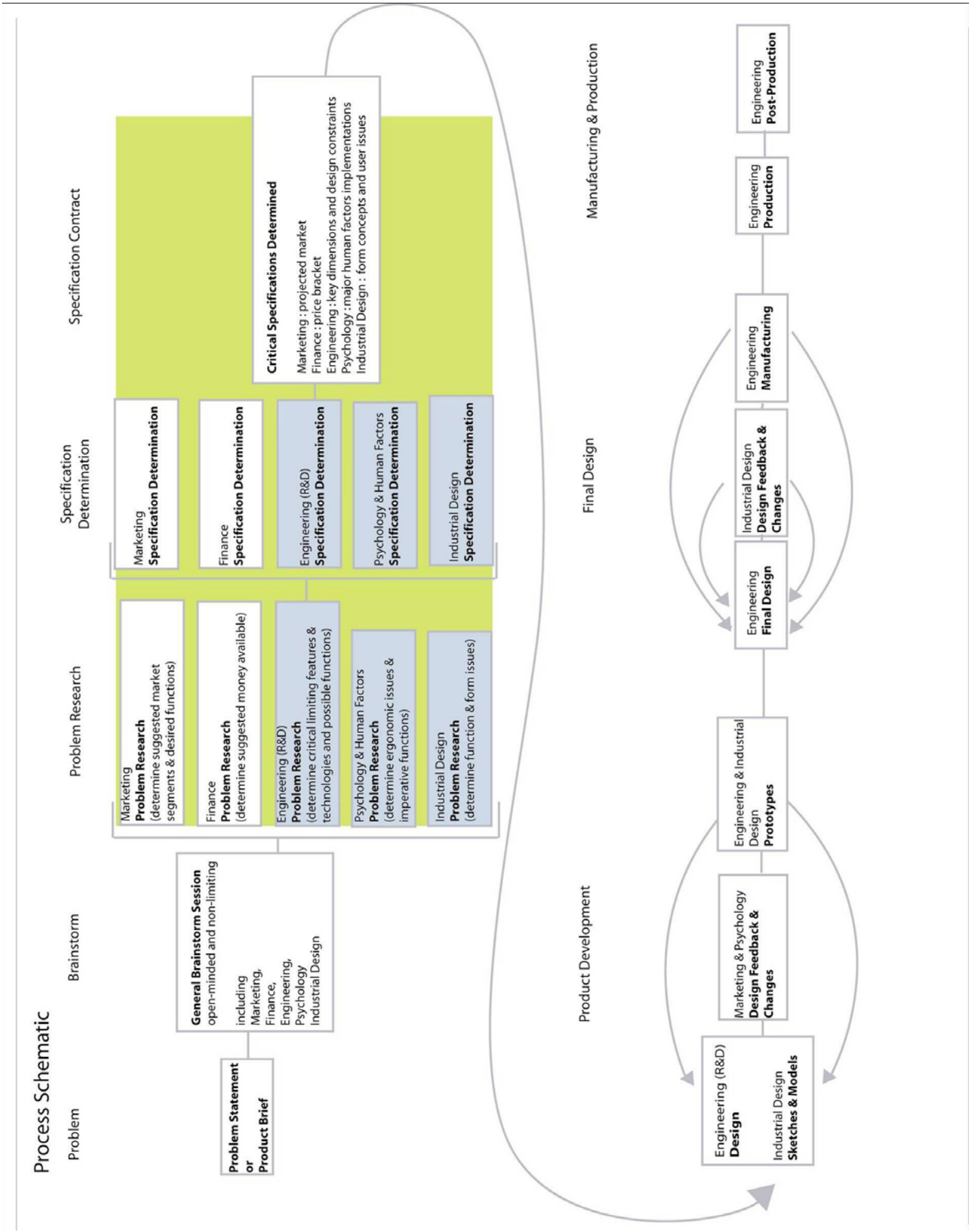


Figure 1.3 Process Schematic (refer to inputs and outputs in the following list)

Quantifiable Design Requirements

From variables in the requirements above, the following are deemed quantifiable:

1) critical design elements (general length, width, thicknesses, list of parts in assembly, energy needs, power supply, battery size and output)
2) usability (letter size, display location for easy viewing, display size, strap size, product body size according to anthropometrics)
3) visual appeal for market segment (overall dimensions, proportions)
4) human factors issues (screen legibility, different strap sizes)
5) # of ways that product improves user experience (softer strap, softer overall material, screen and functionality, no need for separate products)
6) product forms (golden ratio for overall body and display, material properties)
7) product function (heart rate, calories burned, time, metabolism, heat flow)
8) design details (display size, button size, adjustable strap size, body size)

Input	**Output**
1. Market research to get statistics about target consumer	**b =** # of projected consumers in the market (number)
2. Market research about how much users will pay	**p =** price range of final heart rate monitor in $
3. Financial calculation of profit margin	**c =** production cost of monitor in $
4. Financial/Market research	**v =** projected volume of product produced
5. Engineering Designer research	**d =** critical design elements (general length, width, thickness of all design components, all parts needed in final assembly, energy needs, power supply decision, battery size and output)
6. Human Factors & Designers research	**u =** usability (ie. Strap materials suggested for comfort, letter size for display, location of display for easy viewing, size of display, size of strap, size of body of product according to anthropometrics)
7. Industrial Design Studies & Sketches	**vi =** visual appeal for particular market segment (overall dimensions, proportions, material suggestions, color suggestions)
8. Human Factors Detail Studies	**h =** human factors issues solved for particular product (screen legibility, size of strap for different users, problems with viewing it)

9. Brainstorming, R&D, Industrial Design Ideas, Marketing	**n=** innovative, new concepts (how will it stand out from similar products in the market- screen and added functionality)
10. Engineering Technology Research	**t=** critical technologies (rechargeable batteries, needs an attachment to battery charger, wireless internet connection, display screen, sensor for heart rate and heat flow, button for power)
11. Industrial Design & Marketing Brainstorms	**i** = general ideas (heart rate monitor attached to chest, two parts- one wrist watch & one chest strap, no display)
12. Engineering Detailed Studies	**f** = technologically and physically feasible ideas (discovered in brainstorm)
13. Engineering Detailed Studies & Supplier Collaboration	**m** = critical manufacturing issues (plastic housing attachment to other parts)
14. Industrial Design & Psychology User Studies	**e** = # of ways that product improves user experience (softer strap, softer overall material, screen and functionality, no need for separate products with machine and sensor)
15. Industrial Design sketches & models	**fo** = product forms (golden rule proportion for overall body and for display, new materials)
16. Psychology, Engineering, Industrial Design, Marketing	**fu** = product function (main functions are display heart rate, calories burned, and time, provide metabolism and heat flow information)
17. Engineering & Industrial Design Ideas	**dd** = design details (must have a display, button, adjustable strap, body, wireless connection)
18. Engineering Design	**s** = suppliers (battery, housing, display, circuit board, sensors, strap, processor suppliers determined)
19. Engineering Research	**ch** = cost of changes to design as the manufacturing process begins

1.3 Design Requirements

The design requirements for the overall product are listed in categories as follows.

Overall Product

- The overall width of the product body must be no larger than the appendage it is attached to on the body.
- The overall weight of the product should be minimized for users' comfort.
- The product must provide innovative new concepts compared to other heart rate monitors on the market.
- Price range of product must fit within desired consumer bracket.
- Product must be technologically possible.
- Product must enhance the user experience.

Body

- Materials must not scrape the skin.
- The materials must be water resistant.
- The housing must not break when dropped.
- Body must be appropriate size for human's arm (ie not rub against the underarm).
- Body must have a form that has ergonomic and visual appeal for users.

Strap

- Materials must not scrape the skin.
- The materials must be water resistant.
- Strap must meet tensile strength requirement.
- The product must have an adjustable strap for a variety of user proportions.
- The product must be attached to the body in a location that allows for proper heart rate monitoring (ie. chest, upper arm)

Battery

- Batteries must be rechargeable
- The product's battery life must last for three days without recharging
- The product must hook up to an exterior battery charger to provide charging while it is not in use.

Display

- Display must be legible from user's vision angle.
- Output must be easy to obtain.
- Button must be large enough for comfortable pressing.
- Display must be large enough to provide three output values- time of exercising, heart rate, and calories burned.
- Display must be visually appealing.
- Display must provide at any given time three output measures: time of exercise, heart rate, and calories burned.

Sensors

- Sensors must be able to monitor accurate heat flow from skin and heart rate.

Memory

- Memory must be large enough to store ample information.

2. ENGINEERING DESIGN MODEL

2.1 Engineering Analysis Quantification

The outputs shown in the blue boxes in the process model are the ones that can be quantified by engineering analysis. They include issues in engineering, human factors, and industrial design:

1) critical design elements (general length, width, thicknesses, list of parts in assembly, energy needs, power supply, battery size and output)
2) usability (letter size, display location for easy viewing, display size, strap size, product body size according to anthropometrics)
3) visual appeal for market segment (overall dimensions, proportions)
4) human factors issues (screen legibility, different strap sizes)
5) product forms (golden ratio for overall body and display, material properties)
6) design details (display size, button size, adjustable strap size, body size)

2.2 Design Variables, Parameters, Constraints, Objectives

Objective: Minimize the overall volume and weight of the product giving equal weight to both minimization objectives

Design Variables are given in the following Table 2.1.

Design Variables (x)

Name	Description	Value	Units	Min	Max
x1	Thickness of Plastic Housing	**0.80**	cm	0.1	15
x2	Width of Plastic Housing	**4.00**	cm	0.1	6.6
x3	Height of Plastic Housing	**6.64**	cm	0.1	15
x4	Thickness of the Display	**0.80**	cm	0.16	0.27
x5	Width of Display	**4.00**	cm	4	6.6
x6	Height of Display	**6.64**	cm	3.57	15
x7	Thickness of Strap	**0.10**	cm	0.1	15
x8	Width of Strap	**2.00**	cm	1	6.6
x9	Length of Strap	**15.00**	cm	15	80
x10	Thickness of Processor	**0.10**	cm	0.05	6.6
x11	Width of Processor	**1.40**	cm	0.05	6.6
x12	Height of Processor	**1.40**	cm	0.05	15
x14	Thickness of Button	**0.23**	cm	0.23	15
x15	Width of Button	**3.00**	cm	2.5	15
x16	Thickness of Battery	**0.80**	cm	0.8	15
x17	Width of Battery	**2.40**	cm	2.4	6.6
x18	Height of battery	**3.00**	cm	0.1	15
x19	Thickness of Circuitboard	**0.80**	cm	0.75	15
x20	Width of Circuitboard	**4.00**	cm	4	6.6
x21	Height of Circuitboard	**8.00**	cm	8	15
x22	Plastic Housing Density	**1.00**	g/cm3	0.8	1.4
x23	Button Desnity	**0.90**	g/cm3	0.8	1.4
x24	Strap Density	**0.90**	g/cm3	0.8	1.4
x25	Extra Functions	**3.00**		1	6

Table 2.1 Design Variables with their minimum and maximum values

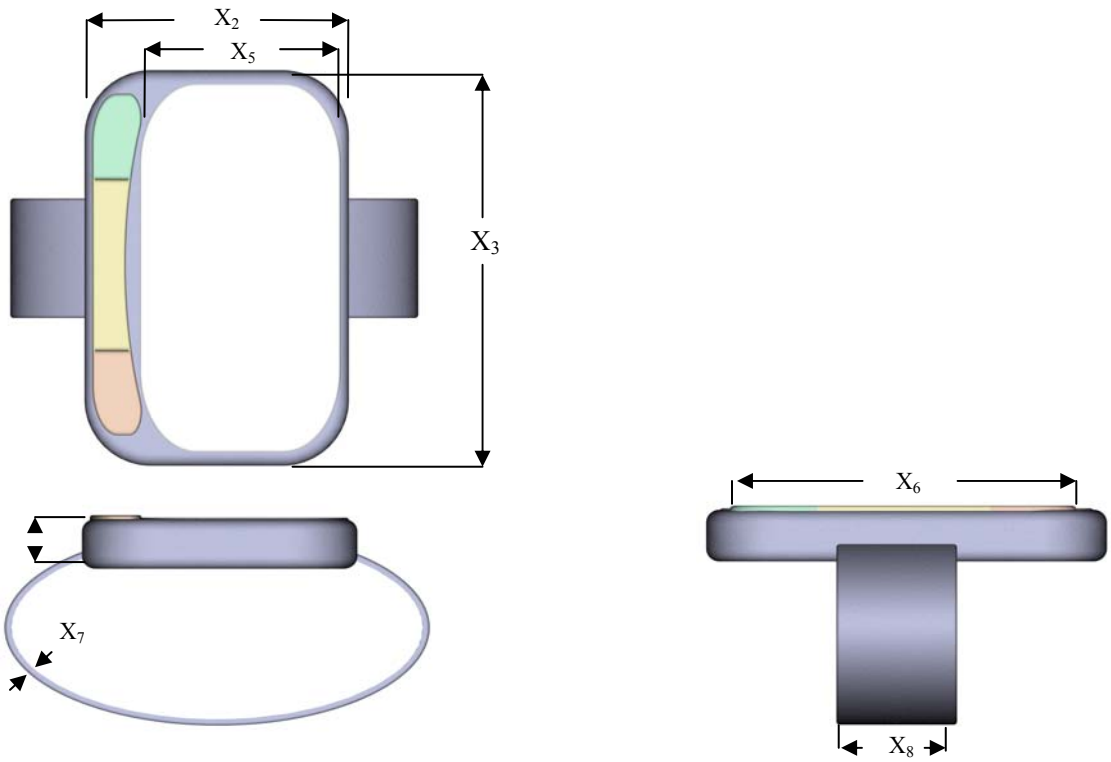


Figure 2.2 shows the main design variables and their relationship to the product.

The following chart shows the parameters in the model.

Parameters (y)			
Name	Description	**Value**	**Units**
y1	Sensor Thickness	**0.10**	cm
y2	Sensor Height	**5.00**	cm
y3	Sensor Width	**2.00**	cm
y4	Display Density	**1.00**	g/cm3
y5	Processor Mass	**2.00**	g
y6	Battery Mass	**7.80**	g
y7	Sensor Density	**8.00**	g/cm3
y8	Sensor Mass	**24.00**	g
y9	Circuitboard density	**0.30**	g/cm3
y10	Processor Density	**0.26**	g/cm3
y11	Battery Density	**1.95**	lbs

Table 2.2 Parameters in the Engineering Optimization Model

Constraints (g(x,y),h(x,y))			
Name	Description	**min**	max
g1	Strength of strap must support product's weight	23.95361	37825
g2	Proportions of the product should adhere to golden rule	6.64	6.64
g3	Thickness of display must be less than thickness of plastic housing	0.27	0.80
g4	Display width must be less than plastic housing width	4.00	4.00
g5	Display height must be less than plastic housing height	6.64	6.64
g6	Display thickness must be less than plastic housing thickness	0.27	0.80
g7	Processor height must be less than plastic housing height	1.40	6.64
g8	Processor width must be less than plastic housing width	1.40	4.00
g9	Processor thickness must be less than plastic housing thickness	0.05	0.80
g10	Battery width must be less than housing width	2.40	4.00
g11	battery height must be less than housing height	3.00	6.64
g12	battery thickness must be less than housing thickness	0.80	0.80
g13	Width of Plastic Housing	0.1	6.6
g14	Height of Plastic Housing	0.1	15
g15	Thickness of the Display	0.16	0.27
g16	Width of Display	4	6.6
g17	Height of Display	3.57	6
g18	Thickness of Strap	0.1	1
g19	Width of Strap	1	6.6
g20	Length of Strap	15	80
g21	Thickness of Processor	0.05	0.8
g22	Width of Processor	0.05	6.6
g23	Height of Processor	0.05	15
g24	Thickness of Button	0.23	0.8
g25	Width of Button	2.5	4
g26	Thickness of Battery	0.8	1
g27	Width of Battery	2.4	6.6
g28	Height of battery	0.1	6.6
g29	Thickness of Circuitboard	0.75	0.8
g30	Width of Circuitboard	4	6.6
g31	Height of Circuitboard	1	6.6
g32	Plastic Housing Density	0.8	1.4
g33	Button Desnity	0.8	1.4
g34	Strap Density	0.8	1.4
g35	extra functions	1.00	6

$37{,}825 \geq W_o$
$x_3 = 1.666 * x_2$, $x_6 = 1.666 * x_5$
$x_4 \leq x_1$
$x_5 \leq x_2$
$x_6 \leq x_3$
$x_4 \leq x_1$
$x_{12} \leq x_3$
$x_{11} \leq x_2$
$x_{10} \leq x_1$
$x_{17} \leq x_2$
$x_{18} \leq x_3$
$x_{16} \leq x_1$
$0.1 \leq x_2 \leq 6.6$
$0.1 \leq x_3 \leq 6.6$
$0.16 \leq x_4 \leq 0.27$
$4 \leq x_5 \leq 6.6$
$3.57 \leq x_6 \leq 6$
$0.1 \leq x_7 \leq 1$
$1 \leq x_8 \leq 6.6$
$15 \leq x_9 \leq 80$
$0.05 \leq x_{10} \leq 0.8$
$0.05 \leq x_{11} \leq 6.6$
$0.05 \leq x_{12} \leq 15$
$0.23 \leq x_{14} \leq 0.8$
$2.5 \leq x_{15} \leq 4$
$0.8 \leq x_{16} \leq 1$
$2.4 \leq x_{17} \leq 6.6$
$0.1 \leq x_{18} \leq 6.6$
$0.75 \leq x_{19} \leq 0.8$
$4 \leq x_{20} \leq 6.6$
$1 \leq x_{21} \leq 6.6$
$0.8 \leq x_{22} \leq 1.4$
$0.8 \leq x_{23} \leq 1.4$
$0.8 \leq x_{24} \leq 1.4$
$1 \leq x_{25} \leq 6$

Table 2.3 Constraints

2.3 Analysis Model Development

Material Properties

- material for strap = nylon
- material for the plastic housing = abs plastic
- material for the display = polymer with high physical strength = silicon carbide
- material for sensor = stainless steal
- material for circuitboard = cellulose

x_{22} = ρ abs plastic = 1.01 – 1.21 Mg/m^3
x_{24} = ρ nylon = 1.00 – 1.42 Mg/m^3
y_4= ρ silicon carbide = 1.00 – 1.42 Mg/m^3
x_{23}= ρ santoprene = 0.92 g/cm^3
y_7= ρ stainless steel type 304 =8.00 g/cm^3
y_9= ρ cellulose = 0.3 g/cm^3

σs nylon = 538 lb/in^2
σs santoprene = 3.3 MPa

Part 1: Display

Equations & Calculations

In order to determine the dimensions of the display, some human factors calculations were necessary. According to human factors data for text readability, the following equation holds true where:

D = viewing distance
K_1 = correction factor for viewing distance and illumination
K_2 = correction factor for importance of material

$H = 0.0022D + K_1 + K_2$

If the viewing distance is approximated to be D = 10 in. and $K_1 = 0.26$ for unfavorable reading conditions and $K_2 = 0.075$ for important markings, then

$H = 0.0022*10 + 0.26 + 0.075 = 0.358$ in

This means that the recommended height of each number on the screen is 0.358 in. There will be three rows of output numbers, with 2.0 mm of space between and on the outside edges. Therefore the final height of the display will need to be at least

height = $x_6 = 4*2.0 + 9.1*3 = 35.3$ mm
$x_6 \geq 35.3$ mm

Characters in the width direction will be approximated at
width = $x_5 = 4*2.0 + 9.1*6 = 62.6$
$x_5 \geq 62.6$

Resulting Constraints:
$x_6 \geq 35.3$ mm
$x_5 \geq 62.6$ mm

display dimensions : $x_6 \geq 35.3$ mm $x_5 \geq 62.6$ mm $1.6\text{mm} \leq x_4 \leq 2.7\text{mm}$

Part 2: Strap

Calculations & Constraints

The strap must hold the body of the product without breaking in tension. This is subject to the material chosen. For this first assignment, a common material for straps was chosen to find values for the other variables in the problem. In the future, this material could be altered to see different results and possibly a smaller, lighter strap. The material chosen is nylon. Making an assumption that the most tension placed on the strap is from that of the product, the following equation can apply, where σ_s is the yield strength of the strap and A is the portion of contact between the strap and product body.

$\sigma s \geq Wo/A$
Wo = total weight of the product
A = portion of the contact between the strap and product body
$A = x_8 * 3cm$, assuming that the strap contacts the main body for a length of 3 cm.
x_8 = width of the strap
$\rho s = \rho$ nylon = 1.00 – 1.42 Mg/m^3
σs nylon = 37.825 kg/cm2 = 37,825 g/cm^2

37,825 $g/cm^2 \geq Wo/(x_8 * 3cm)$

Part 3: Processor

Calculations

Processor dimensions and mass values were found at a supplier's site and approximated for a standard output of

Processor dimensions:
mass = y_5 = 2 g , thickness = x_{10} = 5 mm, height = x_{11} = 36 mm, width = x_{12} = 42 mm
Volume of the processor = $Vp = x_{12} * x_{11} * x_{10}$= 5 mm * 36 mm * 42 mm = 7560 mm^3 = 7.56 cm^3
Weight of the processor = $y_5 * g$ = 2 g * 9.81 m/s^2 / 1000 = .01962 N

Part 4: Battery

Calculations

Using a battery found from a supplier with certain given dimensions the following equations apply:

battery dimensions :
diameter = x_{18} = 24.5 mm, thickness = x_{16} = 8.4 mm, mass = y_6 = 7.8 g
Volume of the batter = $Vb = x_{16} * \pi * (x_{18}/2)^2$
= 8.4 mm * 3.1415 * $(24.5mm/2)^2$ = 3960 mm^3 = 3.96 cm^3

Part 5: Sensor

Calculations

sensor dimensions : height = y_2 = 50 mm, width = y_3 = 20 mm, thickness = y_1 = 1 mm

Sensor dimensions are approximated using a found supplier's product size for a heart rate monitor. Mass can be estimated by assuming that the sensor is made of stainless steel type 304 with a density of

density = $y_7 = \rho$ stainless steel type 304 =8.00 g/cm^3
volume = V_{se} = 50mm * 20 mm * 3 mm = 3000 mm^3 = 3 cm^3
y_7= 8.00 g/cm3 = y_8/Vse, so mass = y_8 = 8.00 g/cm^3 *3 cm^3 = 24 g

Part 6: Sensor Circuit Board

Calculations

Sensor circuit board dimensions are approximated using a found supplier's product size for a heart rate monitor.

sensor circuit board dimensions :
height = x_{21} = 80 mm, width = x_{20} = 40 mm, thickness = x_{19} = 7.5 mm

Mass can be estimated by assuming that the sensor is made of stainless steel type 304 with a density of

density = y_9= ρ cellulose =0.3 g/cm^3
volume = V_{cb} = 80 mm * 40 mm * 7.5 mm = 24000 mm^3 = 24.0 cm^3
y_9= 0.3 g/cm^3 = m_{cb}/ V_{cb} , so m_{cb} = 0.3 g/cm^3 * 24 cm^3 = 7.2 g

Part 7: Button

Calculations

Using human factors guidelines, the power button is given a diameter of x_{15}=25 mm and the thickness is x_{14}=2.3mm. The material for the button is santoprene, so the density is x_{23} = 0.92 g/cm^3.

volume = V_{bu} = x_{14} * π * x_{15} = π * (2.5/2)2 * 0.23 cm = 1.129 cm^3
weight = W_{bu} = 1.129cm^3 * 0.92 g/cm^3 = 1.04 g

Product Overall Shape Constraints

Overall height must be greater than the largest height of the parts in the assembly so
$x_3 \geq$ 42 mm

Overall width must be less than the 1 percentile female's arm width in order not to rub the under arm while running.
$x_2 \leq$ 66.04 mm

The overall thickness must be greater than the thickest component in the overall assembly.
$x_1 \geq$ 13 mm

The proportion of the product is going to be subject to the golden rule for shape proportions to see if this yields a desired output. The following equation relates the length and width of the product's main body housing and the dimensions of the display.
x_2 = 1.66 * x_3

General Size & Weight Calculations

In order to determine the final objective functions the following calculations of overall Volume, Vo, and overall weight, Wo, are performed.

