Biofeedback in Educational Entertainment

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Biofeedback in Educational Entertainment

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Submitted to the Masters Programme in Interaction Design,

Interaction Design Institute Ivrea

June 2003

Abstract

Biofeedback in educational entertainment is a project that introduces new approaches to biofeedback training, wearable computing, and computer gaming. It is an exploration in making physiological information entertaining, engaging, and informative. This project investigates the medium of a wearable, biosensor-effected, computer game as it examines a hypothesis that fun and playful body monitoring devices are more effective at making people understand their disorders than established biofeedback systems.

The project results in a design proposal for a wearable device geared towards children suffering from asthma, a basic platform for body monitoring, a biosensor-enabled computer game, and a series of studies of the proposed device. The prototype analysis has demonstrated that presenting physiological information through a wearable computer game could be an engaging way to achieve the goal of self-efficiency.

Acknowledgments

Firstly I would like to thank both my advisors, Casey Reas and Massimo Banzi, for guiding me through the final year of my stay at the Interaction Design Institute Ivrea.

Thanks to Andrew Davidson for tolerating my academic detours and keeping me on track in my thesis year.

Thanks to other members of the faculty Jan-Christoph Zoels, Stefano Mirti, Walter Aprile, Gillian Crampton Smith, and the visiting professors Camille Norment, Reed Kram, and Bill Verplank for their valuable insights.

Thanks to Linda Norlen for all the editing and support.

Many thanks to Ziga Hajdukovic who so kindly and passionately helped with the implementation of the Bloop! videogame.

I cannot possibly underestimate the benefits from the friendships I had with my professors, mentors, colleagues, and friends: Bojan Petek, Sasa Divjak, Gorazd Golob, Marko Kroflic, Saso Kuntaric, Matevz Tomazevic, Miha Amon, Luka Ferlan, Martin Mozina, Davor Bauk, Rok Krzisnik, Dejan Scernjavic, Richard Vaughan, Jeremy Tai Abbett, Marc Escobosa, and Hernando Barragan.

Thanks to all the members of the Interaction Ivrea community who directly or indirectly contributed to the creative and fun atmosphere and have stood by my side for the last two years.

A very special thank you goes to all my fellow students, the very fist generation of fearless pioneers who made the Interaction Design Institute Ivrea what it is today. I could not have done it without you!

Finally I would like to acknowledge all the friends and colleagues from the PARSEK Corporation, Ltd. for their priceless support.

This thesis is dedicated to my family, my parents Kazimir and Olga, and my brother Matjaz.

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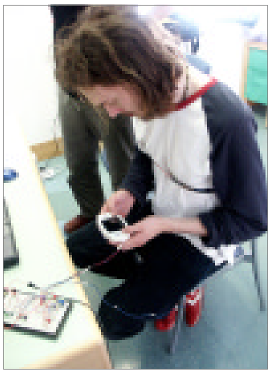
Introduction

Since the late 1950s and early 1960s, when they were first introduced, computer games have taken over the world and won our hearts in only a few decades (fig. 1). Games, almost ubiquitous these days, have mutated, since their beginning, into one of the most engaging and entertaining mediums known today. Compared to other screen based media such as film or television, computer games have changed from scientific explorations and artistic projects to a purely commercial medium almost instantly. In the early 1990s they have became a multi-billion dollar industry and since the introduction of the Internet, sales in the computer game industry have skyrocketed (ELSPA, 2002).

At the same time computer games are shedding their reputation of merely providing amusement for young boys. Covering an astonishing breadth of entertainment, simulation, learning, artistic, competitive, and narrative experiences, they have also found use in education, military, medicine, and business. Computer software has become a condition of our lives; culture is embedded in computers as much as computers are embedded in culture. The time has come, to start taking computer gaming seriously.

Computer games are alarmingly becoming one of the most popular past-time activities. Recently progress on making computer games more physical and phisically engaging has been made. Amidst many irrelevant examples where physical activity is notable are arcade games where players sit on mock-up motorcycles and water jets, wear skis and carry light guns, etc. Fortunately, with the introduction of wearable computing, responsive environments, and interactive objects new opportunities for body engaging gaming are emerging.

1
The first interactive electronic game; the forefather of the Pong.
William Higinbotham, 1958



2
Magnus Torstensson testing an early version of the developed prototype
Jan Raposa, 2003

The focus of this thesis is the exploration of how to make the medium of computer games more physically-engaging and informative.

In this thesis I have:

- Explored the possibilities for creating body engaging computer games
- Developed a hypothesis that fun and playful body monitoring devices are more effective than established biofeedback systems at making people understand their disorders.
- Designed and prototyped a biosensor effected wearable computer game geared towards children with respiratory conditions (fig. 2).
- Studied and documented the efficiency of this approach to biofeedback.

This document is divided into five sections: introduction, background, design and implementation, analysis, and conclusion. The introduction section reveals my personal interests in computer games; it briefly introduces the current state of the computer game medium, and presents a selection of ideas for the thesis exploration. Studying the information in the background section prefaced the development of the physical prototype. The design and implementation section reviews the software explorations and the developed prototype. The last two sections are dedicated to the analysis of the prototype and the questioning the presented hypothesis.

1.1 Motivation

Even though I have been playing computer games almost all my life I have only recently realized the amount of knowledge that I have acquired from this exciting medium. It is responsible for sparking my interest in various areas such as: physics, mathematics, computer science, motion graphics and graphic design, audio and video, geography, and most importantly English. I owe so much to it, if it were not for computer games, there is very little chance that I would find myself where I am today, studying at the Interaction Design Institute Ivrea, exploring this wonderful new field, and writing this document. This thesis is my homage to the medium of the computer game; this is how I repay everything that it has given to me.

Since their beginning, the structure of computer games has changed relatively little. They have become faster, more interactive and engaging, high production audio and video are present in almost every game now, and since the Internet boom, connectivity is becoming increasingly popular in computer games. Although the game medium is progressing rapidly, the ways of controlling and experiencing it seem to have changed little over time. Mice, keyboards, game pads, joysticks, steering wheels, light guns, etc. have been around almost since the beginning of the computer game era.

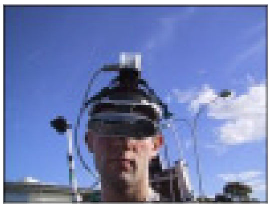
Fundamentally the concept of a computer game has never changed. In most cases, computer games require the player to be physically present in front of a television set or at the computer screen. Lately with the introduction of portable gaming devices and with the medium's expansion to alternative platforms, such as wristwatches or mobile telephones, this is slowly beginning to change. Computer games are becoming more portable and mobile than ever, yet, most of the interaction between a player and the game still happens through familiar inputs such as buttons or joysticks. While playing a game we are still expected to remain relatively still. It is for this reason, that computer gamers are mistakenly seen as inherently lazy and physically inactive people, who spend hours sitting still in front of their computer screens.

Since their beginning, computer games have been designed to engage players' minds rather then their bodies. The ultimate goal of this thesis is to explore how to make the medium of computer games more phisically-engaging and informative.

The following chapters of the introduction section serve as a brief overview of three distinct fields of interaction design in which I believe it is possible to create playful, informative, and body-engaging experiences.

1.1.1
Wearable computing

The term wearable computing brings to mind an image of a human-computer symbiote (fig. 3) with circuitry embedded in his clothing, an electronic monocle or helmet display, complicated input devices, etc.



3
Augmented Reality Quake game interface
Wayne Piekarski, 2002

Fortunately just as personal computers have steered away from the beige box paradigm, the same is now happening in the field of wearable computing. All-purpose wearable computer platforms are becoming a thing of the past and today's wearable devices are becoming more specific, intimate, and personalized than ever before.

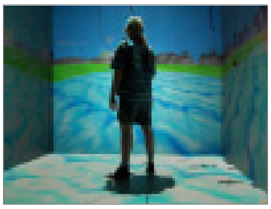
In the late 1990s, great efforts have been made to popularize wearable computing, however, due to its poor usability and poor aesthetic qualities wearable computing has not became a mass phenomenon. To date, wearable computer systems are rarely appropriately designed and are difficult to use.