$V_o = x_1 * x_2 * x_3$

$W_o = W_b + W_d + W_s + W_p + W_{bu} + W_{se} + W_{ba} + W_{cb}$

$W_o = x_{14} * \pi * x_{15} * x_{23} + x_6 * x_5 * x_4 * y_4 + x_9 * x_8 * x_7 * x_{24} + x_{12} * x_{11} * x_{10} * y_{10} + y_1 * y_2 * y_3 * y_7 + x_{16} * \pi * (x_{18}/2)^2 * y_{11} + x_{21} * x_{20} * x_{19} * y_9$

2.4 Design Optimization Model in Negative Null Form

Min v(x) = $0.5 * V_o + 0.5 * W_o$
Min v(x) = $0.5 * (x_1 * x_2 * x_3) + 0.5 * (x_{14} * \pi * x_{15} * x_{23} + x_6 * x_5 * x_4 * y_4 + x_9 * x_8 * x_7 * x_{24} + x_{12} * x_{11} * x_{10} * y_{10} + y_1 * y_2 * y_3 * y_7 + x_{16} * \pi * (x_{18}/2)^2 * y_{11} + x_{21} * x_{20} * x_{19} * y_9)$

Subject to the following constraints

$37{,}825 \geq W_o$
$x_3 = 1.666 * x_2$, $x_6 = 1.666 * x_5$
$x_4 \leq x_1$
$x_5 \leq x_2$
$x_6 \leq x_3$
$x_{12} \leq x_3$
$x_{11} \leq x_2$
$x_{10} \leq x_1$
$x_{17} \leq x_2$
$x_{18} \leq x_3$
$x_{16} \leq x_1$
$0.1 \leq x_2 \leq 6.6$
$0.1 \leq x_3 \leq 6.6$
$0.16 \leq x_4 \leq 0.27$
$4 \leq x_5 \leq 6.6$
$3.57 \leq x_6 \leq 6$
$0.1 \leq x_7 \leq 1$
$1 \leq x_8 \leq 6.6$
$15 \leq x_9 \leq 80$
$0.05 \leq x_{10} \leq 0.8$
$0.05 \leq x_{11} \leq 6.6$
$0.05 \leq x_{12} \leq 15$
$0.23 \leq x_{14} \leq 0.8$
$2.5 \leq x_{15} \leq 4$
$0.8 \leq x_{16} \leq 1$
$2.4 \leq x_{17} \leq 6.6$
$0.1 \leq x_{18} \leq 6.6$
$0.75 \leq x_{19} \leq 0.8$
$4 \leq x_{20} \leq 6.6$
$1 \leq x_{21} \leq 6.6$
$0.8 \leq x_{22} \leq 1.4$
$0.8 \leq x_{23} \leq 1.4$
$0.8 \leq x_{24} \leq 1.4$
$1 \leq x_{25} \leq 6$

The number of Degrees of Freedom = # variables - # of equality constraints = 25 – 2 = 23

2.5 Coded Model & Computed Solution

The active constraints are shown in the answer report below as the “binding” constraints. The constraints that are “not binding” are not active. Changing these constraints would affect the solution.

Microsoft Excel 9.0 Answer Report
Worksheet: [newengineering.xls]Engineering Model (4)
Report Created: 12/14/2003 1:52:39 PM

Target Cell (Min)

Cell	Name	Original Value	Final Value
$F$8	Minimize overall height and weight with equal weight for both Formula	70.23745245	70.23745245

Adjustable Cells

Cell	Name	Original Value	Final Value
$D$25	Thickness of Plastic Housing Value	0.80	0.80
$D$26	Width of Plastic Housing Value	4.00	4.00
$D$27	Height of Plastic Housing Value	6.64	6.64
$D$28	Thickness of the Display Value	0.27	0.27
$D$29	Width of Display Value	4.00	4.00
$D$30	Height of Display Value	6.64	6.64
$D$31	Thickness of Strap Value	0.10	0.10
$D$32	Width of Strap Value	2.00	2.00
$D$33	Length of Strap Value	15.00	15.00
$D$34	Thickness of Processor Value	0.05	0.05
$D$35	Width of Processor Value	1.40	1.40
$D$36	Height of Processor Value	1.40	1.40
$D$37	Thickness of Button Value	0.23	0.23
$D$38	Width of Button Value	3.00	3.00
$D$39	Thickness of Battery Value	0.80	0.80
$D$40	Width of Battery Value	2.40	2.40
$D$41	Height of battery Value	3.00	3.00
$D$42	Thickness of Circuitboard Value	0.80	0.80
$D$43	Width of Circuitboard Value	4.00	4.00
$D$44	Height of Circuitboard Value	6.60	6.60
$D$45	Plastic Housing Density Value	1.00	1.00
$D$46	Button Desnity Value	0.90	0.90
$D$47	Strap Density Value	0.90	0.90
$D$48	Extra Functions Value	3.00	3.00

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$D$27	Height of Plastic Housing Value	6.64	$D$27=1.66*$D$26	Not Binding	0
$D$30	Height of Display Value	6.64	$D$30=1.66*$D$29	Not Binding	0
$D$14	Value		$D$14<=1	Binding	0
$D$29	Width of Display Value	4.00	$D$29<=$D$26	Binding	0
$D$30	Height of Display Value	6.64	$D$30<=$D$27	Binding	0
$D$36	Height of Processor Value	1.40	$D$36<=$D$27	Not Binding	5.240000087
$D$35	Width of Processor Value	1.40	$D$35<=$D$26	Not Binding	2.6
$D$34	Thickness of Processor Value	0.05	$D$34<=$D$25	Not Binding	0.75
$D$40	Width of Battery Value	2.40	$D$40<=$D$26	Not Binding	1.6
$D$41	Height of battery Value	3.00	$D$41<=$D$27	Not Binding	3.640000087
$D$39	Thickness of Battery Value	0.80	$D$39<=$D$25	Binding	0
$D$26	Width of Plastic Housing Value	4.00	$D$26>=$D$67	Not Binding	3.90
$D$26	Width of Plastic Housing Value	4.00	$D$26<=$E$67	Not Binding	2.6
$D$27	Height of Plastic Housing Value	6.64	$D$27>=$D$68	Not Binding	6.54
$D$27	Height of Plastic Housing Value	6.64	$D$27<=$E$68	Not Binding	8.359999913
$D$28	Thickness of the Display Value	0.27	$D$28>=$D$69	Not Binding	0.11
$D$28	Thickness of the Display Value	0.27	$D$28<=$E$69	Binding	0
$D$29	Width of Display Value	4.00	$D$29>=$D$70	Binding	0.00
$D$29	Width of Display Value	4.00	$D$29<=$E$70	Not Binding	2.6
$D$29	Width of Display Value	4.00	$D$29<=$E$70	Not Binding	2.6
$D$30	Height of Display Value	6.64	$D$30>=$D$71	Not Binding	3.07
$D$25	Thickness of Plastic Housing Value	0.80	$D$25<=1	Not Binding	0.2
$D$25	Thickness of Plastic Housing Value	0.80	$D$25>=0.1	Not Binding	0.70
$D$39	Thickness of Battery Value	0.80	$D$39>=$D$80	Binding	0.00
$D$39	Thickness of Battery Value	0.80	$D$39<=$E$80	Not Binding	0.2
$D$34	Thickness of Processor Value	0.05	$D$34<=$E$75	Not Binding	0.75
$D$34	Thickness of Processor Value	0.05	$D$34>=$D$75	Binding	0.00
$D$44	Height of Circuitboard Value	6.60	$D$44<=$E$85	Binding	0
$D$44	Height of Circuitboard Value	6.60	$D$44>=$D$85	Not Binding	5.60

The values in the chart above yielded the following optimization results:

Objective Function			
Name	Description		value
f	Minimize overall height and weight with equal weight for both		70.23745

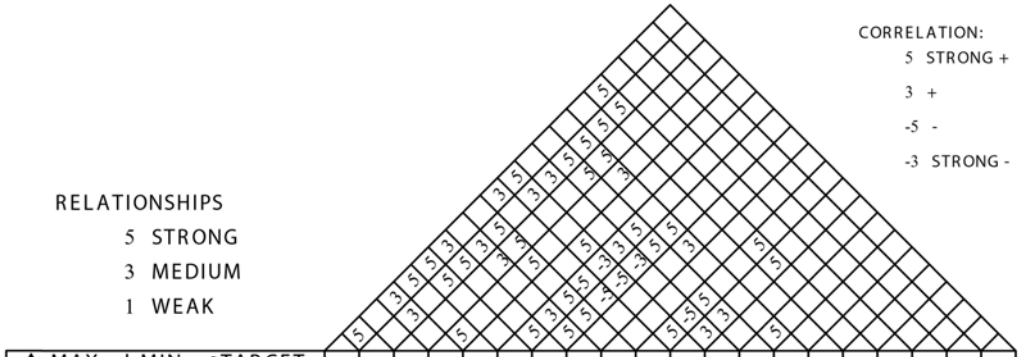
Product Characteristics : $z_E(x,y)$				
Name	Description		units	Formula
z1	Overall Volume (size)		cm3	21.248
z2	Overall Weight		g	143.722

Table 2.4 Results with input values

The results indicate that the overall volume will be 21 cm^3 and the weight will be 143.7 g for this engineering optimization model.

3. MODEL EXTENSION: MICROECEONOMICS

3.1 Benchmarking - QFD Analysis



↑ MAX ↓ MIN oTARGET

CUSTOMER REQUIREMENTS \ DESIGN REQUIREMENTS		Material	Cost	Power Req.	Service Life	Corr. Resis.	Weight	Size	Memory	# Intl comp.	Ergonomics	Form Aesth.	# Buttons	Disp. Size	Battery Size	Sensor Prec	Prod. Range					
IMPORTANCE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Light-weight	1	5	5	1			5	5	3	5	5	1	3	5	5							
Small -size/ compact	2	3	3	1			5	5	5	5	3	1	5	5	5							
Low price	3	5	5	3	5	3	5	5	5	5	3	3	3	5	5	5	5					
Data accuracy	4		5	1					1							5						
Easy-to-use interface	5	3	1					5			5	3	5	5								
Comfort	6	5					5	5			5	5	1	1								
Durability	7	5	5		5	5	1	1		1												
Ease of maintainance	8	3	1		5	5				5			5		1		3					
Multi-functionality	9		5	5	3		3	3	5	5	5	5	5	1	1		5					
Perf. in different envir.	10	5	5		5	5				1	3	5										
Comp. w standart equip.	11		3				3	3	1	5												
Low energy consumption	12		5	5						1				5	5	1						
Visually appealing	13	5	3				3	5			5	5	5	5	3		5					
Adjust. for different users	14	3	5				1	5			5	3		5			5					
Ease in reading	15	3	5				3	5			5	5	3	5								
Enough data storage	16		5	1			3	3	5						1							
Reliability	17	5	5	1	5	1				3					3	5						
	18																					
IMPORTANCE		5	5	3	3	2	5	5	3	1	5	5	2	5	1	2	3					
TOTAL		250	330	54	84	38	200	245	75	36	220	180	70	210	29	32	69					2122
PERCENTAGE		12	15	2.5	4	2	9.5	11.5	3.5	1.5	10.5	8.5	3.5	10	1.5	1.5	3					
COMPETITOR-1		8	25	3	3	1	10	7	1	3	6	10	5	5	2	1	10					POLAR
COMPETITIOR-2		6	35	2	2	2	15	10	1	4	2	3	5	5	2	1	6					CARDIOSPORT
TARGET VALUES		10	10	2	2	3	12	15	2	1	10	14	5	8	2	2	2					

3.2 Profit Maximization Objective Function (assuming a single time period)

$$\Pi = \Theta/\lambda_p * q - 1/\lambda_p * q^2 + 1/\lambda_p * (\lambda_\alpha{}^t \Delta_\alpha) q - c$$

3.3 Revenue Expressed as a function of Design Variables

$$\text{Revenue} = \Theta/\lambda_p * q - 1/\lambda_p * q^2 + 1/\lambda_p * (\lambda^t \Delta_\alpha) q$$

The design variables chosen are price, # of added functions, display size, weight, and overall product size. In order to determine the values for the price elasticity, λ_p, an estimated demand curve was determined by asking a few individuals about their preferences and graphing the results of price verses market quantity demanded. The result is graphed in Figure 3.1 below.

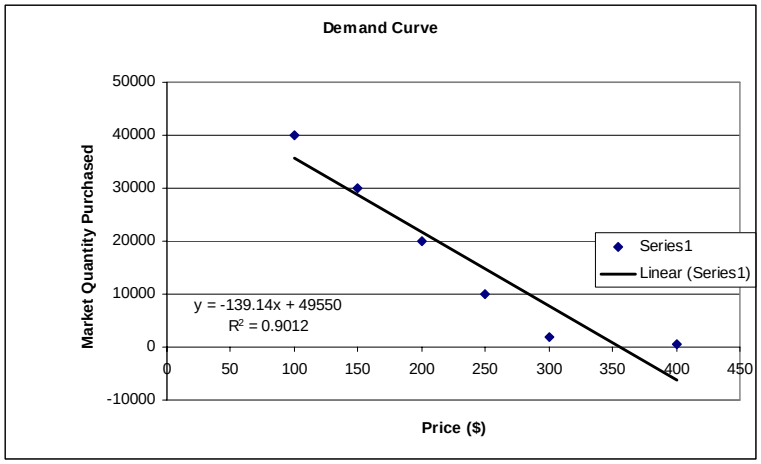


Figure 3.1 Estimated Demand Curve for Price

From this graph the values were found for Θ and λ_p, 49550 and 139.14 respectively. Next, the elasticities for the other four variables were found by estimating demand curves for them as well. Figures 3.2, 3.3, 3.4, and 3.5 are given below.

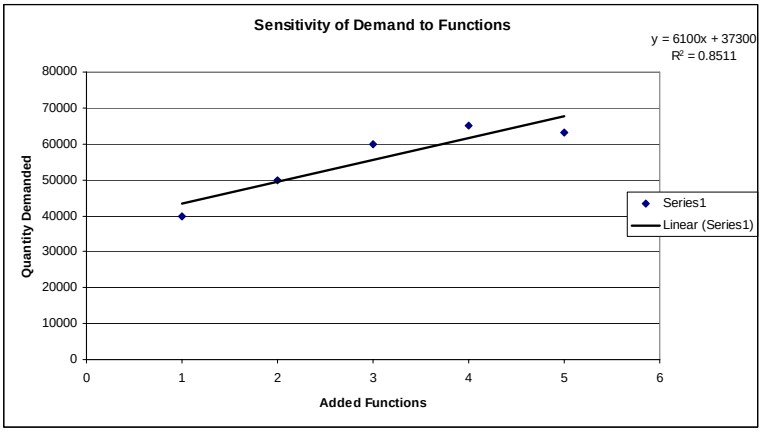


Figure 3.2 Estimated Demand Curve for Added Functions

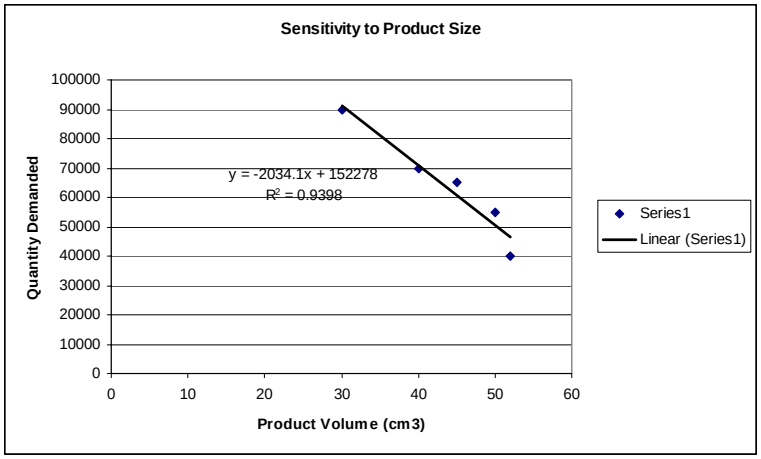


Figure 3.5 Estimated Demand Curve for Overall Product Size

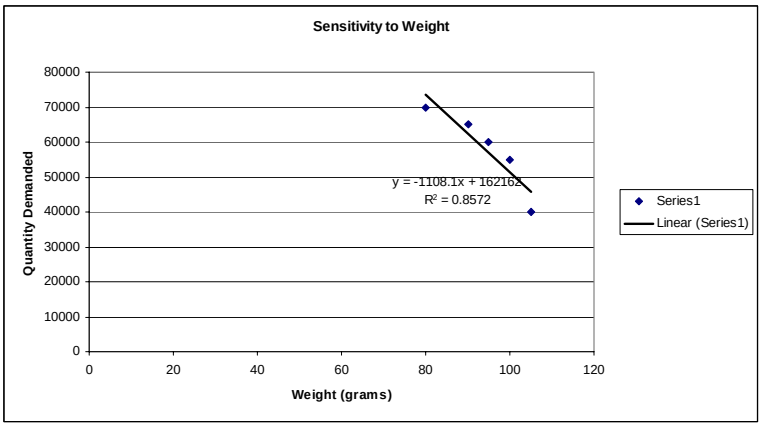


Figure 3.4 Estimated Demand Curve for Weight

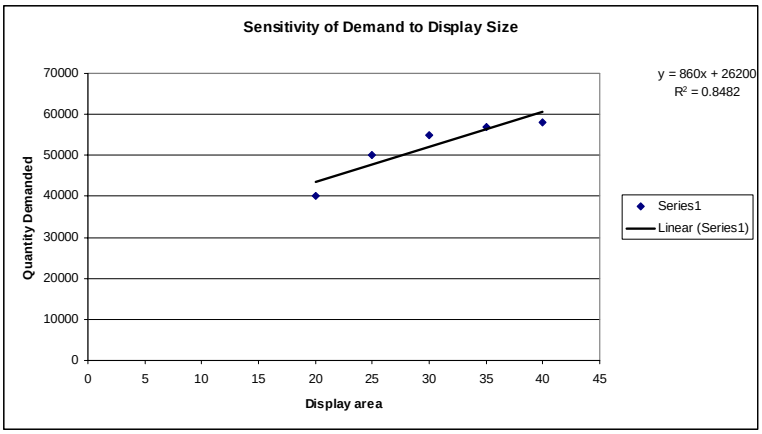


Figure 3.5 Estimated Demand Curve for Display Size

From these curves, the following elasticities were determined- for added functions $\lambda_\alpha = 6100$, for overall product size $\lambda_\alpha = 2034$, for weight $\lambda_\alpha = 1108$, and for display size $\lambda_\alpha = 860$. Given the values indicated above, the following equation for revenue can be found.

$$\text{Revenue} = \Theta/\lambda_p * q - 1/\lambda_p * q^2 + 1/\lambda_p * (\lambda_\alpha{}^t \Delta_\alpha) q$$

$$\text{Revenue} = 49550/139.14 * q - 1/139.14 * q^2 + 1/139.14 * (6100 * \Delta_\alpha + 2034 * \Delta_\alpha + 1108 * \Delta_\alpha + 860 * \Delta_\alpha) * q$$

3.4 Equation for Cost as a Function of Design Variables

Equations to estimate cost for the processor, display, and battery were determined using options on the market and fitting estimation curves to the values of distinct prices, volumes, and weights. The figures below show the curves and equations.

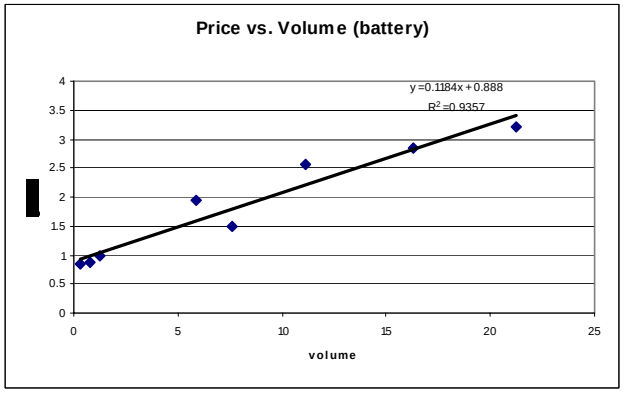


Figure 3.6 Battery Volume/Price Correlation

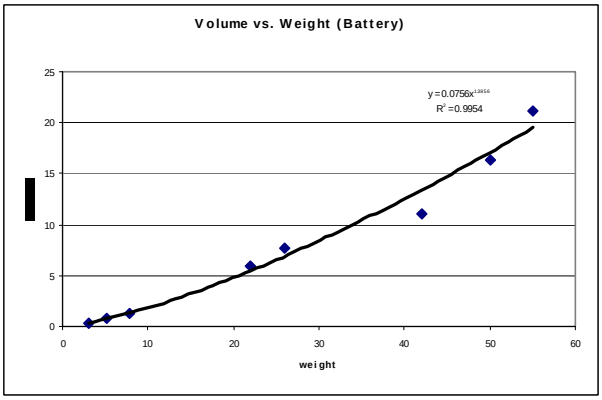


Figure 3.7 Battery Volume/Weight Correlation

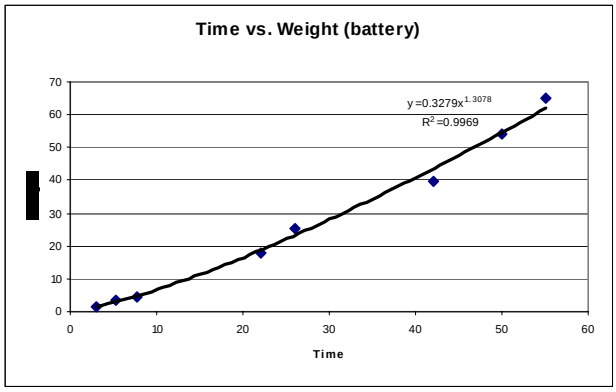


Figure 3.8 Battery Time/Weight Correlation

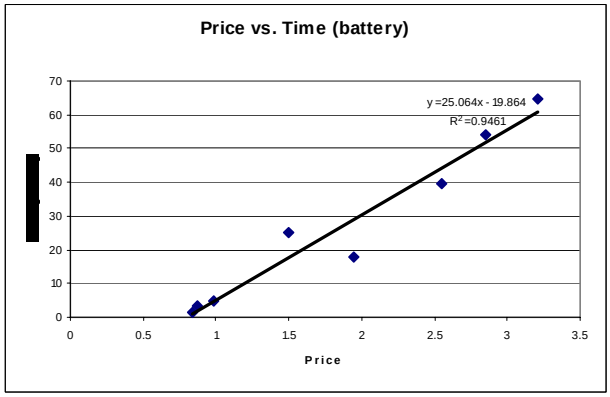


Figure 3.9 Battery Price/Time Correlation

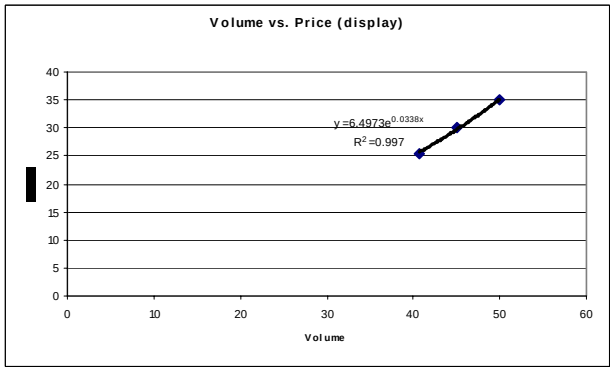


Figure 3.10 Display Volume/Price Correlation

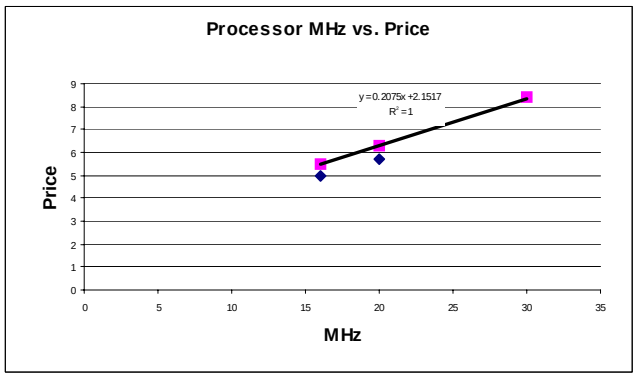


Figure 3.11 Processor MHz/Price Correlation

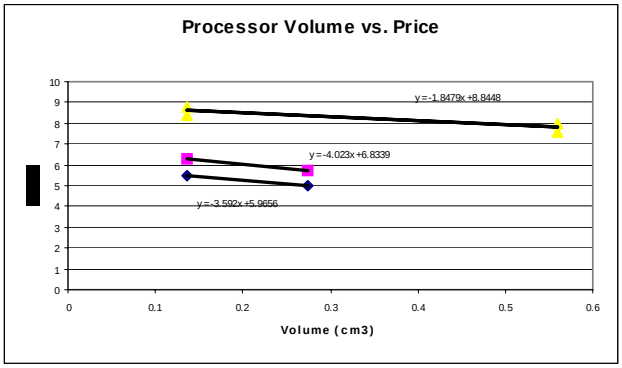


Figure 3.11 Processor Volume/Price Correlation

The costs of the various components in the product are calculated in the Table 3.1 below.