4
Combat oriented wearable technology
Computing Devices International, 1997

A broad research effort has revealed several potentially interesting applications of wearable computers, unfortunately it is still hard to identify the compelling reasons for the general use of such devices (Gerasimov, 2003).
Cases in which wearable computing has been proven to be extremely efficient include devices for military (fig.4), medical use, and athletic monitoring equipment. An overview of the field reveals that in order for the wearable computing solutions to work, they must be designed to be as portable, simple, and unobtrusive as possible.

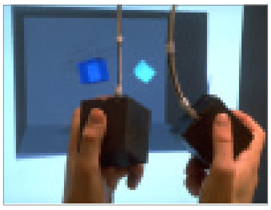
1.1.2
Responsive environments and interactive objects

In contrast to wearable computing, responsive environments and interactive objects pose almost no restrictions on how we can use our bodies to interact with the computer game medium (fig.5). Virtual and augmented reality spaces, artistic installations, advanced fitness equipment, interactive toys, etc. seem to be among the most popular examples where one must engage their entire body in order to fully experience the qualities of a computer game. The downside of the responsive environments and interactive objects is that the players are often required to maneuver within a fixed physical space, or that they are requested to interact with the medium through a very specific input-output device.



5
CAVE virtual reality system
Dave Pape, 1996

In contrast to wearable computing devices, bio-data acquisition is much more difficult to orchestrate in responsive environments. It is only possible to detect a very limited scope of players' physiological factors remotely. This is why wearable devices for bio-data acquisition are often used in combination with responsive environments. In such a space the quality of interaction with the medium is becoming substantially higher as computer vision, motion tracking, projection displays, and audio surround systems are becoming increasingly popular ways for interacting with the computer game medium.



6
Interactive physical object
Reed Kram, 1997

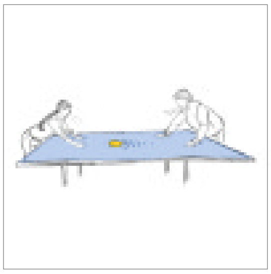
Interactive physical objects that serve as inputs or outputs to the medium seem to offer better chances for bio-data acquisition than responsive environments, however, in most cases, they require constant physical contact with the players, which renders the players relatively immobile (fig.6) .

1.2

Ideation process

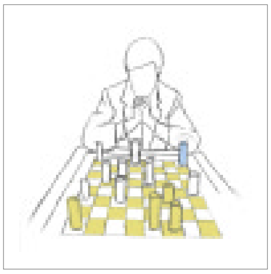
This section presents a small selection of briefly described design ideas I generated for the exploration of making the computer game medium more phisically engaging and informative.

Blow-Pong



Blow-Pong is a mixed media game. It is a "sporty" environment where competition between two or more players takes place. The equivalent of the ping-pong ball is projected from the top and is controlled with the table's sensor equipped surface. Stimulated by the competitive nature of the game, players are lured into training and exploring their respiratory system.

Affective Chessboard

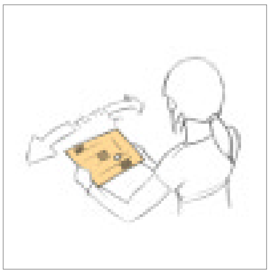


Affective Chessboard is an interactive device for distance chess play. Interaction with the device is supported by light and sound actions. The game should be able to communicate human presence over a great distance. As the figures are being touched on one side they start to glow (communicating presence, thinking, and tension) and pulsate (accordingly to the opponent's heartbeat) on the other. If these signals are correctly decoded, the player can easily analyze the thinking and detect the stress level of his opponent.

Heart Beat

Heart Beat is a multiplayer game where players compete by drumming in sync with their heartbeat, which is displayed through illuminated drum membranes. Players score valuable points if various combinations are played in accordance with their pulse rhythm. The game should encourage group exercise, body synchronization, and collaborative learning.

Tilt Maze

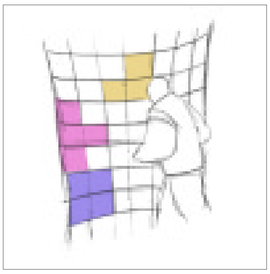


Tilt maze is a physical computer game where difficulty increases as the player's level of stress rises. The goal of the game is to move the ball from one side of the maze to the other while avoiding the holes that expand and contract with every player's heartbeat.

Body Canvas

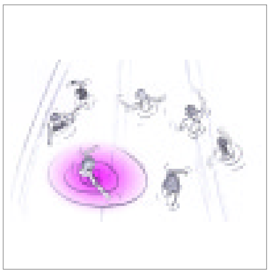
Body Canvas is a reactive surface on which the players can leave visual traces of themselves. While painting on this augmented canvas the players explore their physiological functions such as heartbeat, muscle tension, and galvanic skin response through form and color. The Body Canvas does not have a clear goal; it is merely a reflective device that facilitates constructivist learning.

Building Blox



This pillar shaped Tetris game uses play to encourage rigorous physical activity. The speed of the game is heartbeat dependent; the blocks fall faster as the heart rate is increased. The player has to move around the object and perform various actions in order to change the state of the game. Building Blox should tread a fine line between the fitness equipment and art installations.

Waterobics



This idea explores how group dynamics, collaborative fitness exercises, computer vision, and video projection could be merged in a playful way. Participants in this game compete, play, and learn by performing various exercises. An environment like this should encourage collaborative learning.

Chillboy

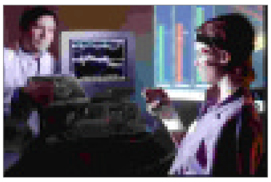
Chillboy is a portable computer game that uses biosensor technology as the main source of input. The sensors are embedded into wearable garments. The “wearability” and the portability of the platform should enable the players to soothingly monitor and explore their physiological functions anywhere. The device becomes active and distracts the player only when stress is detected.

1.3

Idea selection

An exploration of the biosensor technology potential shows that most of the relevant physiological data has to be acquired directly from the human body. Whilst studying the devices for bio-data acquisition I became aware of the intriguing concept of biofeedback. Learning that biofeedback is a training technique through which individuals can acquire voluntary control over a physiological function (Sarafino, 1996) is what guided my research interests toward this particular area of medicine.

Inquiries in the field of biofeedback have revealed that most of the bio—feedback devices and training techniques (with the exception of athletic equipment and training) have the same fundamental flaw as most computer games. While performing the autogenic training, patients are generally required to remain still (fig. 7), in contrast, learning about the body happens primarily through motion and exercise (Jensen, 1997). These findings, based on the facts presented in the Background section, result in a hypothesis that fun and playful body monitoring devices could be more effective at making people understand their disorders than established biofeedback systems.



7
An image of a typical biofeedback session
Neurologisch-verhaltensmedizinische Schmerzklinik Kiel, 1998

To test this hypothesis I decided to first redefine and later prototype and test the Chillboy idea. Now being aware of the greater number of illnesses that biofeedback training can improve, I have, for very personal reasons, turned the Chillboy from a stress control device into a device for educating its users about the respiratory system. Having found substantial evidence that supports the use of biofeedback in asthma treatment (as presented in the Background section of this document), I set out to explore the possibilities for the convergence of wearable computing, body monitoring, and edutainment.

8
For decades doctors have used biofeedback as a way to help control stress and tension. Now NASA technology adds a new twist by combining this mind-over-matter technique with the hand-eye coordination of video games...
www.nasa.gov, Aug. 10, 2000

Background

In this chapter, I present the groundwork that prefaced the design and implementation of the Asthma Buster concept (previously known as the Chillboy) and the Bloop! video game. The first part of the chapter briefly introduces the medium of computer games, as it explores its educational qualities. The second part introduces the reader to the concept of biofeedback training and wearable bio-sensor technology. The last part of the chapter briefly studies the asthma disease in relation to biofeedback training. For more information and references on asthma and biofeedback I recommend Behavioral Treatments for Asthma (Studies in Health and Human Services, Vol 29) by Edward P. Sarafino. To fully understand the potential of game-based learning consult the Digital Game-Based Learning by Marc Prensky.

2.1

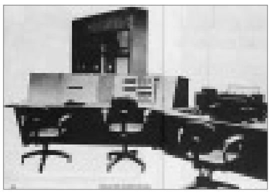
Computer game-based learning

Computer gaming; enormously versatile; adaptable to almost any subject, information, or skill to be learned; meets the learning styles and standards of today's generations. The following chapters of this section briefly sum up what makes the medium of computer game so engaging and study why and how computer-game based learning works.