Part	Functions	Material	Density	Part Volume	Material Cost	Process	Cycle time	Machine time charge	Machine time	Tooling Cost	Setup fee	# Parts	Total	employees
	f		ρ	ν	ς		τ	φ	o	χ	ζ	q		ε
			g/cm3	cm3	$/kg		parts/hour	$/hour	$/part	$	$/part		$	
Plastic Part														
	1	Polypropylene	0.9	20.17961 86	1	Injection Molding	80	60	0.75	60,000	0.05	110,000	89997.8	1200000
	4	Cellulose Acetate	1.2	20.17961 86	3.6	Injection Molding	80	60	0.75	60000	0.05	110,000	97589.4	
	3	Polyethylene	1	20.17961 86	3	Injection Molding	80	60	0.75	60000	0.05	110,000	94659.3	
	6	silicone	2	20.17961 86	10	Injection Molding	80	60	0.75	60000	0.05	110,000	132395	
	2	ABS	1.2	20.17961 86	2	Injection Molding	80	60	0.75	60000	0.05	110,000	93327.4	
	5	Santoprene	0.92	20.17961 86	4.91189427	Injection Molding	80	60	0.75	60000	0.05	110,000	98031	
Processor			0.26	0.4508					7.74898			110,000	852388	
	1.00													
Circuit Board		teflon	2.15	15	16	extruded			3			110,000	386760	
Button		Santoprene	0.92	1.4375	4.91189427	Injectiona Molding	80	60	0.05	60000	0.05	110,000	11714.6	
Strap		Santoprene	0.92	4	4.91189427	Injectiona Molding	80	60	1	60000	0.05	110,000	117488	
Display		Silicon Carbide	3.2	12.52	15.85				9.449			110,000	1039342	
Battery			1.95	5.76					1.56998			110,000	172698	
Sensor		stainless steel 304	8	1.00	8	forming			0.05	3000		110,000	12540	

Table 3.1 Cost Estimations for the various product parts

The overall cost of the product includes the investment and variable costs.

$$Cost = C_{investment} + C_{variable}$$

$$Cost = (C_{investment} + C_{variable})_{plastic\ part} + (C_{investment} + C_{variable})_{processor} + (C_{investment} + C_{variable})_{circuit\ board} + (C_{investment} + C_{variable})_{button} + (C_{investment} + C_{variable})_{strap} + (C_{investment} + C_{variable})_{battery} + (C_{investment} + C_{variable})_{display} + (C_{investment} + C_{variable})_{sensor}$$

From the Table 3.1 the cost equation becomes

$$\textbf{Cost} = (\chi + (\rho/1000*\nu*\varsigma + o)*q)_{\text{plastic part}} + q*(-4*\nu + 6.8339 + 0.2075*f + 2.1517)_{\text{processor}} + q*(\rho/1000*\nu*\varsigma + o)_{\text{circuit board}} + (\chi + (\rho/1000*\nu*\varsigma + o)*q)_{\text{button}} + (\chi + (\rho/1000*\nu*\varsigma + o)*q)_{\text{strap}} + q*(0.1184*\nu + 0.888)_{\text{battery}} + q*(6.49*e^{(0.03*\nu)})_{\text{display}} + (\chi + (\rho/1000*\nu*\varsigma + o)*q)_{\text{sensor}}$$

3.5 Constraints for Microeconomic Model

The constraints are basically the same from the engineering model, with the addition of constraints for the additional added functions and material types. The added functions range from 1 to 5 and the materials choices range from 1 to 6. Below chart shows the variables and their min and max values.

Design Variables (x)						
Name	**Description**	**Value**	**Units**	**Min**	**Max**	
x1	Thickness of Plastic Housing	**0.89**	cm	0.1	1	
x2	Width of Plastic Housing	**4.02**	cm	0.1	6.6	
x3	Height of Plastic Housing	**7.01**	cm	0.1	15	
x4	function change	**5.00**		1	5	
x5	material change	**6.00**		1	6	
x6	Thickness of the Display	**0.27**	cm	0.16	0.27	
x7	Width of Display	**4.02**	cm	2	6.6	
x8	Height of Display	**7.01**	cm	3.57	15	
x9	demand	**50710.03**	people			

3.6 Optimization using Profit Objective

a. The dimensions of the housing, the function changes and material changes are changed to the following values. The demand was also changed to 100000 people.

Design Variables (x)						
Name	**Description**	**Value**	**Units**	**Min**	**Max**	
x1	Thickness of Plastic Housing	**0.50**	cm	0.1	1	
x2	Width of Plastic Housing	**5.96**	cm	0.1	6.6	
x3	Height of Plastic Housing	**6.22**	cm	0.1	15	
x4	function change	**5.00**		1	5	
x5	material change	**6.00**		1	6	
x6	Thickness of the Display	**0.27**	cm	0.16	0.27	
x7	Width of Display	**5.96**	cm	2	6.6	
x8	Height of Display	**6.22**	cm	3.57	15	
x9	demand	**100000**	people			

Target Cell (Max)

Cell	Name	Original Value	Final Value
$F$7	Maximize Profit Formula	29601317.33	31685469.13

Adjustable Cells

Cell	Name	Original Value	Final Value
$Q$22	Thickness of Plastic Housing Value	0.80	0.80
$Q$23	Width of Plastic Housing Value	4.00	5.30
$Q$24	Height of Plastic Housing Value	6.14	6.99
$Q$25	function change Value	5.00	5.00
$Q$26	material change Value	6.00	6.00
$Q$27	Thickness of the Display Value	0.27	0.27
$Q$28	Width of Display Value	4.00	5.30
$Q$29	Height of Display Value	6.14	6.99
$Q$30	demand Value	99999.99587	99999.99536

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$K$22	Max Function Change	5.00	$K$22<=$M$22	Binding	0
$K$28	cm Material Change	6	$K$28<=$M$28	Binding	0
$K$34	cm Size (6=5,5=6)	10.00000027	$K$34<=$M$34	Binding	0
$K$36	cm Size (7=4,6=5,5=6,4=7)	25	$K$36<=$N$36	Binding	0
$Q$28	Width of Display Value	5.30	$Q$28<=$Q$23	Binding	0
$Q$29	Height of Display Value	6.99	$Q$29<=$Q$24	Binding	0
$Q$27	Thickness of the Display Value	0.27	$Q$27<=$T$27	Binding	0
$Q$28	Width of Display Value	5.30	$Q$28<=$T$28	Not Binding	1.29947629
$Q$29	Height of Display Value	6.99	$Q$29<=$T$29	Not Binding	8.012570064
$Q$25	function change Value	5.00	$Q$25<=$T$25	Binding	0
$Q$26	material change Value	6.00	$Q$26<=$T$26	Binding	0

With the above configuration, the profit is maximized at $31,685,466.63.

Changing the values by reducing thickness, functions, materials, and increasing demand are given as the values below.

Design Variables (x)						
Name	**Description**	**Value**	**Units**	**Min**	**Max**	
x1	Thickness of Plastic Housing	**0.30**	cm	0.1	1	
x2	Width of Plastic Housing	**5.85**	cm	0.1	6.6	
x3	Height of Plastic Housing	**6.33**	cm	0.1	15	
x4	function change	**1.00**		1	5	
x5	material change	**1.00**		1	6	
x6	Thickness of the Display	**0.27**	cm	0.16	0.27	
x7	Width of Display	**5.85**	cm	2	6.6	
x8	Height of Display	**6.33**	cm	3.57	15	
x9	demand	**200000**	people			

The maximized profit at these values is -78999417.48.

Changing only the demand and other dimensions, the following values result.

Design Variables (x)						
Name	**Description**	**Value**	**Units**	**Min**	**Max**	
x1	Thickness of Plastic Housing	**0.30**	cm	0.1	1	
x2	Width of Plastic Housing	**5.00**	cm	0.1	6.6	
x3	Height of Plastic Housing	**7.41**	cm	0.1	15	
x4	function change	**5.00**		1	5	
x5	material change	**6.00**		1	6	
x6	Thickness of the Display	**0.27**	cm	0.16	0.27	
x7	Width of Display	**5.00**	cm	2	6.6	
x8	Height of Display	**7.41**	cm	3.57	15	
x9	demand	**50000**	people			

The maximized profit is $33,071,079.69.

c. Nearly every constraint above is active because changing them would cause a change in the optimum value. There are several degrees of freedom when the values are changed.

d. In Assignment #2, other constraints hindered the design from yielding certain geometries that were allowable in this model. For example, the golden ration constraint would have altered the results as follows:

Design Variables (x)						
Name	**Description**	**Value**	**Units**	**Min**	**Max**	
x1	Thickness of Plastic Housing	**0.80**	cm	0.1	1	
x2	Width of Plastic Housing	**6.60**	cm	0.1	6.6	
x3	Height of Plastic Housing	**10.96**	cm	0.1	15	
x4	function change	**5.00**		1	5	
x5	material change	**6.00**		1	6	
x6	Thickness of the Display	**0.27**	cm	0.16	0.27	
x7	Width of Display	**6.60**	cm	2	6.6	
x8	Height of Display	**10.96**	cm	3.57	15	
x9	demand	**99999.99**	people			

These results yield the following profit of $ 37,577,764.33. The above values show that the heights and widths of the part changed. The active constraints and degrees of freedom change with this addition of a new constraint. In the engineering model, the constraint yields the following values for housing and display:

Design Variables (x)						
Name	**Description**	**Value**	**Units**	**Min**	**Max**	
x1	Thickness of Plastic Housing	**0.80**	cm	0.1	15	
x2	Width of Plastic Housing	**4.00**	cm	0.1	6.6	
x3	Height of Plastic Housing	**6.64**	cm	0.1	15	
x4	Thickness of the Display	**0.80**	cm	0.16	0.27	
x5	Width of Display	**4.00**	cm	4	6.6	
x6	Height of Display	**6.64**	cm	3.57	15	

Target Cell (Max)

Cell	Name	Original Value	Final Value
$F$7	Maximize Profit Formula	9645616.599	37577765.5

Adjustable Cells

Cell	Name	Original Value	Final Value
$Q$22	Thickness of Plastic Housing Value	0.80	0.80
$Q$23	Width of Plastic Housing Value	1.00	6.60
$Q$24	Height of Plastic Housing Value	3.00	10.96
$Q$25	function change Value	2.00	5.00
$Q$26	material change Value	2.00	6.00
$Q$27	Thickness of the Display Value	0.27	0.27
$Q$28	Width of Display Value	1.00	6.60
$Q$29	Height of Display Value	3.00	10.96
$Q$30	demand Value	99999.99087	99999.98732

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$Q$28	Width of Display Value	6.60	$Q$28<=$Q$23	Binding	0
$Q$29	Height of Display Value	10.96	$Q$29<=$Q$24	Binding	0
$Q$29	Height of Display Value	10.96	$Q$29=$P$34	Binding	0
$Q$24	Height of Plastic Housing Value	10.96	$Q$24=$P$33	Binding	0
$Q$29	Height of Display Value	10.96	$Q$29>=$S$29	Not Binding	7.39
$Q$28	Width of Display Value	6.60	$Q$28>=$S$28	Not Binding	4.60
$Q$24	Height of Plastic Housing Value	10.96	$Q$24>=$S$24	Not Binding	10.86
$Q$23	Width of Plastic Housing Value	6.60	$Q$23>=$S$23	Not Binding	6.50
$Q$27	Thickness of the Display Value	0.27	$Q$27<=$T$27	Binding	0
$Q$28	Width of Display Value	6.60	$Q$28<=$T$28	Binding	0
$Q$29	Height of Display Value	10.96	$Q$29<=$T$29	Not Binding	4.044000149
$Q$25	function change Value	5.00	$Q$25<=$T$25	Binding	0
$Q$26	material change Value	6.00	$Q$26<=$T$26	Binding	0

Overall, the dimensions are bigger when maximizing profit in the microeconomics model compared to minimizing weight and size in the engineering model.

4. MODEL EXTENSION: MARKETING

4.1 Specific Market Size

The heart rate monitor will be marketed to teenagers and adults that exercise in the United States. According to the U.S. Census Bureau, there are 219,038,111 people between 16 years 85 years in the United States. Of these, an estimated 23% participate in sustained, leisure-time activity according to the U.S. Department of Health and Human Services. This gives us an estimated market size of 50,378,765 people in the United States. In order to provide a realistic estimate of the actual number of people who might purchase this product, only half of the exercising adults were used as a target market size- about 25,000,000.

4.2 Functional Relationship of product utility with respect to price and two product characteristics

The four characteristics chosen to represent utility are the price, screen and body orientation, screen and body shape, and size. Appendix 4.1 shows the different shapes, orientations, and sizes. The reason for this choice was that the appearance of electronic products like a watch

plays a vital role in customer's decision to purchase them or not. The size also greatly affects consumers' purchasing patterns.

4.3 Logit Model Discretization and Interpolation Scheme

a. Levels and Orthogonal Array

There were 3 levels chosen for orientation- angled, vertical, and horizontal. There were four levels chosen for price- $50, $100, $150, $200. There were four levels chosen for size- 4 cm length side, 5 cm length side, 6 cm length side, and 7 cm length side. See the Appendix 1.0 for images of these sizes. There were four levels chosen for the shape of the body and screen- rectangle, square, circle, and organic. The SAS software was used to generate an orthogonal array. Unfortunately, an orthogonal array could not be generated by SAS for our inputs.

b. Survey

The survey was created using the code given in Appendix 2.0. The survey that was administered is given in Appendix 3.0.

c. Maximum Likelihood Formula

The calculations for Maximum likelihood and results are given in Appendix 1.0.

4.4 Demand Function Calculation for the given Market

Objective Function

Name	Description	Value	Units	Scaled	Formula
f	Maximize profit while minimizing deviation from engineering design	**-1324316562**	-	-132.432	$f = -\Pi + \varepsilon$
Π	Profit	**$1,324,316,562**	$		$\Pi = q(p - c_V) - c_I$
ε	Weighted deviation	**0**	-		$\varepsilon = \left\| \mathbf{w} \circ (\mathbf{z}_M - \mathbf{z}_E) \right\|_2^2$

Decision Variables : z_M,p

Name	Description		Units	Scaled	Min	Max
z1	Orientation	**1**	lbs	0.417	1	4
z2	Price	**200.000**	-	0.337	50	200.000
z3	size	**4.0**	in^2	0.606	4	7
z4	shape	**2.0307**	in	0.590	1.000	4

Intermediate Calculations

Name	Description	Value	Units		Formula
vp	Interpolated part worth of orientation	**-0.144**	-		
v1	Interpolated part worth of price	**-0.555**	-		
v2	Interpolated part worth of size	**-0.013**	-		
v3	Interpolated part worth of shape	**-0.026**	-		
v	Total deterministic component of utility	**-0.738**	-		$\Psi_\beta(\mathbf{z}, p)$
S	Market Share	**32.33%**	-		$S = \frac{e^v}{1+e^v}$
q	Demand	**8,083,638**	units		$q = s\frac{e^v}{1+e^v}$

Parameters

Name	Description	Value	Units
s	Size of market	**25,000,000**	-
cV	Variable cost per unit	**$36.00**	$
cI	Investment cost	**$1,400,000**	$
u0	Utility of the outside good	**0**	-

$Q_m = e^{(\psi_{orientation} + \psi_{price} + \psi_{size} + \psi_{shape})} / (1 + e^{(\psi_{orientation} + \psi_{price} + \psi_{size} + \psi_{shape})})$
$Q_m = (e^{1.518} / (1 + e^{1.518})) * 25{,}000{,}000$

According to the Excel Table above, the demand q= 8,083,638 units at the point of optimized profit. Although this was the optimized solution, the demand greatly changes if the design was to fit perfectly the customers' choice. As seen below, the demand increases to nearly 20,500,000 but does not result in as much profit. This explains the high prices and high functionality of many of these monitors on the market.

Objective Function

Name	Description	Value	Units	Scaled	Formula
f	Maximize profit while minimizing deviation from engineering design	**-286175682**	-	-28.618	$f = -\Pi + \varepsilon$
Π	Profit	**$286,175,682**	$		$\Pi = q(p - c_V) - c_I$
ε	Weighted deviation	**0**	-		$\varepsilon = \left\| \mathbf{w} \circ (\mathbf{z}_M - \mathbf{z}_E) \right\|_2^2$

Decision Variables : z_M,*p*

Name	Description		Units	Scaled	Min	Max
z1	Orientation	**1**	lbs	0.417	1	4
z2	Price	**50.000**	-	0.337	50	200.000
z3	size	**4.0**	in^2	0.606	4	7
z4	shape	**2.0000**	in	0.590	1.000	4

Intermediate Calculations

Name	Description	Value	Units		Formula
vp	Interpolated part worth of orientation	**-0.144**	-		
v1	Interpolated part worth of price	**1.711**	-		
v2	Interpolated part worth of size	**-0.013**	-		
v3	Interpolated part worth of shape	**-0.026**	-		
v	Total deterministic component of utility	**1.528**	-		$\Psi_\beta(\mathbf{z}, p)$
S	Market Share	**82.16%**	-		$S = \frac{e^v}{1+e^v}$
q	Demand	**20,541,120**	units		$q = s\frac{e^v}{1+e^v}$

Parameters

Name	Description	Value	Units
s	Size of market	**25,000,000**	-
cV	Variable cost per unit	**$36.00**	$
cI	Investment cost	**$1,400,000**	$
u0	Utility of the outside good	**0**	-

4.5 Linearize Demand Function using Taylor Series

We only used two of the same product attributes for the survey and the Assignment #3. We used size with a postulated demand function of q = -2034.1x + 152278 with x equal to the increasing size. The elasticity is therefore 2034. In order to calculate the elasticity using Taylor Series for the size, the baseline of (horizontal, $50, 4 cm, circle) was calculated to have a demand of 19,383,097. For a next size larger, (horizontal, $50, 5 cm, circle) the demand was 16,693,821. Therefore the elasticity is $(dq/dp) = (q_1 - q_o) / k = (16{,}693{,}821 - 19{,}383{,}097) / (5cm*5cm*1cm-$

4cm*4cm*1cm) = 298,808. These elasticities vary greatly proving a lack of validity in the estimated curves used in assignment #3.

We also used price as a common product attribute. The postulated demand function of price was q = -139.14x + 49550 where x is the increasing price of the product. The elasticity according to this model is therefore 139.14. In order to calculate the elasticity using Taylor Series for the price, the baseline of (horizontal, $50, 4 cm, circle) was calculated to find a demand of 19,383,097. For the next price up, say $70, the demand is equal to 16,982,744. Therefore the elasticity is $(dq/dp) = (q_1 - q_o) / k = (16{,}982{,}744 - 19{,}383{,}097) / (70-50) = 120{,}017$. These elasticities vary greatly proving a lack of validity in the estimated curves used in assignment #3.

4.6 New Demand Function Reoptimization of Model for Assignment #3

Due to the survey design, we used different product characteristics for Assignment #3 and #4. The optimization of the new demand function gives the following results that are also discussed above.

Objective Function

Name	Description	Value	Units	Scaled	Formula
f	Maximize profit while minimizing deviation from engineering design	-1324316562	-	-132.432	$f = -\Pi + \varepsilon$
Π	Profit	$1,324,316,562	$		$\Pi = q(p - c_V) - c_I$
ε	Weighted deviation	0	-		$\varepsilon = \left\| \mathbf{w} \circ (\mathbf{z}_M - \mathbf{z}_E) \right\|_2^2$

Decision Variables : z_M,p

Name	Description		Units	Scaled	Min	Max
$z1$	Orientation	1	lbs	0.417	1	4
$z2$	Price	200.000	-	0.337	50	200.000
$z3$	size	4.0	in^2	0.606	4	7
$z4$	shape	2.0307	in	0.590	1.000	4

Intermediate Calculations

Name	Description	Value	Units		Formula
vp	Interpolated part worth of orientation	-0.144	-		
$v1$	Interpolated part worth of price	-0.555	-		
$v2$	Interpolated part worth of size	-0.013	-		
$v3$	Interpolated part worth of shape	-0.026	-		
v	Total deterministic component of utility	-0.738	-		$\Psi_\beta(\mathbf{z}, p)$
S	Market Share	32.33%	-		$S = \frac{e^v}{1+e^v}$
q	Demand	8,083,638	units		$q = s\frac{e^v}{1+e^v}$

Parameters

Name	Description	Value	Units
s	Size of market	25,000,000	-
cV	Variable cost per unit	$36.00	$
cI	Investment cost	$1,400,000	$
$u0$	Utility of the outside good	0	-

As is shown by this table, the optimized orientation is horizontal, the price is $200, the size is 4cm, and the shape is close to a rectangle. The demand is low, but profit high. Comparing our results to the Assignment #3 would not be appropriate, since we have changed the product characteristics.