2.1.1

Evolution of the computer game medium

Since 1960s, when they were first introduced, computer games have taken over the world in only a few decades. Almost ubiquitous now, they have since their beginning mutated into the most engaging and entertaining medium known today. This section briefly illustrates the evolution of the medium, and loosely studies its relation to the body through the attached imagery.



9
PDP-1, the first computer to run a computer game.
MIT, 1961

The first internationally accepted interactive computer game was produced by the MIT student Steve Russell in 1961. Spacewar, as it was titled, ran on a Digital PDP-1 (Programmed Data Processor-1) minicomputer (fig. 9). Limited by the computer technology of the time, Spacewar used Teletype terminals with CRT screens to display the graphics.

During the following years companies such a Sega, Magnavox, Atari, Tatio, Williams, Midway, Namco, Nintendo etc. became the big names in coin—operated video and arcade game industry.

10
Magnavox Oddysey
Magnavox, 1972

With the increasing popularity of the television medium, Magnavox was the first company to introduce the concept of home gaming (game) console to the market (fig. 10). Many others followed this step and soon video games started to migrate from game parlors into people's homes. Created by the Atari, a game named Pong became one of the biggest commercial successes that marked that period.

Almost at the same time in 1977 Midway, in collaboration with Tatio, introduced Gunfight, the first game to use a microprocessor and the video game industry changed. Analogue devices were immediately rendered obsolete, and computer games became a strictly digital medium.

11
Baseball, the first portable game console.
Mattel, 1977

The late 1970s and early 1980s were the golden days of the computer game industry. The market was flooded by various entertainment devices such as; television enabled console games, hand held LED (fig. 11) and LCD-based games, arcade-type videogames, etc. Interestingly the only platform on which the computer games were not doing well was the computer itself.

With the introduction of inexpensive personal computers such as: Apple II (fig. 12), IBM PC, Sinclair ZX series, Amstrad, Commodore C64 and Amiga series, Atari ST series, etc. a change happened almost overnight. The concept of licensing computer games was already familiar to many entertainment companies who were simply producing the video games and selling them in a cartridge form for home consoles. The medium's "reinvasion" of the computer was unavoidable.

In the late 1970s and early 1980s, with the introduction of new technologies, devices for computer game based entertainment have split into two separate groups. Having failed to find the appropriate terminology I coined these as "stationary" and "portable" computer game devices.

The devices for stationary gaming have changed little since that time. Video arcades are slowly closing down as computer games and platforms are becoming increasingly affordable. The medium is slowly leaving personal computers behind as it is migrating towards the television. Computer game consoles are becoming increasingly popular.

Joysticks, steering wheels, haptic mice, game pads, etc. indicate that new game input devices are gradually evolving and seizing their share of the market, while at the same time, output devices mostly remain the same.

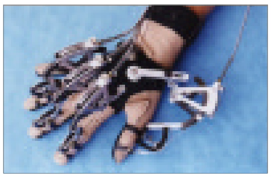
Lately the concepts of virtual and augmented reality, motion tracking, computer vision, video projection, audio surround systems, and haptic interactivity (fig. 13) have been introduced, but their success in the computer game world still needs to be validated.

In contrast to fixed—location games, portable computer games have seen much improvement in the last two decades. Shortly after in 1977, Mattel introduced a line of LED-based hand held "video" games, the competition has realized the enormous economic potential of portable gaming.

As the LCD technology progressed various inexpensive devices ranging from handheld computer games to game watches have over flooded the market. For a while everything was quiet in the portable game world until in the 1989 Nintendo released the Game Boy console. Following Nintendo's footsteps companies such as Sega, Bandai, Tiger, etc tried to get their share of the market. In spite the tough competition Nintendo (fig. 14) managed to hold on to their position until today by constantly inovating new entertainment platforms. Shortly after the introduction of mobile telephony, the telephones became yet another platform that was invaded and transformed by the medium (fig. 15).

Today, as the technology advances, concepts of wearable and ubiquitous computing are being explored with the intent to make computer games more portable and personal and intuitive to use.