5. FURTHER AESTHETICS STUDY

5.1 Purpose

The purpose of the study is to take *semantic* qualities that are often used in industrial design and use the marketing model to determine if there is a correlation between the user preferences and the perceived attributes that lead the to design decisions.

> ***Product Semantics:*** a study of symbolic qualities of man-made forms in the cognitive and social context of their use and application of knowledge gained to objects of industrial design. The symbolic meanings of *forms, shapers and texture* are the most characteristic concerns of product semantics. (Butter and Krippendorff, 1984)

5.2 Method

Researching papers on semantics yielded various words that could be used to translate a literal shape idea into forms. After researching the design characteristics used in similar semantics studies, three words were selected that would be the basis of aesthetic design decisions. These design decisions were then applied to the "Sprinter" in order to produce a survey for users to take. The results were gathered and analyzed using the same process as in the marketing model extension-SAS and logit modeling.

5.3 Method Details

In order to reduce the number of variables in the study, words were chosen that were at the most objective level possible. We researched various words to represent design characteristics with particular meanings when it comes to form.

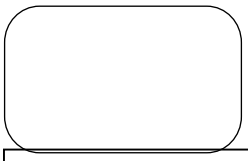
Other researchers, such as Jean-Francios Petiot and Bernard Yannou in *"How to comprehend and Assess Product Semantics"* used descriptors such as "originality, smartness, stability and fragility" for the table glasses they picked as their case study. Another study about aesthetics management was done by Pamela W. Henderson and Joseph A. Cote. They have studied the *impact of logos on consumer perceptions* and picked the design characteristics as "elaborative ness, naturalness, association and symmetry". After reviewing these studies, appropriate words for the heart rate monitor related to "comfort, dependability and ease of use" were selected to determine which design characteristics best predict whether or not consumers prefer a heart rate monitor. According to the design characteristics the words chosen were "**familiarity** - *common and ordinary*", "**cohesiveness** - *well integrated*" and "**complexity** - *complicated in structure*".

The hypothesis conjectured that users would prefer a heart rate monitor that was "familiar", "cohesive", and "simple". In addition, the users were asked to rank the objects according to these three descriptors. The hypothesis was that the users would be able to make solid judgments about the degree of the three adjectives.

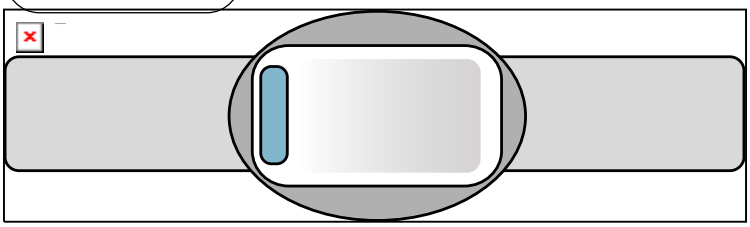
Each of the three words was analyzed to determine what design characteristics would be modified into levels for the survey. The results from the prior survey in Assignment #4 were used, dictating that the overall shape of the product would be similar to a rectangle, the orientation angle of the product body would be horizontal and the size of the overall product has to be as small as possible. Then each word was analyzed to find out what product characteristics to change.

a- Familiarity

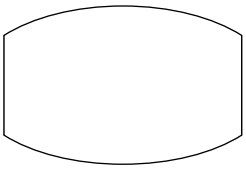
For the descriptor "familiarity", the overall shape of the product was changed for the 3 levels.



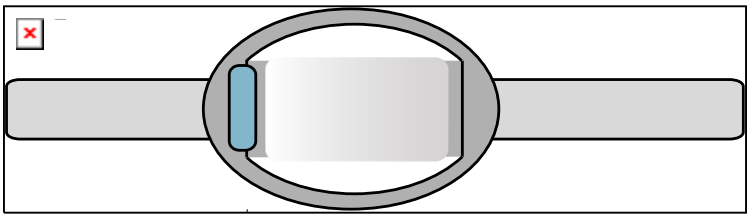
1- The first shape, which was considered most familiar to the users, was a rectangle according to the first survey analysis. Therefore, the main shape was chosen to be a rectangle, like shown to the left.



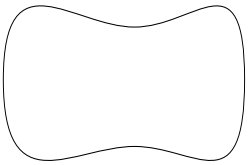
This shape within a product can be seen at the left for reference.



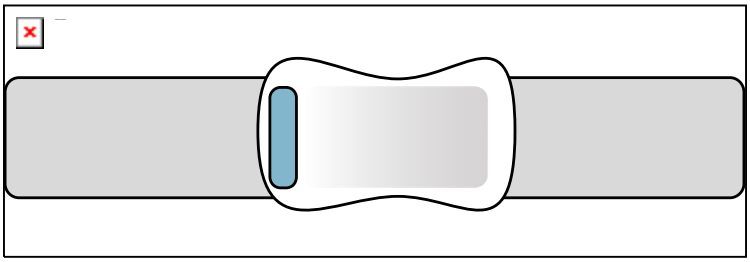
2- Next, the next level of familiarity of a shape was a mix between the familiar circle and rectangle and is shown to the left.



This shape in a product for reference is given.

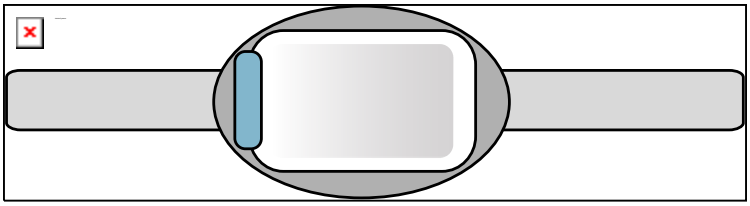


3- The least familiar shape chosen as the last level is shown below.

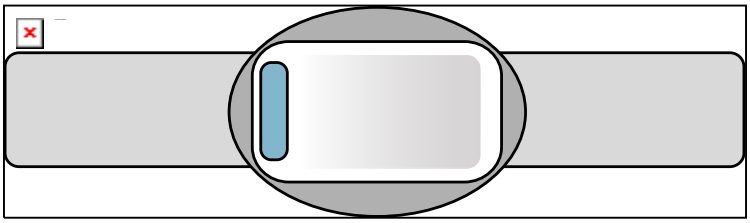


This shape used in a product is shown here.

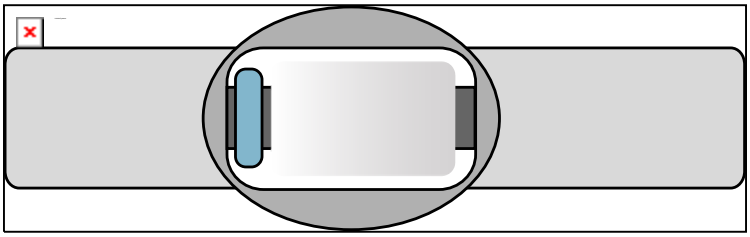
b- Cohesiveness



1- In order to represent cohesiveness, the button and screen were manipulated to be more or less included in the inner shape (least cohesive can be seen here). As you can see, the button is not located within the inner shape, keeping it slightly separate from the overall form. It seems a bit unconnected or disjointed sitting halfway in and halfway out.

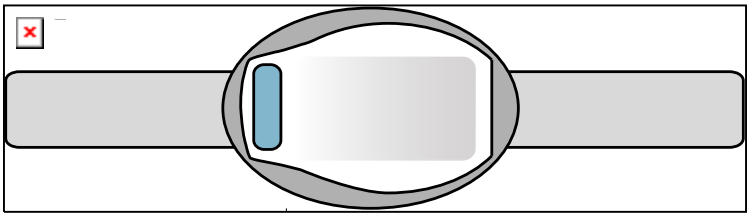


2- The next level, given at the left, shows a bit more cohesiveness because the button is located within the inner shape, seems more part of the elements and gives the perception of integration.

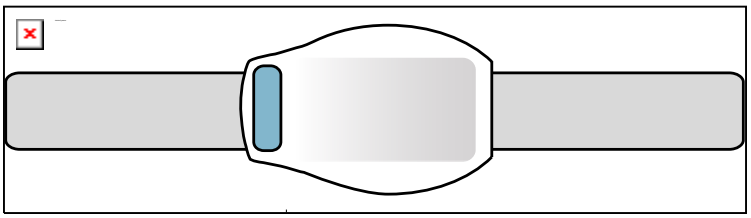


3- The last level of cohesiveness, the most cohesive one, uses an extra piece of material to link the button with the inner shapes as in the picture. This product shows the most cohesiveness because of the inner darker shape that serves as a connector piece.

c- Complexity



1- The last product attribute is "complexity". Complexity was added with no extra function. The background oval is changed from opaque to transparent, giving the product more visual details without any functionality.



2- The least complex level is seen to the left. The main change in complexity is in the added lines, color change and details.

5.4 Survey Results

After completing the design characteristics decisions, the survey was created using the SAS program. The final survey is show in Appendix 5.1.

The results from the survey are show below. The graphs of betas verses the product attributes show the preference for each of the given levels.

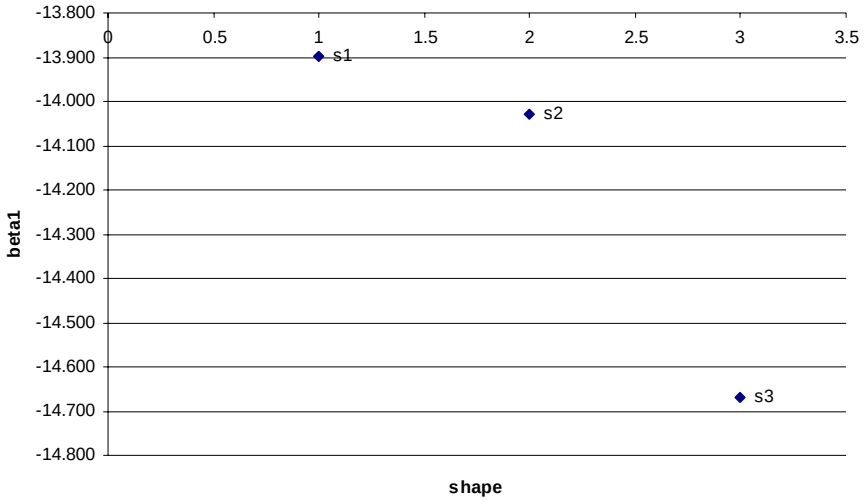


Figure 5.1 Preferences for Shape

(s1= rectangular shape and most familiar, s2= oval shape and second most familiar, s3= concave shape and least familiar)

Figure 5.1 indicates that the users surveyed preferred the rectangular shape that was determined by the designers to be the most familiar. The next preference was the oval (second most familiar) and the third preference was the concave shape (least familiar). The results, however, do not indicate that the users understood the designers' intent and found the products familiar. The results only indicate that if the designers make a conscious decision to design a product using what they may believe to be familiar, the product may in turn be perceived as comfortable.

The next product attribute is cohesiveness and the preference graph is shown below in Figure 5.2

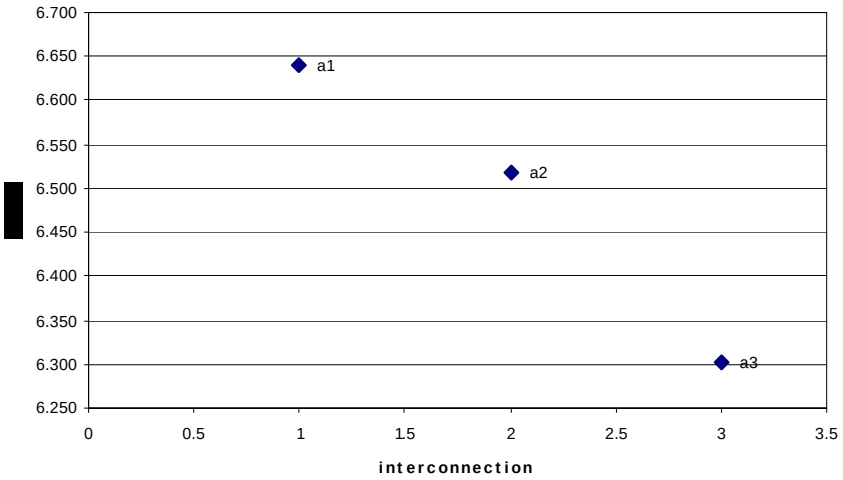


Figure 5.2 Preferences for Cohesiveness (a1= most cohesive, a2= second most cohesive, a3= least cohesive)

As Figure 5.2 indicates, the preference for cohesiveness varies from liking most cohesive to least cohesive. As in the last case, however, these results do not indicate that the users actually attribute their preference to the perceived "cohesiveness." The results indicate that their preferences do correlate with the designers' ideas for forms that they believe exemplify cohesiveness.

The next Figure 5.3 shows the relationship between the designers' concepts for complexity and the users' preferences.

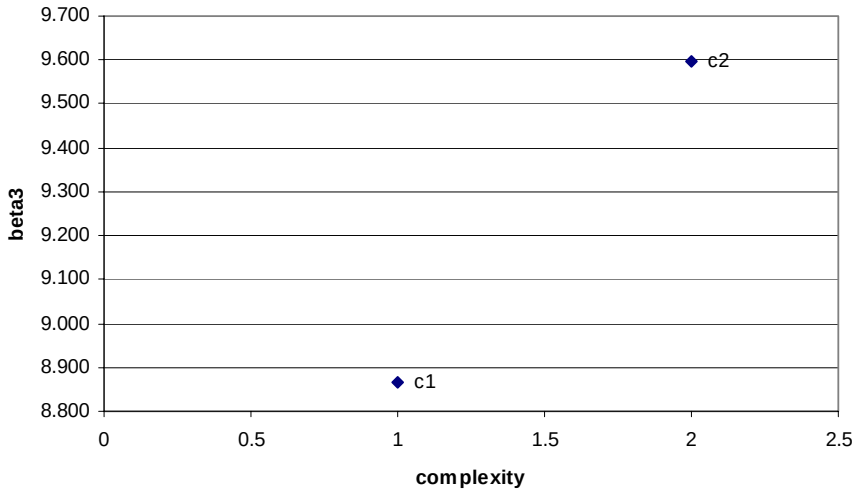


Figure 5.3 Preferences for complexity

(c1= most complex and c2= least complex)

This graph shows that the users preferred the least complex of the two choices. Again, this is not to say that the users can directly link their choice to complexity, but the results do indicate that the designers' idea of "complex" correlates to the users' preferences.

The second part of the survey entailed the determination of whether the users felt the products aligned with the designers' concepts for "familiarity", "cohesiveness", and "complexity". As shown in the Appendix 5.1, the users were asked to rank the products according to the three terms from 1 to 5. The data yields no concrete correlations. Some users did follow a perception that related to the designers' intentions, but many did not. The graphs below show the results from a few of those surveyed. They show no distinct trend in their responses.

5.5 Second Part of the Survey – User perceptions

The second part of the survey entailed the determination of whether the users felt the products aligned with the designers' concepts for "familiarity", "cohesiveness", and "complexity". As shown in the Appendix 5.1, the users were asked to rank the products according to the three terms from 1 to 5. The data yields no concrete correlations. Some users did follow a perception that related to the designers' intentions, but many did not. They show no distinct trend in their responses, but a couple conclusions can be inferred.

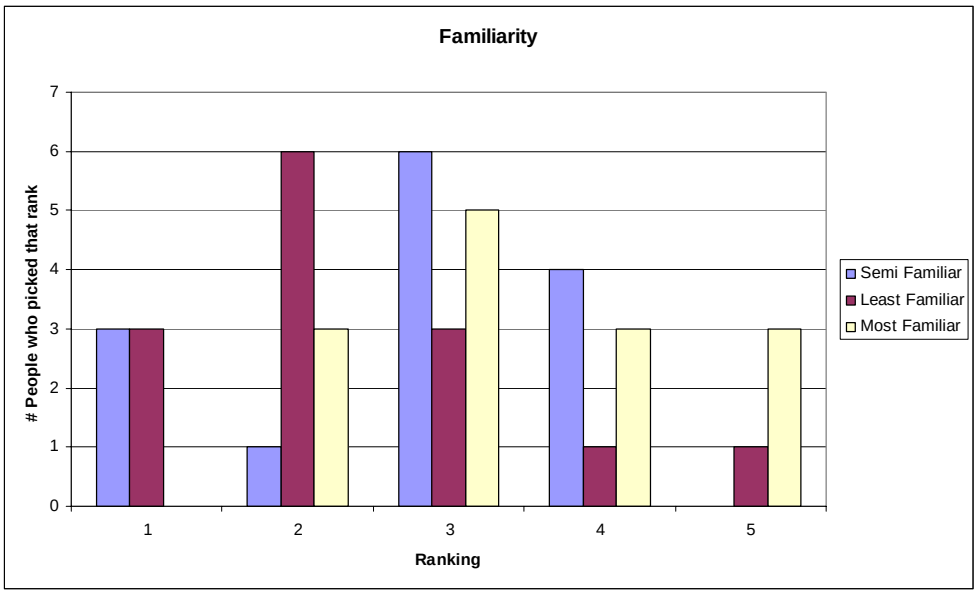


Figure 5.4 Familiarity - ranking of people's perceptions of the various products

The above Figure 5.4 shows the number of individuals who ranked the three products according to familiarity. The results do not show any concrete trends. One inference can be made that the users ranking of the "Most Familiar" tended to have higher numbers suggesting that perhaps they felt it was more familiar. The "Least Familiar" product had lower rankings, which suggests that the users did find this one less familiar. The "Semi-familiar" form sort of lingered in the middle. This conclusion, however, require a large amount of extrapolation and further studies would need to be done in order to verify any of the tendencies.

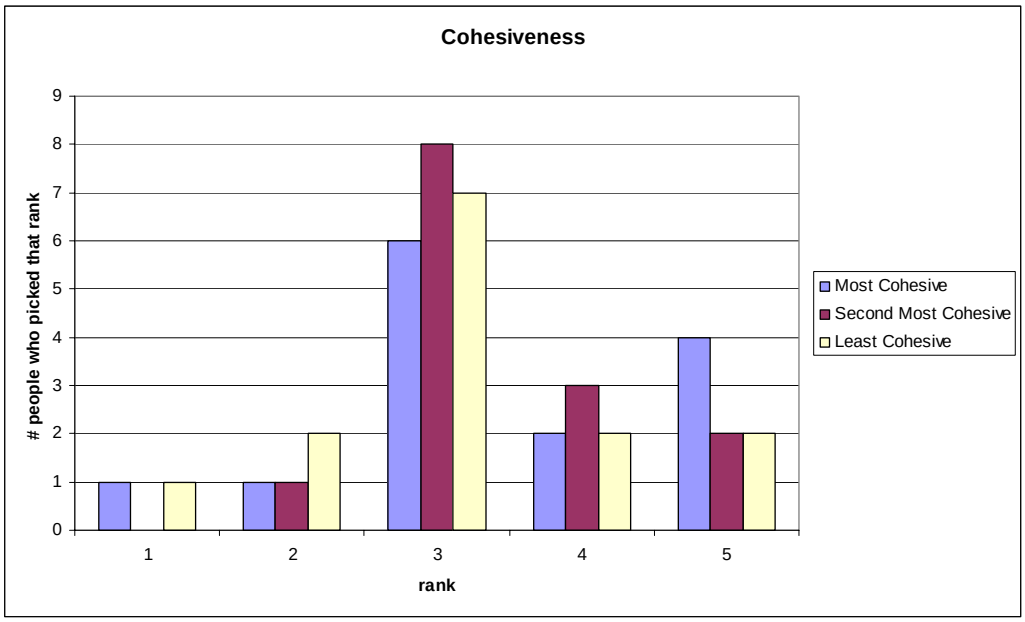


Figure 5.5 Cohesiveness - ranking of people's perceptions of the various products

Figure 5.5 shows the users' rankings of "cohesiveness" for the different products. From these results, it can be surmised that perhaps the users did not find much difference in the cohesiveness of the various products. The "Most Cohesive" products did tend to have higher rankings in a general sense and the "Least Cohesive" had lower ranking values. Overall, the perception of cohesiveness stays neutral and does not vary much between products.

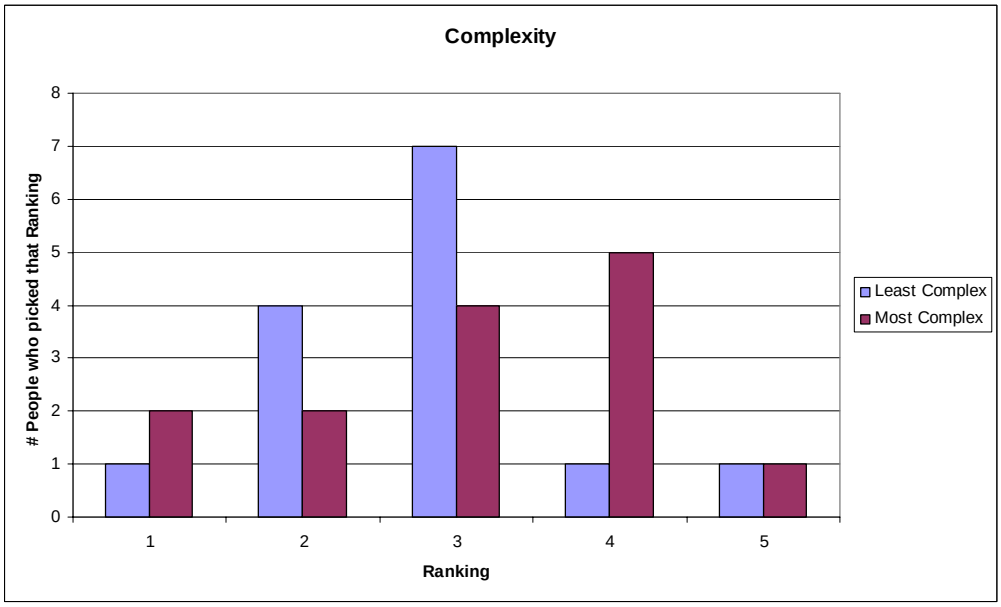


Figure 5.6 Complexity ranking of people's perceptions of the various products

The next figure, Figure 5.6, shows the ranking of the users' perception of complexity of the products. From this figure, the "Most Complex" product had higher rankings and the "Least Complex" and more lower rankings. However, the results are still not very clear and further studies like usage of physical models in focus groups would need to be done.

5.6 Conclusion

This assignment provides some interesting results. According to the gathered data, the designers' product characteristics aligned with the users' preferences. Using this data, the hypothesis can be supported. In other words, this data suggests that under the specific circumstances of this study, these users preferred a heart rate monitor that has a "familiar", "cohesive", and "simple" form in the eyes of the designer. These results suggest that perhaps if industrial designers consciously make decisions about how visual characteristics relate to semantic concepts, such as "familiarity", "complexity", and "cohesiveness", then there may be a link with the users' preferences.

The second part of the survey attempted to link the user's preferences with their notion of whether the products had the same meaning as the designers conjectured. Unfortunately, this hypothesis can not be proven by the results. A solid correlation could not be found between the users' perception of "familiarity", "complexity", and "cohesiveness" and the designers' idea for translation of these descriptors into product form. There were some extrapolated generalizations that could be made that somewhat linked their concepts of complexity and familiarity to those of the designers, but the results are not clear. A tentative conclusion can be made that although the preferences aligned with the designers' intent, the semantic understanding of the forms did not directly link.

Even though a conscious attempt was made to eliminate as many variables as possible, it must be noted that the results may be skewed. Culture, ergonomics, and demographics are important factors to consider when designing products and they were neglected in the survey and study. In order to gather more robust data, the same survey should be given to people from different demographics, to people under different environmental circumstances, and to people of different cultures. These alterations would affect the results because the people would differ in their need for complexity, familiarity, and shape. Ergonomics would require different shapes, familiarity would vary between users, and the product would need to have different levels of complexity for different tasks.

6. CONCLUSION

In order to get realistic results, additional constraints would need to be added to the engineering model regarding design of circuit boards, processors, sensors, and product assembly. This model was simplified in order to focus on the users' point of view and add in the constraints that aligned with their goals. After determining the users' preference for a rectangular shape, it was noted that the engineering model results compete with the preference for users to have a rectangular product. This result is due to the fact that minimizing size and weight would result in a square shaped product. By introducing the golden ratio into the engineering model, the size and weight must be larger than if this constraint was not included.

The microeconomics and marketing model differ in their results for a few reasons. Firstly, the elasticities were extreme estimates not taken from accurate statistical data about preference. Second, the demand curve was also an estimation made without accurate data. The marketing model data may be skewed due to ineffective survey creation and inability to provide real physical products to those being surveyed.

The results from the microeconomics and marketing models differ because the microeconomics model takes into account more design attributes- function, material, size, display size, and price. The marketing model includes shape, orientation, size, and price. Therefore, there are only two overlaps- size and price. The quantity demanded and the optimized associated profit also vary. The microeconomics model yielded a maximum profit of $35,180,681.91 at a demand of 100,000 units sold. The marketing model yielded a profit of $50,723,546 with a demand of 270,766 units sold.

Interesting results emerged from the final survey and study of aesthetics. The designers picked three words, "familiarity", "cohesiveness", and "complexity", which industrial designers commonly use to describe products during conceptualization. The designers modeled levels of design attributes after these three words. The results of a survey yielded a trend in which the users preferred the most familiar, most cohesive, and most simple choices that the designers had created. When asked to rank the level of "familiarity", "cohesiveness", and "complexity" the majority of the rankings did not align with the designers' attribute levels. In other words, the users liked the hypothesized designs but could not align their preference with the designers' decisions. More effective surveys may have revealed more information, or perhaps, it is hard to users to justify their preferences for visual objects.

REFERENCES

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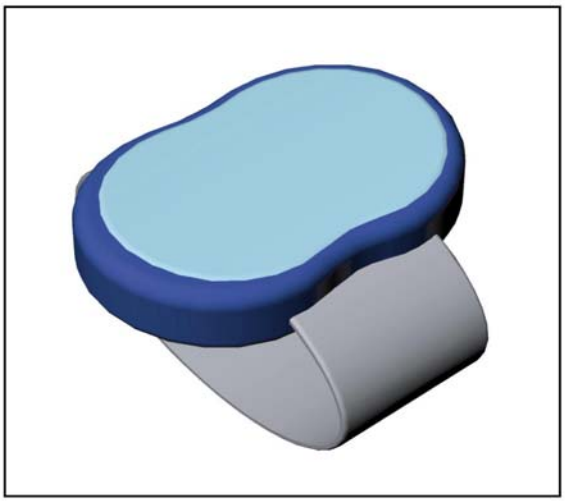
APPENDICES

Appendix 1. Heart Rate Monitor Survey I – Design Characteristics

1.1 Images of Product Characteristic Levels & Shapes

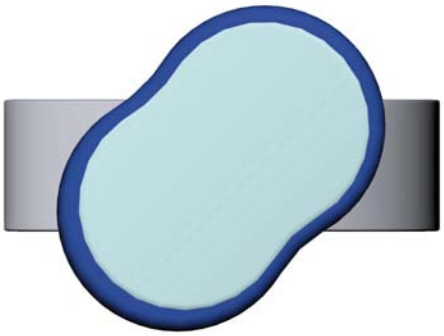


Organic Shape

Rectangle Shape

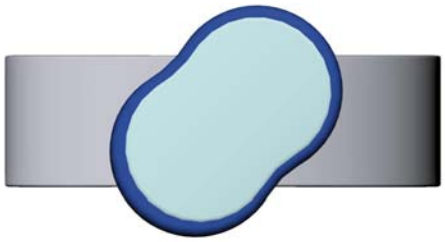
Circle Shape

Square Shape

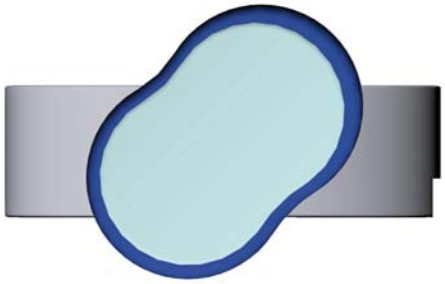


Orientation: Angled
Shape: Organic

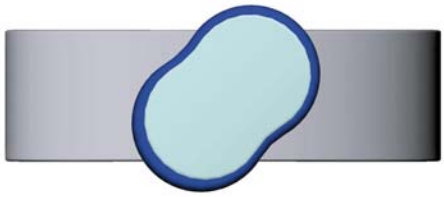
Size: 7x4.6 cm



Size: 5x3.3 cm

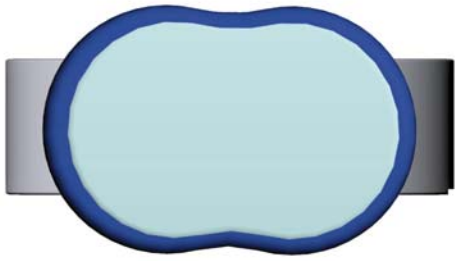


Size: 6x4 cm



Size: 4x2.6 cm

Orientation: Horizontal
Shape: Organic

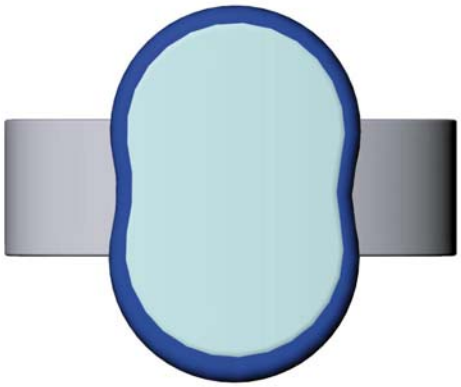


Size: 7x4.6 cm

Size: 5x3.3 cm

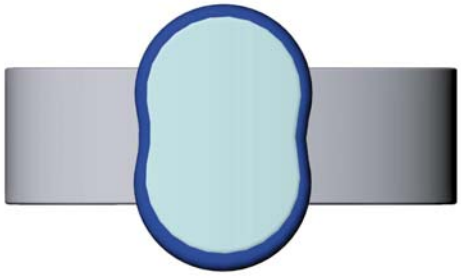
Size: 6x4 cm

Size: 4x2.6 cm

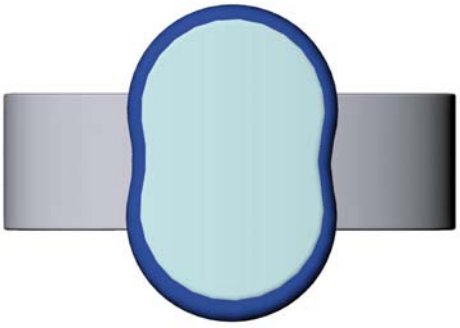


Orientation: Vertical
Shape: Organic

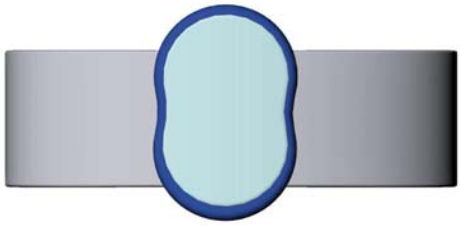
Size: 7x4.6 cm



Size: 5x3.3 cm



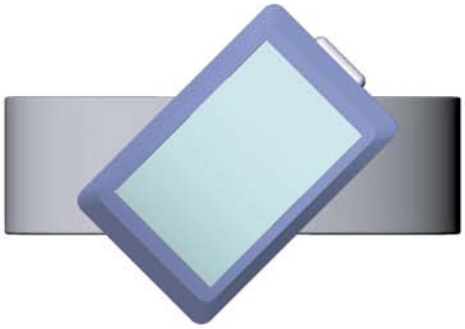
Size: 6x4 cm



Size: 4x2.6 cm

Orientation: Angled
Shape: Rectangle

Size: 7x4.6 cm



Size: 5x3.3 cm

Size: 6x4 cm

Size: 4x2.6 cm

Orientation: Horizontal
Shape: Rectangle

Size: 7x4.6 cm

Size: 5x3.3 cm

Size: 6x4 cm

Size: 4x2.6 cm

Orientation: Vertical
Shape: Rectangle

Size: 7x4.6 cm

Size: 5x3.3 cm

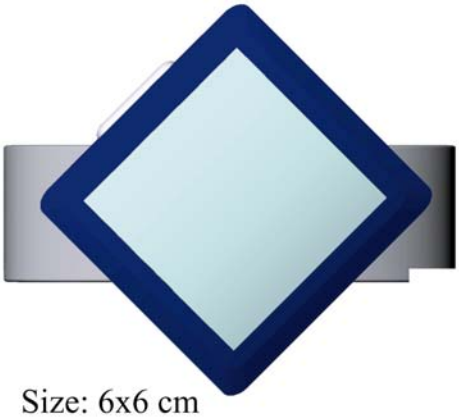
Size: 6x4 cm

Size: 4x2.6 cm

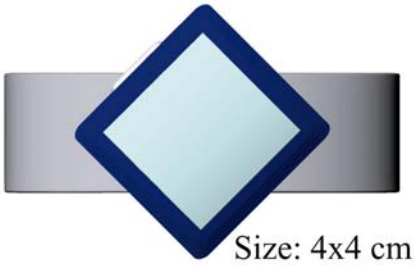
Orientation: Angled
Shape: Square

Size: 7x7 cm

Size: 5x5 cm



Size: 6x6 cm



Size: 4x4 cm

Orientation: Vertical/
Horizontal
Shape: Square

Size: 7x7 cm

Size: 5x5 cm

Size: 6x6 cm

Size: 4x4 cm

1.2 SAS Code for Determining Survey Questions

```
%include 'H:\SAS MACROS\mktallo.sas';
%include 'H:\SAS MACROS\mktbal.sas';
%include 'H:\SAS MACROS\mktblock.sas';
%include 'H:\SAS MACROS\mktdes.sas';
%include 'H:\SAS MACROS\mktdups.sas';
%include 'H:\SAS MACROS\mkteval.sas';
%include 'H:\SAS MACROS\mktex.sas';
%include 'H:\SAS MACROS\mktkey.sas';
%include 'H:\SAS MACROS\mktlab.sas';
%include 'H:\SAS MACROS\mktmerge.sas';
%include 'H:\SAS MACROS\mktorth.sas';
%include 'H:\SAS MACROS\mktroll.sas';
%include 'H:\SAS MACROS\mktruns.sas';
%include 'H:\SAS MACROS\choiceff.sas';
%include 'H:\SAS MACROS\phchoice.sas';
%include 'H:\SAS MACROS\plotit.sas';



%mktruns(3 3 3 3 4 4 4 4 4 4 4 4 4 4 4 4);
%let m=5;
%let mm1=%eval(&m-1);
%let n=81;
%mktex(3 3 3 3 4 4 4 4 4 4 4 4 4 4 4 4,n=81);
proc format;
value orientation 1='vertical' 2='horizontal' 3='angled';
value price 1='$50' 2='$100' 3='$150' 4='$200';
value size 1='4x2.666 cm' 2='5x3.33333 cm' 3=' 6x4 cm' 4=' 7x4.66666 cm';
value shape 1='circle shape' 2='rectangle shape' 3='square shape' 4='organic shape';
run;
%mktlab(data=randomized, vars=x1-x16, out=sasuser.des)
%mkteval(data=design, print=freqs);
proc data=sasuser.des; run;
options ls=80 ps=60 nonumber nodate;
data _null_;
array alternatives[&mm1] $ 10 _temporary_ ('alter.1 ' 'alter.2 ' 'alter.3 ' 'alter.4');
array orientation[3] $10 _temporary_ ('vertical' 'horizontal' 'angled');
array price[4]   $13 _temporary_ ('$50' '$100' '$150' '200');
array size[4]   $10 _temporary_ ('4x2.666 cm' '5x3.333 cm' '6x4 cm' '7x4.666 cm');
array shape[4]   $10 _temporary_ ('circle shape' 'rectangle shape' 'square shape' 'organic shape');

array x[16];
file print linesleft=ll;
set sasuser.des;
put _page_;
put @50 'Form: ' ' Subject: -------'//;
if ll<51 then put _page_;
put _n_ 2. ') Circle your choice of alternative :';
do pi = 1 to &mm1;
  put '    ' pi 1. ') ' alternatives[pi]
  +(-1) ' orientation:' orientation[x[pi]]
  +(-1) ', price:' price[x[&mm1+pi]]
  +(-1) ' size: ' size[x[2*&mm1+pi]]
```

```
+(-1) 'shape: ' shape[x[2*&mm1+pi]]
  +(-1) '.';
end;
put "    &m) none"/;
run;
data key;
   input Product $ Orientation $ Price $ Size $ Shape $;
          datalines;
          P1 x1 x5 x9 x13
          P2 x2 x6 x10 x14
   P3 x3 x7 x11 x15
          P4 x4 x8 x12 x16
          None . . .
          ;
          proc print; run;
          %mktroll(design=randomized,key=key,alt=product, out=rolled);
proc print data=rolled; format price price. Energyc Energyc. capacity capacity. Shape shape.; run;
```

1.3 Heart Rate Monitor Survey

1) Circle your choice of alternative :
   1) orientation:horizontal, price:$100 size: 4x2.666 cm shape: circle shape
   2) orientation:vertical, price:$100 size: 5x3.333 cm shape: rectangle shape
   3) orientation:vertical, price:$50 size: 4x2.666 cm shape: circle shape
   4) orientation:angled, price:$100 size: 4x2.666 cm shape: circle shape
   5) none

2) Circle your choice of alternative :
   1) orientation:vertical, price:$100 size: 7x4.666 cm shape: organic shape
   2) orientation:horizontal, price:$50 size: 7x4.666 cm shape: organic shape
   3) orientation:vertical, price:$100 size: 7x4.666 cm shape: organic shape
   4) orientation:vertical, price:$50 size: 4x2.666 cm shape: circle shape
   5) none

3) Circle your choice of alternative :
   1) orientation:vertical, price:$100 size: 5x3.333 cm shape: rectangle shape
   2) orientation:horizontal, price:200 size: 4x2.666 cm shape: circle shape
   3) orientation:vertical, price:$150 size: 4x2.666 cm shape: circle shape
   4) orientation:vertical, price:$100 size: 6x4 cm shape: square shape
   5) none

4) Circle your choice of alternative :
   1) orientation:vertical, price:$100 size: 4x2.666 cm shape: circle shape
   2) orientation:horizontal, price:200 size: 7x4.666 cm shape: organic shape
   3) orientation:angled, price:$50 size: 7x4.666 cm shape: organic shape
   4) orientation:angled, price:$150 size: 5x3.333 cm shape: rectangle shape
   5) none

5) Circle your choice of alternative :
   1) orientation:angled, price:$50 size: 5x3.333 cm shape: rectangle shape
   2) orientation:angled, price:$150 size: 6x4 cm shape: square shape
   3) orientation:angled, price:$100 size: 4x2.666 cm shape: circle shape
   4) orientation:angled, price:$100 size: 4x2.666 cm shape: circle shape
   5) none

6) Circle your choice of alternative :
1) orientation:vertical, price:$50 size: 7x4.666 cm shape: organic shape
2) orientation:vertical, price:$150 size: 5x3.333 cm shape: rectangle shape
3) orientation:vertical, price:$50 size: 7x4.666 cm shape: organic shape
4) orientation:horizontal, price:$100 size: 5x3.333 cm shape: rectangle shape
5) none

7) Circle your choice of alternative :
1) orientation:horizontal, price:$50 size: 7x4.666 cm shape: organic shape
2) orientation:horizontal, price:200 size: 5x3.333 cm shape: rectangle shape
3) orientation:angled, price:$150 size: 6x4 cm shape: square shape
4) orientation:angled, price:200 size: 7x4.666 cm shape: organic shape
5) none

8) Circle your choice of alternative :
1) orientation:vertical, price:$150 size: 4x2.666 cm shape: circle shape
2) orientation:angled, price:200 size: 4x2.666 cm shape: circle shape
3) orientation:angled, price:$100 size: 6x4 cm shape: square shape
4) orientation:horizontal, price:$50 size: 7x4.666 cm shape: organic shape
5) none

9) Circle your choice of alternative :
1) orientation:horizontal, price:$50 size: 4x2.666 cm shape: circle shape
2) orientation:angled, price:$50 size: 4x2.666 cm shape: circle shape
3) orientation:vertical, price:$100 size: 7x4.666 cm shape: organic shape
4) orientation:angled, price:200 size: 7x4.666 cm shape: organic shape
5) none

10) Circle your choice of alternative :
1) orientation:horizontal, price:$150 size: 5x3.333 cm shape: rectangle shape
2) orientation:horizontal, price:$150 size: 4x2.666 cm shape: circle shape
3) orientation:horizontal, price:$50 size: 7x4.666 cm shape: organic shape
4) orientation:angled, price:$150 size: 4x2.666 cm shape: circle shape
5) none

11) Circle your choice of alternative :
1) orientation:horizontal, price:$50 size: 7x4.666 cm shape: organic shape
2) orientation:horizontal, price:$150 size: 4x2.666 cm shape: circle shape
3) orientation:horizontal, price:200 size: 4x2.666 cm shape: circle shape
4) orientation:angled, price:200 size: 5x3.333 cm shape: rectangle shape
5) none

12) Circle your choice of alternative :
1) orientation:vertical, price:$50 size: 4x2.666 cm shape: circle shape
2) orientation:vertical, price:200 size: 7x4.666 cm shape: organic shape
3) orientation:vertical, price:$150 size: 6x4 cm shape: square shape
4) orientation:vertical, price:200 size: 5x3.333 cm shape: rectangle shape
5) none

13) Circle your choice of alternative :
1) orientation:vertical, price:$50 size: 6x4 cm shape: square shape
2) orientation:horizontal, price:200 size: 5x3.333 cm shape: rectangle shape
3) orientation:horizontal, price:200 size: 5x3.333 cm shape: rectangle shape
4) orientation:angled, price:$100 size: 4x2.666 cm shape: circle shape
5) none

14) Circle your choice of alternative :
1) orientation:angled, price:$100 size: 4x2.666 cm shape: circle shape
2) orientation:angled, price:$150 size: 7x4.666 cm shape: organic shape
3) orientation:horizontal, price:$150 size: 5x3.333 cm shape: rectangle shape
4) orientation:horizontal, price:$150 size: 6x4 cm shape: square shape
5) none

15) Circle your choice of alternative :
1) orientation:angled, price:$150 size: 6x4 cm shape: square shape
2) orientation:horizontal, price:200 size: 7x4.666 cm shape: organic shape
3) orientation:vertical, price:200 size: 7x4.666 cm shape: organic shape
4) orientation:horizontal, price:$150 size: 4x2.666 cm shape: circle shape
5) none

16) Circle your choice of alternative :
1) orientation:horizontal, price:200 size: 4x2.666 cm shape: circle shape
2) orientation:angled, price:200 size: 5x3.333 cm shape: rectangle shape
3) orientation:angled, price:200 size: 7x4.666 cm shape: organic shape
4) orientation:vertical, price:$50 size: 5x3.333 cm shape: rectangle shape
5) none

17) Circle your choice of alternative :
1) orientation:angled, price:200 size: 4x2.666 cm shape: circle shape
2) orientation:horizontal, price:$150 size: 7x4.666 cm shape: organic shape
3) orientation:vertical, price:$150 size: 4x2.666 cm shape: circle shape
4) orientation:vertical, price:$100 size: 7x4.666 cm shape: organic shape
5) none

18) Circle your choice of alternative :
1) orientation:vertical, price:$150 size: 5x3.333 cm shape: rectangle shape
2) orientation:horizontal, price:$100 size: 6x4 cm shape: square shape
3) orientation:vertical, price:200 size: 5x3.333 cm shape: rectangle shape
4) orientation:angled, price:$50 size: 7x4.666 cm shape: organic shape
5) none

19) Circle your choice of alternative :
1) orientation:horizontal, price:$100 size: 7x4.666 cm shape: organic shape
2) orientation:horizontal, price:200 size: 6x4 cm shape: square shape
3) orientation:vertical, price:$150 size: 6x4 cm shape: square shape
4) orientation:horizontal, price:$150 size: 4x2.666 cm shape: circle shape
5) none

20) Circle your choice of alternative :
1) orientation:angled, price:$150 size: 5x3.333 cm shape: rectangle shape
2) orientation:vertical, price:200 size: 4x2.666 cm shape: circle shape
3) orientation:horizontal, price:$150 size: 5x3.333 cm shape: rectangle shape
4) orientation:vertical, price:200 size: 4x2.666 cm shape: circle shape
5) none

21) Circle your choice of alternative :
1) orientation:vertical, price:200 size: 6x4 cm shape: square shape
2) orientation:angled, price:$100 size: 5x3.333 cm shape: rectangle shape
3) orientation:horizontal, price:$50 size: 6x4 cm shape: square shape
4) orientation:horizontal, price:$100 size: 7x4.666 cm shape: organic shape
5) none

22) Circle your choice of alternative :
1) orientation:angled, price:$150 size: 5x3.333 cm shape: rectangle shape
2) orientation:horizontal, price:$100 size: 5x3.333 cm shape: rectangle shape
3) orientation:vertical, price:200 size: 4x2.666 cm shape: circle shape
4) orientation:horizontal, price:200 size: 5x3.333 cm shape: rectangle shape
5) none

23) Circle your choice of alternative :
1) orientation:vertical, price:$150 size: 4x2.666 cm shape: circle shape
2) alter.2 orientation:vertical, price:$50 size: 5x3.333 cm shape: rectangle shape
3) orientation:horizontal, price:$150 size: 4x2.666 cm shape: circle shape
4) orientation:angled, price:$50 size: 6x4 cm shape: square shape
5) none

24) Circle your choice of alternative :
1) orientation:angled, price:200 size: 6x4 cm shape: square shape
2) orientation:angled, price:200 size: 7x4.666 cm shape: organic shape
3) orientation:vertical, price:$50 size: 4x2.666 cm shape: circle shape
4) orientation:angled, price:$50 size: 6x4 cm shape: square shape
5) none

25) Circle your choice of alternative :
1) orientation:angled, price:$150 size: 7x4.666 cm shape: organic shape
2) orientation:vertical, price:200 size: 4x2.666 cm shape: circle shape
3) orientation:horizontal, price:$50 size: 6x4 cm shape: square shape
4) orientation:angled, price:$50 size: 6x4 cm shape: square shape
5) none

26) Circle your choice of alternative :
1) orientation:horizontal, price:200 size: 4x2.666 cm shape: circle shape
2) orientation:vertical, price:$100 size: 4x2.666 cm shape: circle shape
3) orientation:vertical, price:$100 size: 5x3.333 cm shape: rectangle shape
4) orientation:horizontal, price:200 size: 4x2.666 cm shape: circle shape
5) none

27) Circle your choice of alternative :
1) orientation:horizontal, price:$50 size: 6x4 cm shape: square shape
2) orientation:vertical, price:$50 size: 7x4.666 cm shape: organic shape
3) orientation:vertical, price:$100 size: 5x3.333 cm shape: rectangle shape
4) orientation:angled, price:$150 size: 6x4 cm shape: square shape
5) none

28) Circle your choice of alternative :
1) orientation:vertical, price:200 size: 5x3.333 cm shape: rectangle shape
2) orientation:horizontal, price:$50 size: 5x3.333 cm shape: rectangle
3) orientation:vertical, price:$150 size: 7x4.666 cm shape: organic
4) orientation:angled, price:200 size: 7x4.666 cm shape: organic
5) none

29) Circle your choice of alternative :
1) orientation:angled, price:$100 size: 7x4.666 cm shape: organic
2) orientation:angled, price:$150 size: 6x4 cm shape: square
3) orientation:vertical, price:200 size: 7x4.666 cm shape: organic
4) orientation:angled, price:$50 size: 7x4.666 cm shape: organic
5) none

30) Circle your choice of alternative :
1) orientation:vertical, price:$50 size: 5x3.333 cm shape: rectangle.
2) orientation:angled, price:$150 size: 4x2.666 cm shape: circle
3) orientation:vertical, price:200 size: 6x4 cm shape: square
4) orientation:horizontal, price:$150 size: 4x2.666 cm shape: circle
5) none

31) Circle your choice of alternative :
1) orientation:vertical, price:$50 size: 7x4.666 cm shape: organic
2) orientation:vertical, price:$100 size: 7x4.666 cm shape: organic
3) orientation:angled, price:200 size: 4x2.666 cm shape: circle
4) orientation:vertical, price:$150 size: 7x4.666 cm shape: organic
5) none

32) Circle your choice of alternative :
1) orientation:vertical, price:200 size: 5x3.333 cm shape: rectangle.
2) orientation:vertical, price:200 size: 6x4 cm shape: square
3) orientation:horizontal, price:$100 size: 4x2.666 cm shape: circle
4) orientation:vertical, price:$150 size: 5x3.333 cm shape: rectangle
5) none

33) Circle your choice of alternative :
1) orientation:vertical, price:$150 size: 4x2.666 cm shape: circle
2) orientation:angled, price:$150 size: 7x4.666 cm shape: organic
3) orientation:angled, price:200 size: 4x2.666 cm shape: circle
4) orientation:angled, price:200 size: 4x2.666 cm shape: circle
5) none

34) Circle your choice of alternative :
1) orientation:angled, price:$100 size: 7x4.666 cm shape: organic
2) orientation:horizontal, price:$100 size: 5x3.333 cm shape: rectangle
3) orientation:angled, price:$100 size: 4x2.666 cm shape: circle
4) orientation:vertical, price:$150 size: 4x2.666 cm shape: circle
5) none

35) Circle your choice of alternative :
1) orientation:horizontal, price:$100 size: 6x4 cm shape: square
2) orientation:vertical, price:200 size: 6x4 cm shape: square
3) orientation:horizontal, price:200 size: 4x2.666 cm shape: circle
4) orientation:horizontal, price:200 size: 5x3.333 cm shape: rectangle
5) none

36) Circle your choice of alternative :
1) orientation:angled, price:200 size: 7x4.666 cm shape: organic
2) orientation:vertical, price:$150 size: 6x4 cm shape: square
3) orientation:vertical, price:$100 size: 5x3.333 cm shape: rectangle
4) orientation:angled, price:200 size: 6x4 cm shape: square
5) none

37) Circle your choice of alternative :
1) orientation:angled, price:200 size: 4x2.666 cm shape: circle
2) orientation:horizontal, price:$50 size: 4x2.666 cm shape: circle.
3) orientation:angled, price:200 size: 6x4 cm shape: square
4) orientation:angled, price:$150 size: 5x3.333 cm shape: rectangle
5) none

38) Circle your choice of alternative :
1) orientation:horizontal, price:$150 size: 6x4 cm shape: square
2) orientation:angled, price:$150 size: 5x3.333 cm shape: rectangle
3) orientation:vertical, price:$50 size: 5x3.333 cm shape: rectangle
4) orientation:vertical, price:$150 size: 6x4 cm shape: square
5) none

39) Circle your choice of alternative :
1) orientation:angled, price:$50 size: 5x3.333 cm shape: rectangle
2) orientation:angled, price:200 size: 5x3.333 cm shape: rectangle
3) orientation:horizontal, price:$100 size: 7x4.666 cm shape: organic
4) orientation:horizontal, price:$100 size: 6x4 cm shape: square
5) none

40) Circle your choice of alternative :
1) orientation:horizontal, price:$150 size: 5x3.333 cm shape: rectangle
2) orientation:vertical, price:$50 size: 5x3.333 cm shape: rectangle
3) orientation:angled, price:200 size: 4x2.666 cm shape: circle
4) orientation:horizontal, price:$50 size: 4x2.666 cm shape: circle
5) none

41) Circle your choice of alternative :
1) orientation:horizontal, price:$50 size: 4x2.666 cm shape: circle
2) orientation:angled, price:$100 size: 5x3.333 cm shape: rectangle
3) orientation:vertical, price:200 size: 6x4 cm shape: square
4) orientation:vertical, price:$150 size: 6x4 cm shape: square
5) none

42) Circle your choice of alternative :
1) orientation:vertical, price:$150 size: 6x4 cm shape: square
2) orientation:angled, price:$50 size: 6x4 cm shape: square
3) orientation:horizontal, price:$50 size: 6x4 cm shape: square
4) orientation:vertical, price:200 size: 4x2.666 cm shape: circle
5) none

43) Circle your choice of alternative :
1) orientation:vertical, price:$50 size: 6x4 cm shape: square
2) orientation:vertical, price:$150 size: 6x4 cm shape: square
3) orientation:angled, price:$150 size: 7x4.666 cm shape: organic
4) orientation:vertical, price:$50 size: 4x2.666 cm shape: circle
5) none

44) Circle your choice of alternative :
1) orientation:angled, price:$150 size: 7x4.666 cm shape: organic
2) orientation:angled, price:$50 size: 7x4.666 cm shape: organic
3) orientation:horizontal, price:$50 size: 4x2.666 cm shape: circle
4) orientation:vertical, price:200 size: 5x3.333 cm shape: rectangle
5) none

45) Circle your choice of alternative :
1) orientation:horizontal, price:$150 size: 4x2.666 cm shape: circle
2) orientation:angled, price:$100 size: 6x4 cm shape: square
3) orientation:horizontal, price:$150 size: 7x4.666 cm shape: organic
4) orientation:horizontal, price:$150 size: 6x4 cm shape: square
5) none

46) Circle your choice of alternative :
1) orientation:angled, price:$50 size: 4x2.666 cm shape: circle
2) orientation:horizontal, price:$50 size: 5x3.333 cm shape: rectangle
3) orientation:horizontal, price:$100 size: 5x3.333 cm shape: rectangle
4) orientation:vertical, price:$50 size: 4x2.666 cm shape: circle
5) none

47) Circle your choice of alternative :
1) orientation:horizontal, price:$100 size: 5x3.333 cm shape: rectangle
2) orientation:vertical, price:$50 size: 4x2.666 cm shape: circle
3) orientation:angled, price:200 size: 7x4.666 cm shape: organic
4) orientation:vertical, price:$100 size: 6x4 cm shape: square
5) none

48) Circle your choice of alternative :
1) orientation:angled, price:$150 size: 5x3.333 cm shape: rectangle
2) orientation:vertical, price:$50 size: 6x4 cm shape: square
3) orientation:vertical, price:$150 size: 6x4 cm shape: square
4) orientation:vertical, price:$100 size: 5x3.333 cm shape: rectangle
5) none

49) Circle your choice of alternative :
1) orientation:vertical, price:200 size: 7x4.666 cm shape: organic
2) orientation:vertical, price:$100 size: 4x2.666 cm shape: circle
3) orientation:horizontal, price:200 size: 7x4.666 cm shape: organic
4) orientation:angled, price:$100 size: 4x2.666 cm shape: circle
5) none

50) Circle your choice of alternative :
1) orientation:horizontal, price:200 size: 5x3.333 cm shape: rectangle
2) orientation:horizontal, price:$150 size: 7x4.666 cm shape: organic
3) orientation:horizontal, price:$100 size: 6x4 cm shape: square
4) orientation:horizontal, price:$50 size: 5x3.333 cm shape: rectangle
5) none

51) Circle your choice of alternative :
1) orientation:vertical, price:$100 size: 5x3.333 cm shape: rectangle
2) orientation:angled, price:$100 size: 7x4.666 cm shape: organic
3) orientation:horizontal, price:$100 size: 6x4 cm shape: square
4) orientation:angled, price:$50 size: 6x4 cm shape: square
5) none

52) Circle your choice of alternative :
1) orientation:horizontal, price:$100 size: 7x4.666 cm shape: organic
2) orientation:angled, price:$50 size: 7x4.666 cm shape: organic
3) orientation:angled, price:$150 size: 6x4 cm shape: square
4) orientation:horizontal, price:$100 size: 4x2.666 cm shape: circle
5) none

53) Circle your choice of alternative :
1) orientation:angled, price:$50 size: 6x4 cm shape: square.
2) orientation:vertical, price:$100 size: 7x4.666 cm shape: organic
3) orientation:horizontal, price:$150 size: 7x4.666 cm shape: organic
4) orientation:horizontal, price:$50 size: 5x3.333 cm shape: rectangle
5) none

54) Circle your choice of alternative :
1) orientation:angled, price:$50 size: 6x4 cm shape: square
2) orientation:angled, price:$100 size: 4x2.666 cm shape: circle
3) orientation:angled, price:$150 size: 4x2.666 cm shape: circle
4) orientation:horizontal, price:$50 size: 7x4.666 cm shape: organic
5) none

55) Circle your choice of alternative :
1) orientation:vertical, price:$150 size: 7x4.666 cm shape: organic
2) orientation:horizontal, price:$100 size: 7x4.666 cm shape: organic
3) orientation:angled, price:$150 size: 5x3.333 cm shape: rectangle
4) orientation:horizontal, price:$100 size: 6x4 cm shape: square
5) none

56) Circle your choice of alternative :
1) orientation:horizontal, price:$50 size: 4x2.666 cm shape: circle
2) orientation:horizontal, price:$100 size: 6x4 cm shape: square
3) orientation:horizontal, price:$50 size: 6x4 cm shape: square
4) orientation:vertical, price:$50 size: 7x4.666 cm shape: organic
5) none

57) Circle your choice of alternative :
1) orientation:angled, price:200 size: 6x4 cm shape: square
2) orientation:vertical, price:$100 size: 5x3.333 cm shape: rectangle
3) orientation:angled, price:$100 size: 6x4 cm shape: square
4) orientation:angled, price:$150 size: 4x2.666 cm shape: circle
5) none

58) Circle your choice of alternative :
1) orientation:angled, price:200 size: 7x4.666 cm shape: organic
2) orientation:horizontal, price:$50 size: 6x4 cm shape: square
3) orientation:angled, price:200 size: 6x4 cm shape: square
4) orientation:horizontal, price:200 size: 6x4 cm shape: square
5) none

59) Circle your choice of alternative :
1) orientation:angled, price:200 size: 4x2.666 cm shape: circle
2) orientation:horizontal, price:200 size: 6x4 cm shape: square
3) orientation:horizontal, price:200 size: 7x4.666 cm shape: organic
4) orientation:vertical, price:$100 size: 6x4 cm shape: square
5) none

60) Circle your choice of alternative :
1) orientation:horizontal, price:$150 size: 7x4.666 cm shape: organic
2) orientation:vertical, price:200 size: 5x3.333 cm shape: rectangle
3) orientation:angled, price:$100 size: 5x3.333 cm shape: rectangle
4) orientation:vertical, price:200 size: 7x4.666 cm shape: organic
5) none

61) Circle your choice of alternative :
1) orientation:vertical, price:$100 size: 7x4.666 cm shape: organic
2) orientation:vertical, price:$150 size: 5x3.333 cm shape: rectangle
3) orientation:horizontal, price:200 size: 5x3.333 cm shape: rectangle
4) orientation:horizontal, price:$50 size: 7x4.666 cm shape: organic
5) none

62) Circle your choice of alternative :
1) orientation:vertical, price:200 size: 7x4.666 cm shape: organic
2) orientation:angled, price:200 size: 4x2.666 cm shape: circle
3) orientation:horizontal, price:$150 size: 5x3.333 cm shape: rectangle
4) orientation:angled, price:$150 size: 5x3.333 cm shape: rectangle
5) none

63) Circle your choice of alternative :
1) orientation:horizontal, price:200 size: 5x3.333 cm shape: rectangle
2) orientation:vertical, price:$100 size: 7x4.666 cm shape: organic
3) orientation:angled, price:$50 size: 7x4.666 cm shape: organic
4) orientation:angled, price:200 size: 6x4 cm shape: square
5) none

64) Circle your choice of alternative :
1) orientation:horizontal, price:200 size: 7x4.666 cm shape: organic
2) orientation:angled, price:200 size: 6x4 cm shape: square
3) orientation:vertical, price:$50 size: 4x2.666 cm shape: circle
4) orientation:horizontal, price:$50 size: 4x2.666 cm shape: circle
5) none

65) Circle your choice of alternative :
1) orientation:vertical, price:$100 size: 6x4 cm shape: square
2) orientation:horizontal, price:$150 size: 4x2.666 cm shape: circle
3) orientation:angled, price:$50 size: 6x4 cm shape: square
4) orientation:vertical, price:200 size: 6x4 cm shape: square
5) none

66) Circle your choice of alternative :
1) orientation:angled, price:$100 size: 4x2.666 cm shape: circle
2) orientation:vertical, price:$150 size: 4x2.666 cm shape: circle
3) orientation:horizontal, price:$100 size: 4x2.666 cm shape: circle
4) orientation:horizontal, price:$100 size: 7x4.666 cm shape: organic
5) none

67) Circle your choice of alternative :
1) orientation:horizontal, price:$100 size: 5x3.333 cm shape: rectangle.
2) orientation:angled, price:$50 size: 6x4 cm shape: square
3) orientation:horizontal, price:$150 size: 4x2.666 cm shape: circle
4) orientation:angled, price:$150 size: 7x4.666 cm shape: organic
5) none

68) Circle your choice of alternative :
1) orientation:vertical, price:$50 size: 4x2.666 cm shape: circle
2) orientation:vertical, price:$50 size: 6x4 cm shape: square
3) orientation:angled, price:$50 size: 5x3.333 cm shape: rectangle.
4) orientation:horizontal, price:$100 size: 5x3.333 cm shape: rectangle
5) none

69) Circle your choice of alternative :
1) orientation:horizontal, price:$150 size: 6x4 cm shape: square
2) orientation:horizontal, price:$150 size: 5x3.333 cm shape: rectangle
3) orientation:horizontal, price:$100 size: 6x4 cm shape: square
4) orientation:angled, price:$100 size: 5x3.333 cm shape: rectangle.
5) none

70) Circle your choice of alternative :
1) orientation:vertical, price:$100 size: 6x4 cm shape: square
2) orientation:horizontal, price:$100 size: 6x4 cm shape: square
3) orientation:angled, price:$100 size: 7x4.666 cm shape: organic
4) orientation:horizontal, price:200 size: 6x4 cm shape: square
5) none

71) Circle your choice of alternative :
1) orientation:vertical, price:$150 size: 6x4 cm shape: square
2) orientation:horizontal, price:$50 size: 4x2.666 cm shape: circle
3) orientation:vertical, price:$100 size: 4x2.666 cm shape: circle
4) orientation:horizontal, price:$150 size: 7x4.666 cm shape: organic
5) none

72) Circle your choice of alternative :
1) orientation:horizontal, price:200 size: 6x4 cm shape: square
2) orientation:horizontal, price:$150 size: 4x2.666 cm shape: circle
3) orientation:angled, price:$150 size: 4x2.666 cm shape: circle
4) orientation:vertical, price:$50 size: 6x4 cm shape: square
5) none

73) Circle your choice of alternative :
1) orientation:angled, price:$100 size: 6x4 cm shape: square
2) orientation:angled, price:$50 size: 5x3.333 cm shape: rectangle
3) orientation:angled, price:$150 size: 5x3.333 cm shape: rectangle
4) orientation:angled, price:$50 size: 5x3.333 cm shape: rectangle
5) none

74) Circle your choice of alternative :
1) orientation:angled, price:200 size: 5x3.333 cm shape: rectangle
2) orientation:vertical, price:$150 size: 5x3.333 cm shape: rectangle
3) orientation:angled, price:$50 size: 7x4.666 cm shape: organic
4) orientation:vertical, price:$150 size: 7x4.666 cm shape: organic
5) none

75) Circle your choice of alternative :
1) orientation:horizontal, price:200 size: 6x4 cm shape: square.
2) orientation:angled, price:$50 size: 7x4.666 cm shape: organic
3) orientation:horizontal, price:200 size: 5x3.333 cm shape: rectangle.
4) orientation:vertical, price:$100 size: 7x4.666 cm shape: organic
5) none

76) Circle your choice of alternative :
1) orientation:horizontal, price:$150 size: 7x4.666 cm shape: organic
2) orientation:angled, price:$100 size: 4x2.666 cm shape: circle
3) orientation:vertical, price:$100 size: 7x4.666 cm shape: organic
4) orientation:vertical, price:$100 size: 5x3.333 cm shape: rectangle
5) none

77) Circle your choice of alternative :
1) orientation:angled, price:$100 size: 5x3.333 cm shape: rectangle
2) orientation:angled, price:$100 size: 4x2.666 cm shape: circle
3) orientation:vertical, price:$50 size: 5x3.333 cm shape: rectangle
4) orientation:vertical, price:200 size: 5x3.333 cm shape: rectangle
5) none

78) Circle your choice of alternative :
1) orientation:angled, price:$150 size: 4x2.666 cm shape: circle
2) orientation:horizontal, price:$100 size: 6x4 cm shape: square
3) orientation:angled, price:$50 size: 5x3.333 cm shape: rectangle
4) orientation:angled, price:$100 size: 5x3.333 cm shape: rectangle
5) none

79) Circle your choice of alternative :
1) orientation:angled, price:$100 size: 6x4 cm shape: square.
2) orientation:vertical, price:200 size: 7x4.666 cm shape: organic
3) orientation:vertical, price:200 size: 6x4 cm shape: square
4) orientation:angled, price:$100 size: 7x4.666 cm shape: organic
5) none

80) Circle your choice of alternative :
1) orientation:angled, price:$50 size: 7x4.666 cm shape: organic
2) orientation:horizontal, price:$50 size: 4x2.666 cm shape: circle
3) orientation:horizontal, price:$50 size: 4x2.666 cm shape: circle
4) orientation:horizontal, price:$150 size: 6x4 cm shape: square
5) none

81) Circle your choice of alternative :
1) orientation:horizontal, price:$50 size: 5x3.333 cm shape: rectangle
2) orientation:horizontal, price:200 size: 7x4.666 cm shape: organic
3) orientation:angled, price:$50 size: 5x3.333 cm shape: rectangle
4) orientation:horizontal, price:$100 size: 7x4.666 cm shape: organic
5) non

1.4 Levels & Beta & Overall Log Likelihood Results from Excel

LevNum	Level	BETAS
1	hori	-0.154
2	verti	-0.163
3	angle	-0.285
1	50.000	1.711
2	100.000	0.570
3	150.000	-0.144
4	200.000	-0.555
1	4	-0.013
2	5	-0.554
3	6	-0.749
4	7	-0.724
1	c	-0.306
2	r	-0.026
3	s	-0.201
4	o	-0.266

Log Likelihood
-3306.55

Table 1.4.1 Levels, Betas, and Log Likelihood

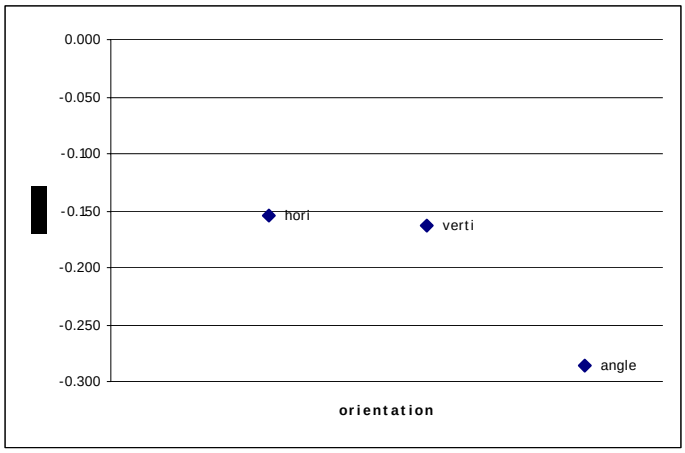


Figure 1.4.1 Betas for Orientation

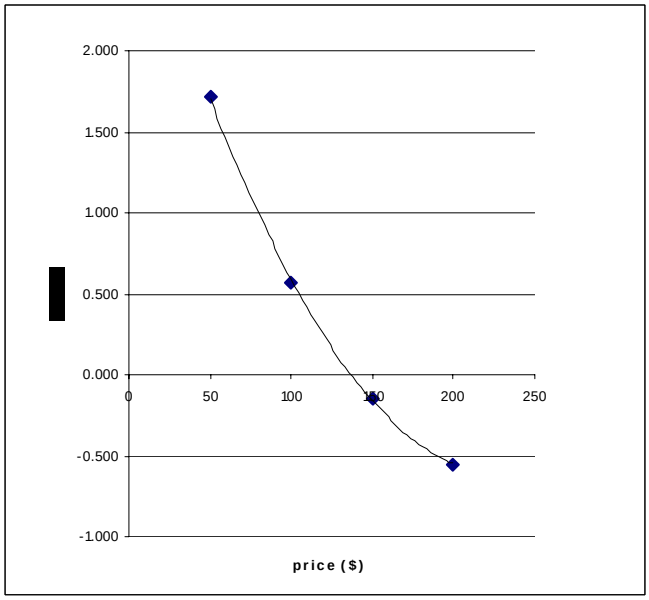


Figure 1.4.2 Betas for Price

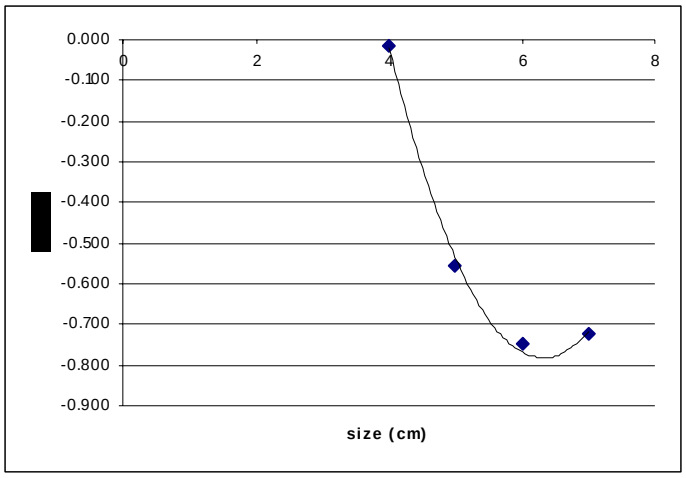


Figure 1.4.3 Betas for Size

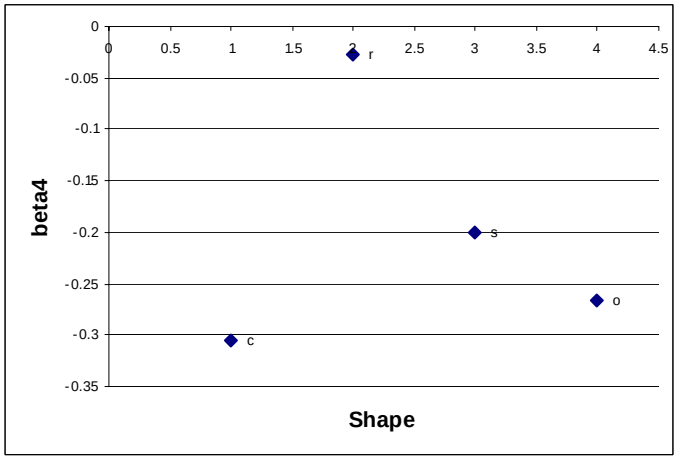


Figure 1.4.4 Betas for shape

Appendix 2.Heart Rate Monitor Survey II – User Perceptions

HEART RATE MONITOR DESIGN

CUSTOMER SURVEY

The *Heart Rate Monitor* is like a coach that guides you through each workout. For endurance workouts, it paces you so you don't overdo it. For tempo runs, it keeps you on track. And for interval workouts, it makes sure you go hard enough and you recover when it's time. It can show you when you are dehydrating, or running out of nutrition, or not recovered from a previous day's workout. It allows you to analyze workouts and races so you can identify your weaknesses and turn them into strengths.

The designed product will be attached on the upper arm and be operated with a button. The target market will be mostly the professional athletes and amateurs who are doing exercises frequently.

Please answer the following questions. They will help us to get the general information about people who are doing the survey.

1- FEMALE / MALE

2- Your Age

3- Do you have a heart rate monitor?

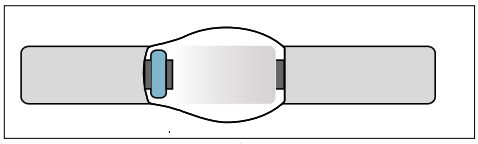
4- How often do you exercise?
- a- do not have time
- b- once a week
- c- everyday

5- What kinds of exercise/ sports do you do?

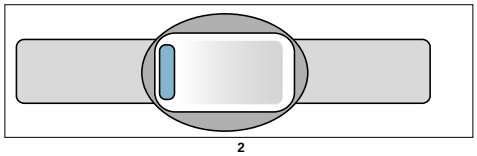
6- Which of the products do you have?
- a- MP3 Player
- b- CD Player
- c- MD Player
- d- none

Please complete the survey. Thank you for participating.

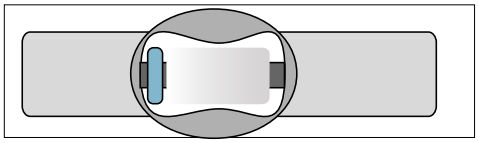
1- Indicate your choice of heart rate monitor:



1



2

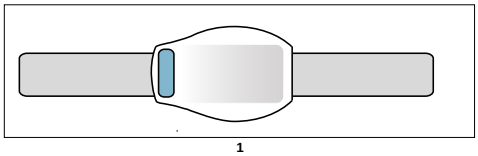


3

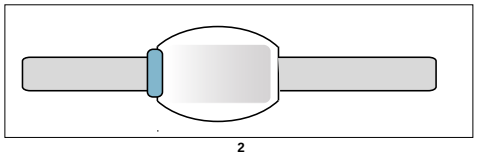
NONE

4

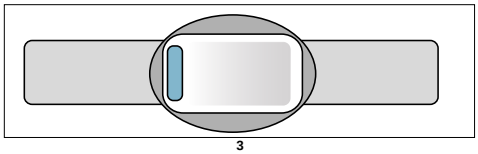
2- Indicate your choice of heart rate monitor:



1



2

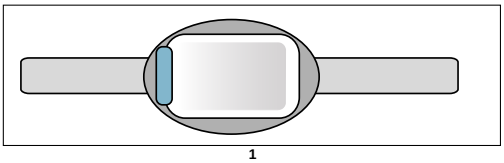


3

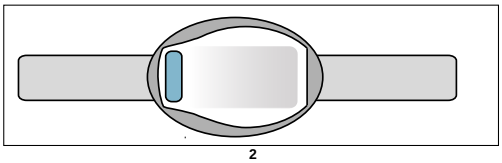
NONE

4

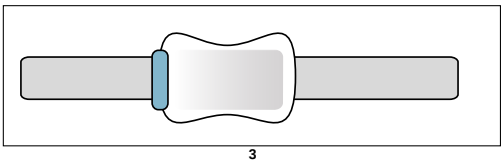
3- Indicate your choice of heart rate monitor:



1



2

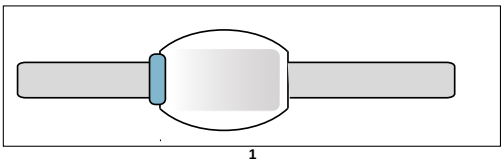


3

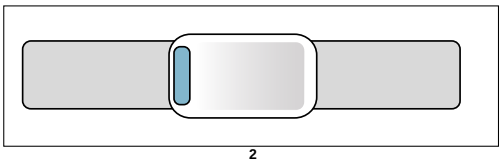
NONE

4

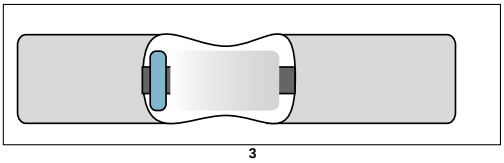
4- Indicate your choice of heart rate monitor:



1



2

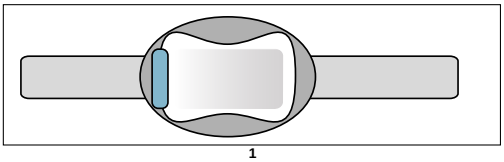


3

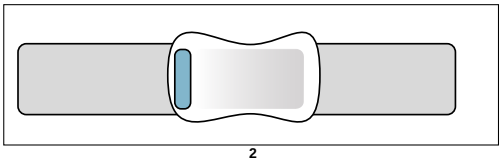
NONE

4

5- Indicate your choice of heart rate monitor:



1



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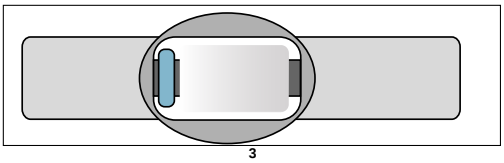

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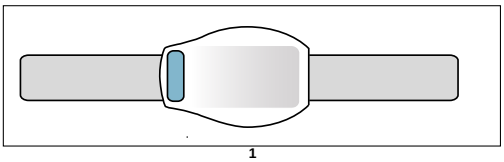

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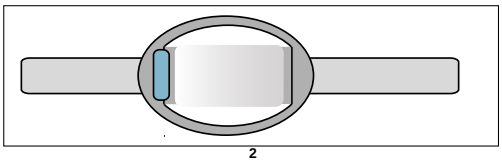

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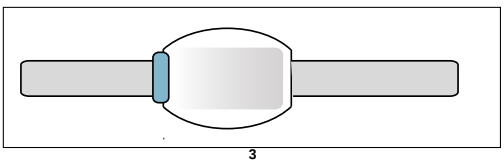

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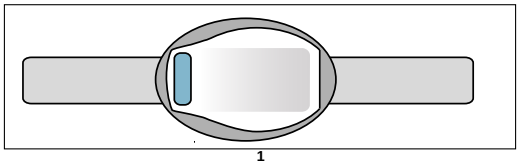

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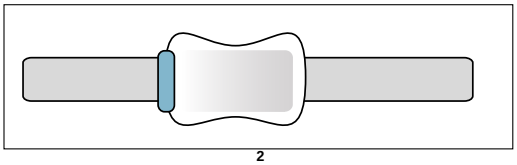

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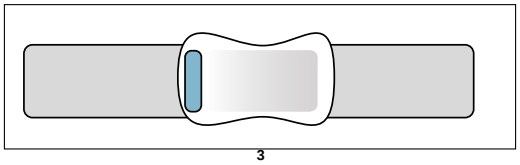

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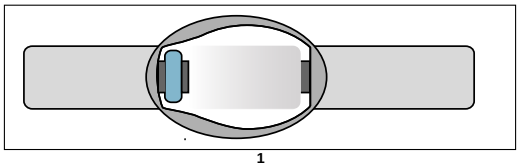

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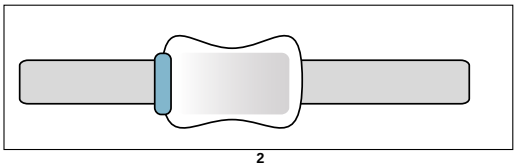

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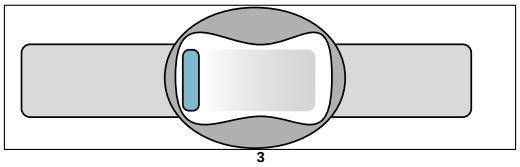

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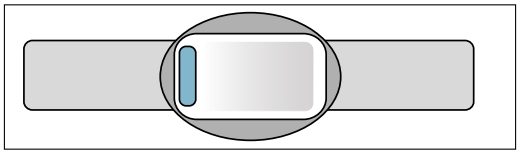

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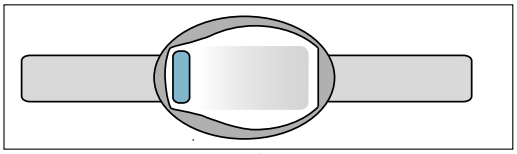

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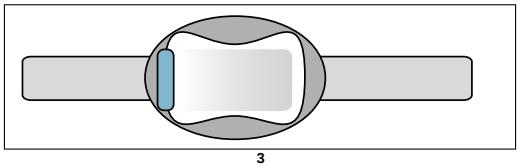

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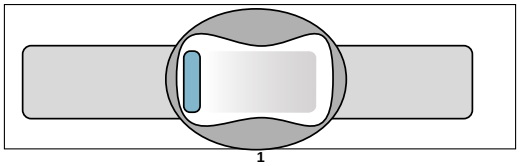

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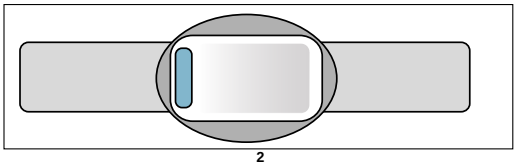

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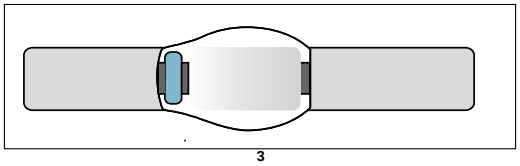

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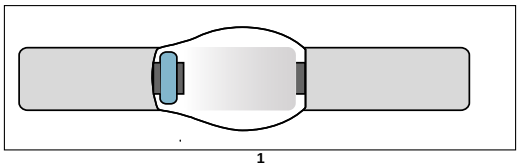

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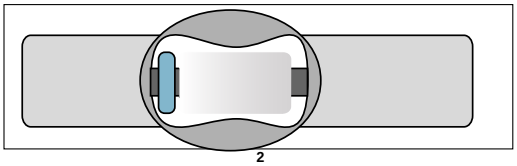

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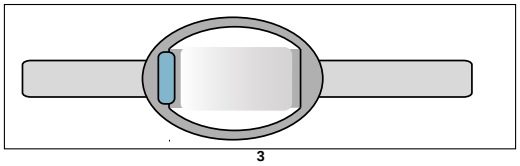

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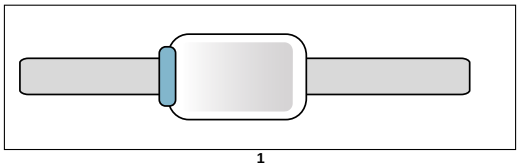

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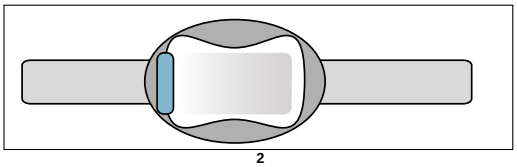

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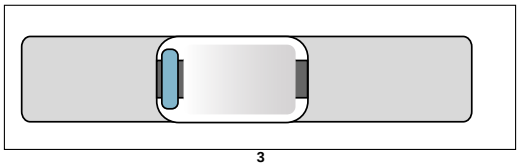

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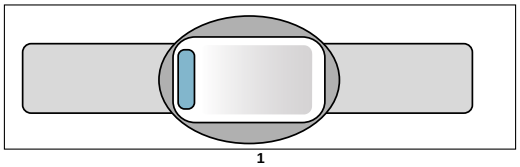

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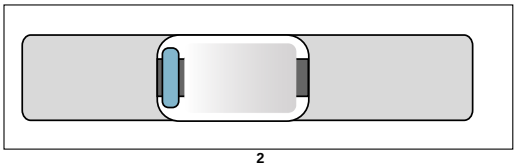

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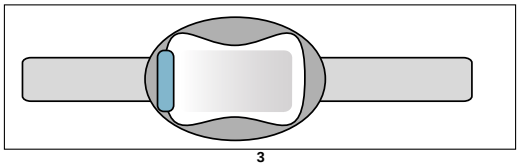

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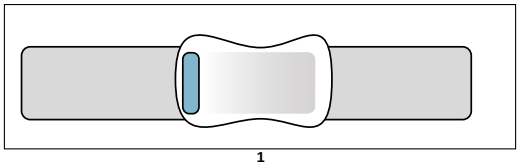

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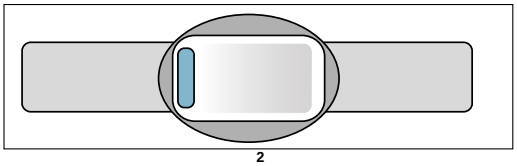

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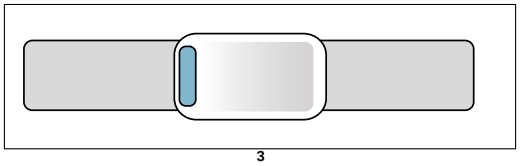

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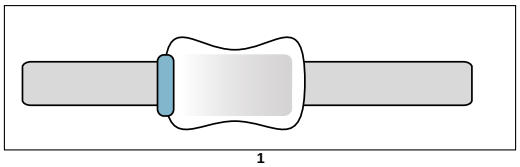

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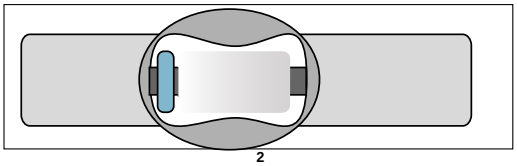

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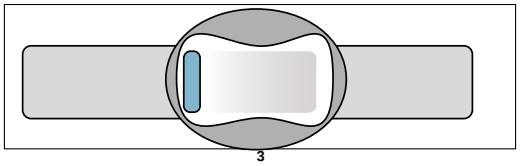

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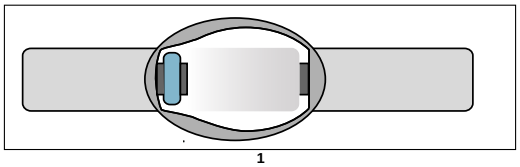

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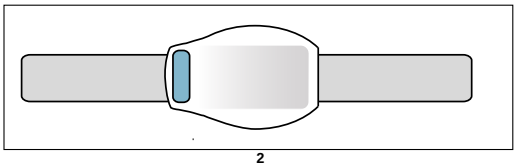

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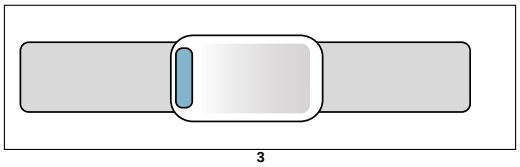

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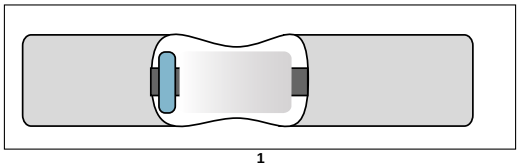

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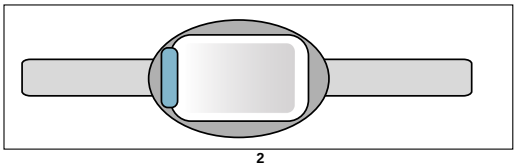

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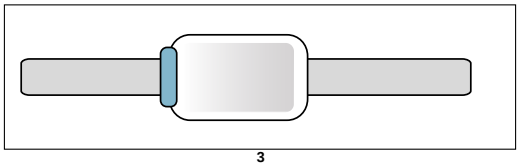

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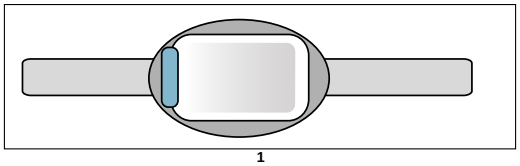

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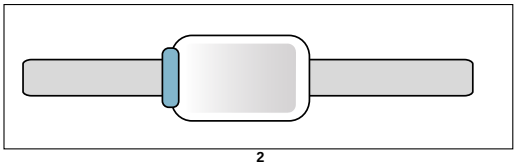

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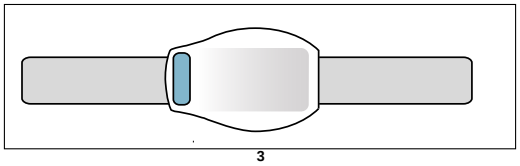

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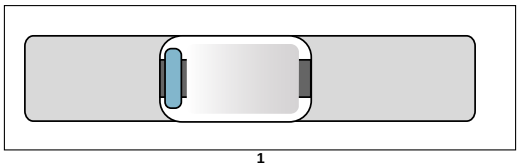

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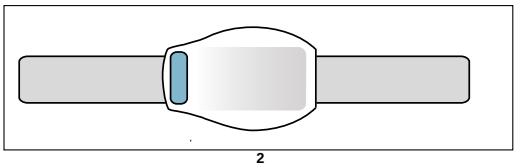

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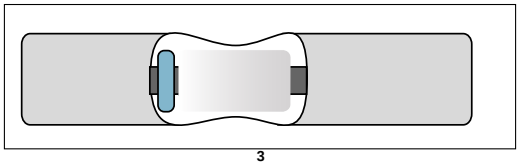

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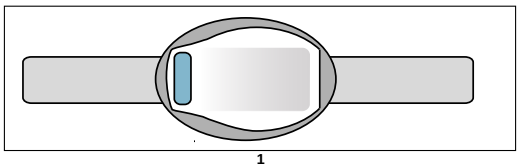

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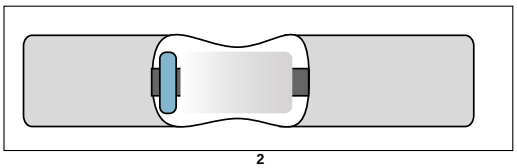

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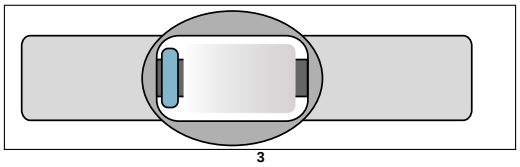

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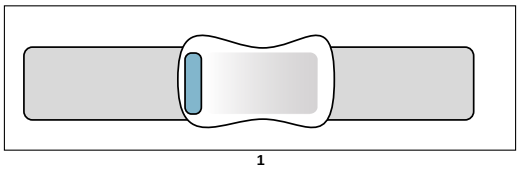

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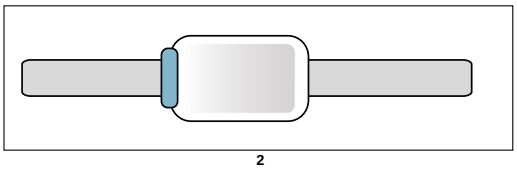

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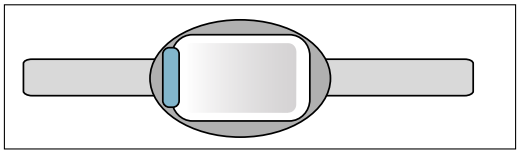

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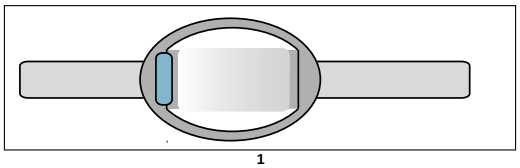

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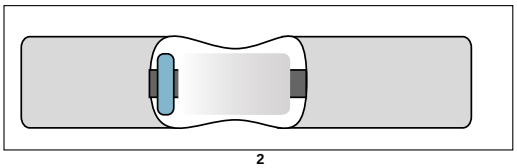

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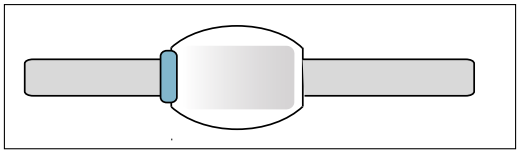

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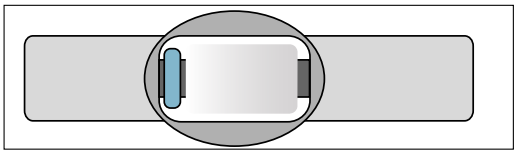

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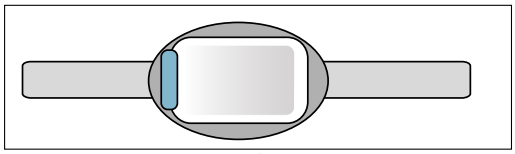

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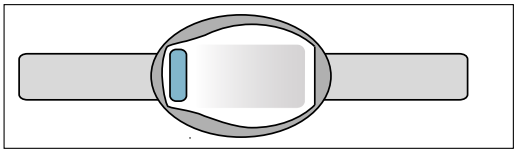

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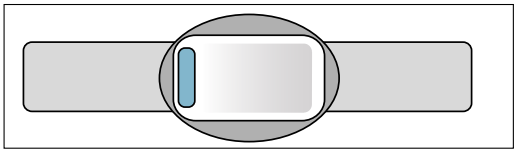

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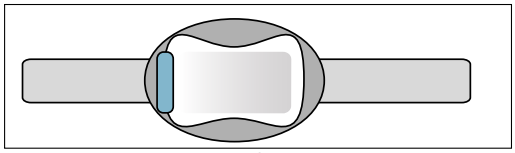

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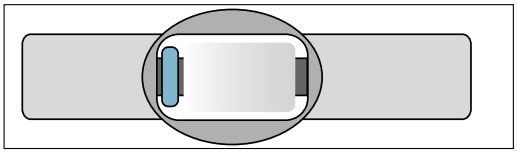

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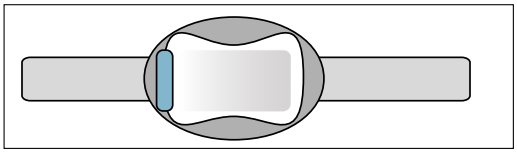

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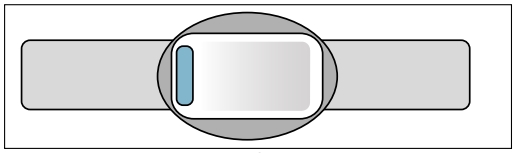

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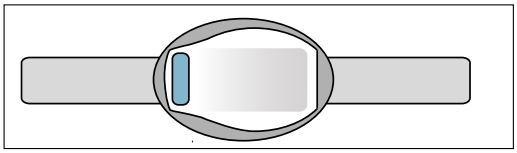

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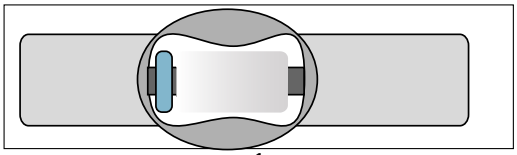

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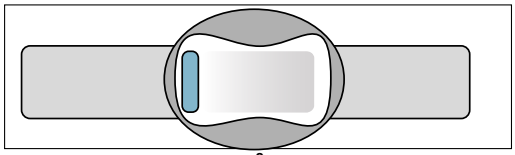

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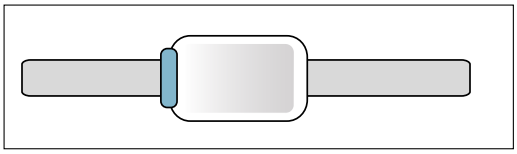

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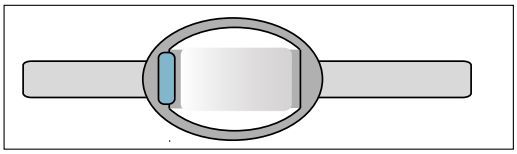

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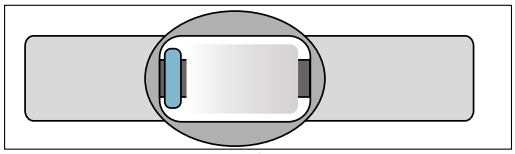

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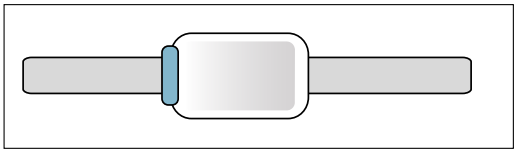

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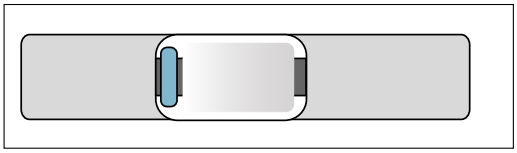

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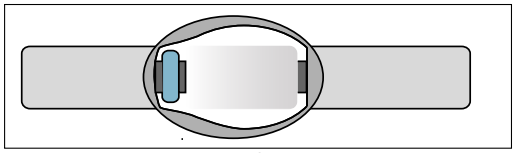

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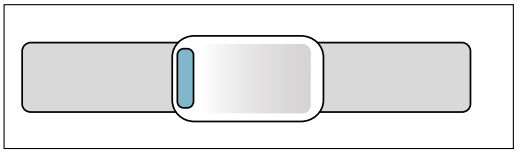

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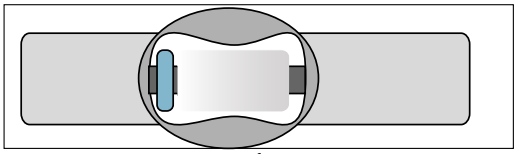

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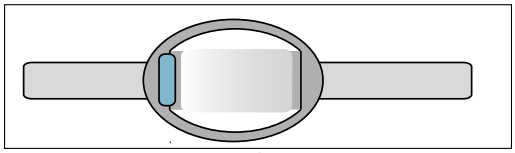

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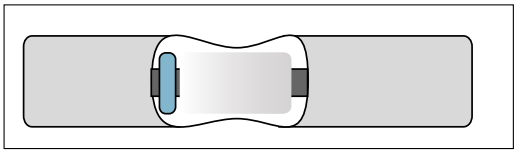

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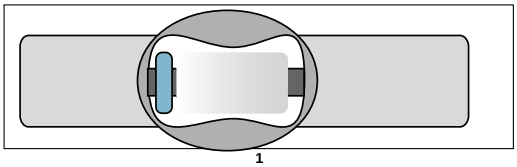

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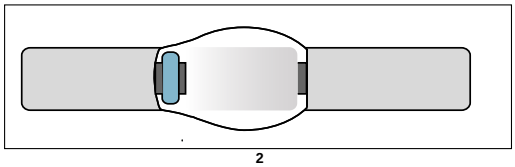

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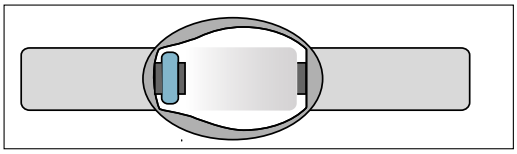

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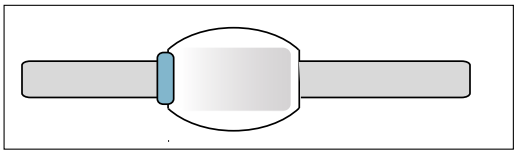

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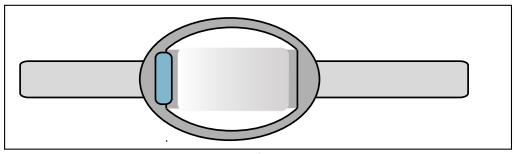

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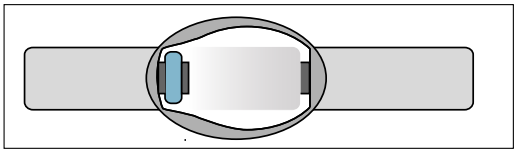

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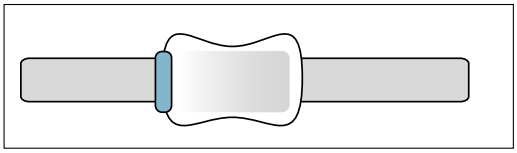

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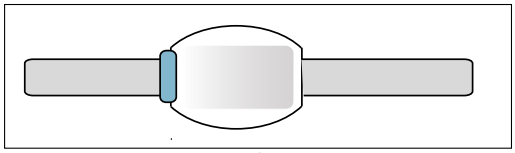

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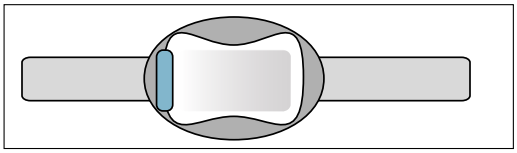

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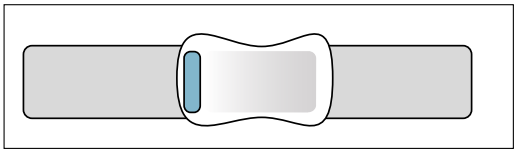

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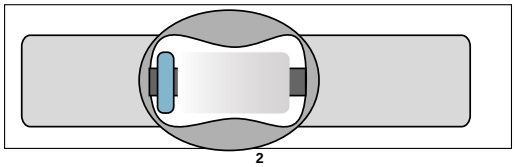

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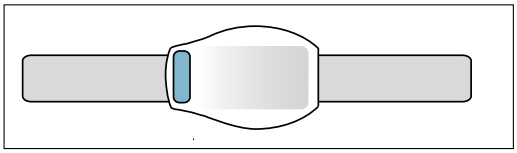

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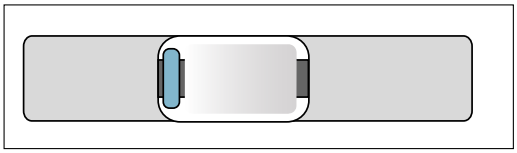

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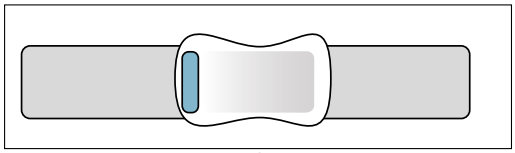

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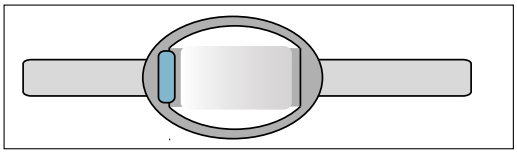

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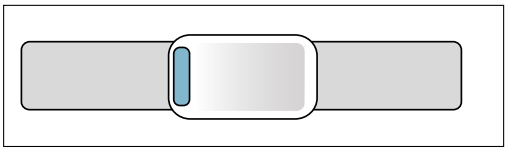

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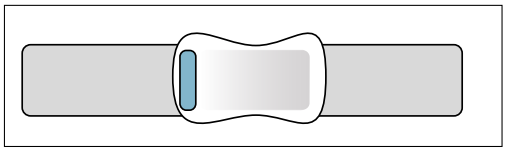

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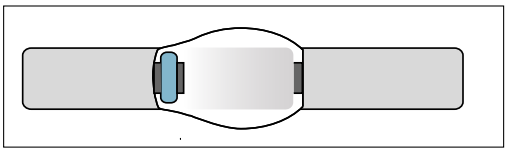

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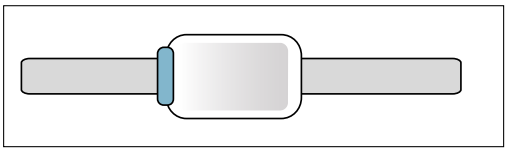

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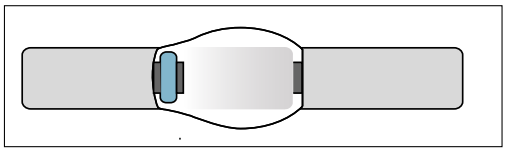

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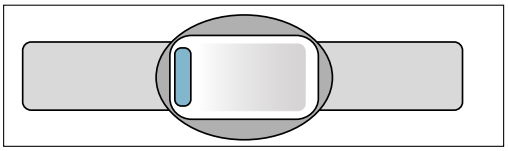

3

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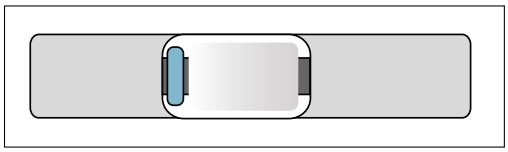
4

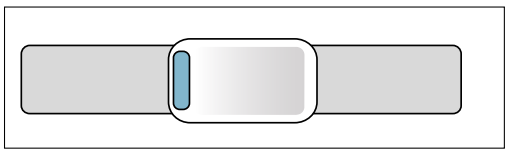
Please give values to the forms from **1 to 5** according to the strength of the attributes following.

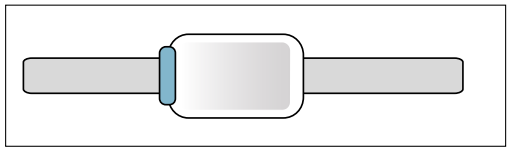
Familiarity: Within normal everyday experience. Common and ordinary.

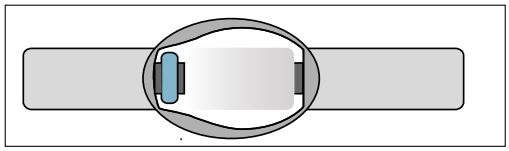
Cohesiveness : Well integrated

Complexity: Complicated in structure









1 --- not strong *in perception* **5 ---- very strong** *in perception*

Familiarity

Cohesiveness

Complexity

Familiarity

Cohesiveness

Complexity

Familiarity

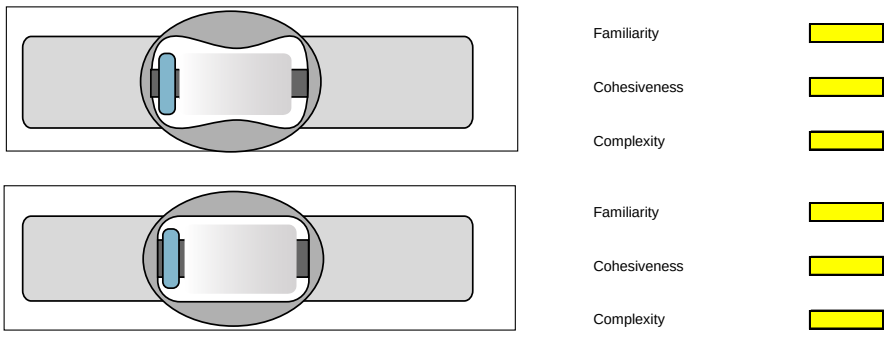
Cohesiveness

Complexity

Familiarity

Cohesiveness

Complexity



Appendix 3.Business Plan

3.1 Business Opportunity

1. Focus on the new targets to achieve sales beyond the $52 million mark by 2005.
2. Maintain a market share of 30% after first year.
3. Increase the net profit to more than 3% each year.

b- Product Description

The **"Sprinter"** will feature advanced heart monitoring functions and are targeted primarily at fitness enthusiasts, professional runners, cyclists. Sprinter is also used by post-operative heart patients. It enables heart patients undergoing rehabilitation to monitor their heart beat and detect irregularities that may threaten their lives.

How does **Sprinter** work? It measures a person's heartbeat with its strap-on transmitter attached on the upper arm. Electrical signals from the heart are picked up from the strap-on upper arm band by a receiver which is as accurate as an electro-cardiogram (ECG). By comparing your heart rate with a chart which gives the recommended training rate, you can target your heart to perform safely and efficiently. By maintaining the maximum heart beat for the recommended length of time in an exercise program, you can achieve the right fitness level to reduce weight or maintain your shape.

This smart-looking heart rate monitor is a mid-range, high-performance product, designed for the budget-conscious fitness enthusiast. It will also measure the calories burned and keep the data in its memory. A dual display LCD screen shows the heart rate and exercise time. The Sprinter's programmable target heart rate zone can be used to chart different levels for different cardiovascular exercises. If you exceed the programmed target zones, the heart rate monitor will trigger off an alarm to alert you.

The receiver also doubles up as a watch, complete with alarm and stopwatch. Its large display makes it easy for the user on the go. Featuring electro-luminescent glow, it enables the wearer to

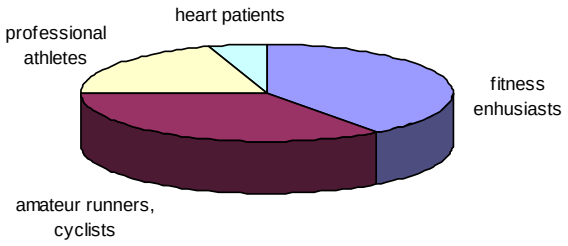
exercise at night without having to stop at streetlamps to check heart rate readings. Attaching the **Sprinter** is easy and the strap is comfortable enough for long wear. It is designed to be worn against the skin (upper arm) which allows you to track your health issues spontaneously.

c- Market Analysis Summary

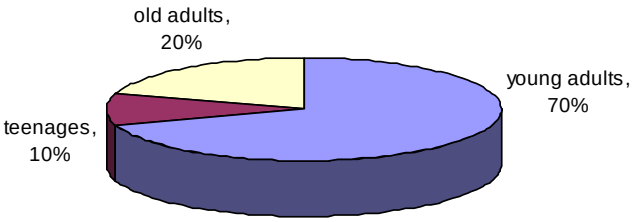
The health measuring goods market as whole and especially the market for heart rate monitors are multi-billion and multi-million dollar markets respectively. The "Sprinter" represents a new category in the vital signs measuring products market. The targeted consumers are the young adults who are aware of their health issues and concerned about their heart rate tracking.

Product will be sold to hospitals, bike stores, clubs, schools, sporting goods stores and to the government. We expect the sales to grow by adding new features and creating new target markets so that people will always need and buy heart rate monitors not just for their health but also for the new trends.

market segmentation according to the target market



market segmentation according to age



Competitors

The market for heart rate monitors appears to be growing rapidly. In addition to serious athletes, fire and police departments as well as the military are using them to refine their own training techniques.

Currently, there are two leading competitive entries in this segment, Polar Electro Inc and Cardio sport. Both of these firms have strong brand equity, but there is room in this market for a new product is not high on potential consumers' reasons for purchasing.

The leading company POLAR has sales of $82 million while having $11 million profit for year 2003. The second leading company in the market Cardiosport has $8.5 million sales with a 41 percent increase over 2002.

3.2 Financial data

a- Capital Equipment and supply list

The equipment that is needed to produce the Sprinter is shown in the cost estimation chart below. The capital equipment that is needed includes (1) injection molding tools for the plastic housing, (2) injection molding tools for the button, (3) injection molding tool for the strap, (4) forming tool for the sensor, and a (5) tool for the display. The other parts will be fully outsourced, including the (1) processor, (2) circuit board, (3) battery, and (4) sensor.

Part	Functions	Material	Density	Part Volume	Material Cost	Process	Cycle time	Machine time charge	Machine time	Tooling Cost	Setup fee	# Parts	Total	employees
	f		ρ	v	ς		τ	φ	o	χ	ζ	q		ε
			g/cm 3	cm3	$/kg		parts/hour	$/hour	$/part	$	$/part		$	
Plastic Part														
	1	Polypropylene	0.9	20.1796186	1	Injection Molding	80	60	0.75	60,000	0.05	110,000	89997.8	1200000
	4	Cellulose Acetate	1.2	20.1796186	3.6	Injection Molding	80	60	0.75	60000	0.05	110,000	97589.4	
	3	Polyethylene	1	20.1796186	3	Injection Molding	80	60	0.75	60000	0.05	110,000	94659.3	
	6	silicone	2	20.1796186	10	Injection Molding	80	60	0.75	60000	0.05	110,000	132395	
	2	ABS	1.2	20.1796186	2	Injection Molding	80	60	0.75	60000	0.05	110,000	93327.4	
	5	Santoprene	0.92	20.1796186	4.91189427	Injection Molding	80	60	0.75	60000	0.05	110,000	98031	
Processor			0.26	0.4508					7.74898			110,000	852388	
	1.00													
Circuit Board		teflon	2.15	15	16	extruded			3			110,000	386760	
Button		Santoprene	0.92	1.4375	4.91189427	Injectiona Molding	80	60	0.05	60000	0.05	110,000	11714.6	
Strap		Santoprene	0.92	4	4.91189427	Injectiona Molding	80	60	1	60000	0.05	110,000	117488	
Display		Silicon Carbide	3.2	12.52	15.85				9.449	60000		110,0002.	1039342	
Battery			1.95	5.76					1.56998			110,000	172698	
Sensor		stainless steel 304	8	1.00	8	forming			0.05	3000		110,000	12540	

Table 3.1 Cost estimation Chart

b- Breakeven Analysis

Using the Figure 3.1 above, the overall investment cost includes the salary of 20 employees ($1,200,000), four injection molding tools ($60,000), and one forming tool ($3,000). This total cost is approximated at 60000*4 + 3000 + 1,200,000 = $1,443,000.

According the cost estimation Table, the variable cost per product is about $24.69.
If we sell the product at a price of $210, and sell 100,000 units in a year (the value obtained by optimizing the microeconomics model), then the monthly revenue, excluding fixed investment costs, is

100,000/12 * 210 - 100,000/12 * 24.69 = 1,541,667

If we include the fixed investment costs, then after the first month we will have made 1,541,667 - 1,443,000 = $ 98666.67.

The monthly units to break even are calculated by x*210 – x*24 – 1443000/x = 0, where x is the quantity of units sold per month to break even. In this case x= 88 after the first month in order to cover all fixed investment costs. In other words, the company must sell 88 products at $210 dollars in one month in order to break even on the first month.

c- Pro-forma Income and Cost Projections (Profit & Loss Statements)

The most meaningful way to analyze the results we gathered on this project is to compare the optimization of profit from the two points of view- Marketing and Microeconomics for three years. The revenues and quantities were used that were found in the optimizations earlier. Then for the first year, the investment costs were included in the calculations. For the second and third year, only the variable costs were included. Looking at the Figure 6.2 below, it is clear that the overall profit increases with each year because the investment costs are consumed in the first year. Overall, both models predict a similar total profit, but at very different quantities sold.

2003	quantity sold in a year	Revenue	Cost (fixed & variable)	Profit
Marketing Model Optimization	270,766	57,943,902	7,339,850	50,723,546
Microeconomics Model Optimization	100,000	39,092,294	3,911,612	35,180,682

These results indicate that after three years the product will either be making 155,000,000 if the marketing model is used and the quantity sold is 270,000 units or 108,000,000 if the microeconomics model is used and 100,000 units are sold each year.

2004	quantity sold in a year	Revenue	Cost (fixed & variable)	Profit
Marketing Model Optimization	270,766	57,943,902	5,956,850	51,987,052
Microeconomics Model Optimization	100,000	39,092,294	2,468,612	36,623,682

2005	quantity sold in a year	Revenue	Cost (fixed & variable)	Profit	Total Three Year Profit
Marketing Model Optimization	270,766	57,943,924	5,956,852	51,987,072	154697670
Microeconomics Model Optimization	100,000	39,092,294	2,468,612	36,623,682	108496658

3.3 Supporting Documents

a- Existing patents

According to the search from the United States patents, there are around 80 different patents obtained by Polar Electro and Cardio sport, the two leading companies in the field of heart rate monitors. The first of the selected patents is related with caloric exercise monitor, while the second one is related with the measuring devices on the human body.

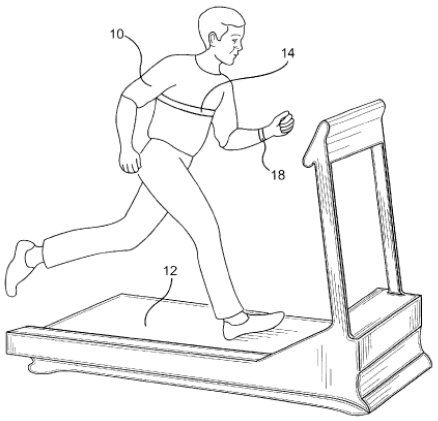
1- Caloric exercise monitor

United States Patent **6,605,044**
Bimbaum **August 12, 2003**

Abstract

A caloric exercise monitor and method for monitoring a person's caloric expenditure during exercising. The caloric exercise monitor generally includes a means for measuring the person's heart rate during exercise, an input device for enabling the person to enter an exercise goal, a calculating unit including a mathematical algorithm for calculating a caloric expenditure rate of the person during exercise based on the measured heart rate and a display for displaying an exercise parameter necessary to reach the entered exercise goal based on the calculated caloric expenditure rate. The displayed exercise parameter can be either or both the calories remaining to be expended to reach the entered goal or the remaining exercise time required to reach the entered goal.

FIG. 1



2- Measuring device and method of controlling same

United States Patent **6,418,394**
Puolakanaho , et al. **July 9, 2002**

Abstract

The invention relates to a measuring device carried by a user during exercise for measuring non-invasively at least one signal from the body, e.g. a wireless heart rate monitor, and to a method of controlling same. The measuring device comprises a user interface. The user interface comprises selection means, e.g. push buttons, and display means, e.g. a liquid crystal display. The user interface displays different operating modes, e.g., a watch mode, a set mode and an operating mode for measuring a signal from the body. The operating modes have different sub-operating modes for displaying parameter associated with exercising. In accordance with the invention, the user is shown specified operating modes and sub-operating modes. There is also a special help operating mode, which, when being switched on, allows each selection means available in said operating mode or sub-operating mode to be indicated to the user by automatic stepping, and the function to be performed by selecting said selection means to be specified.