12
Apple II
Apple Corporation, 1977



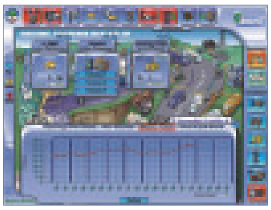
13
Cybergrasp force feedback glove
Virtual Technologies, Inc., 1999

14
Pocket Pikachu Pedometer
Nintendo, 1998

15
Nokia Ngage
Nokia, 1998

2.1.2
Growing up in the gaming era

Learning with computer games works because games are extremely exciting and engaging. Construction, discovery, quests, relationships, action and interaction, rules and structure, communities are only a few out of hundreds of elements that make a computer game exciting and interesting. Since the days of Pong and Space Battle, learning has been present in all computer games. Players that are caught up in a loop between a machine and their minds experience flows of information. Absorbing this information, regardless of how it is fed to the player, is seen as active computer game based learning. Most of it even happens without the players realizing that they are actually learning something.



16
Race toward shareholder value
Root Learning, Inc., 2002

Edutainment, a word that describes educational entertainment and is often used as a substitute for digital game based learning, is present everywhere. Preschoolers now learn alphabet and basic math through computer games, and children that play computer games are expected to score higher grades on their school tests, financial traders use complex game-like simulations to hone their skills (fig. 16), military uses simulations (fig. 17) to lower the training expences, etc.

Since the late 1970s people have been surrounded with computer games and they have and still are growing up with them. This vivid, intense, fast, and colorful medium has literally altered how younger generations think and how their minds work.

17
Flight simulator
From Link Simulation & Training, Ltd., 2001

Cognitive changes that occurred over the last few decades are widening the gap between standard and new ways of learning. As Marshal McLuhan describes in his “War and Peace in the Global Village”, new mediums and technologies bring “pain and misery” to the young generations. Children that have grown up playing computer games and living the fast lives in them are instructed to go back to reading books, writing on the paper, and are literally forced to keep quiet and slow down.

Based on the latest scientific research in neurology, there is no longer any questioning that stimulation of various kinds actually changes our brain structures and affects the way we think. The brain changes and reorganizes itself constantly; based on the received input. This phenomenon is known as neuroplasticity and it occurs throughout our child and adult lives (Paul Perry in the American Way, May, 15, 2000)

As children these days are exposed to computer games at a very early stage in their lives, they get used to them very quickly. Often they even develop various skills that even their parents don’t have. And skills developed while playing computer games go far beyond the hand-eye coordination (Greenfield, 1984).

Representational competence, mental paper folding (picturing the results), creativity, great interest in discovery, formulating hypotheses on the fly, multitasking and attention division, positive responses in unexpected situations, quick decision making, ability to decode iconic representations, etc. are just some of the most interesting and applicable skills that gamers are developing. Game generation children seem to process information differently, in parallel, they prefer play to work, fantasy to reality, they befriend technology faster than non-gamers, they are better at understanding abstract metaphors, and are capable of filtering information quickly.

However, computer games can also negatively influence the players; shorter attention spans, disappearing reflection skills, and cravings for visual stimuli and twitch speed seem to be among the most worrying consequences. The ability to pause, stop, and reflect is the key point in the process of learning, and computer games sadly very rarely offer this experience. In the computer game world usually things work differently; you stop, you die, and this very fact concerns many educators (Herz, 1997).

One of the most important lessons that the games generations learn from growing up with the video games is that if you put in the hours and master the game, you will be rewarded – with the next level, with high scores, with a win, with communal praise, etc. And all that effort is what makes computer games hard fun.

Computer games excel at giving feedback and the payoff for any action is typically very clear and is well worth the wait and the effort put into mastering a certain task. High scores, virtual heaps of money, hidden levels are proven to motivate the players enough to finish a game or complete a certain task. If a game is stimulating enough, there are no obstacles that the player will not force himself to overcome, in order to finish. He will train, practice, learn, and try harder every time he is pushed back.

2.1.3

Game-based learning

Learning is a highly complex phenomenon with huge numbers of variables. While there are many things known about learning, we still do not exactly know how it works. Learning cannot be measured precisely, although, like many things, we know when we see it and feel ourselves doing it.

A short inquiry in epistemology reveals that learning works best when:

- One is engaged in hard and challenging activities.
- Learning comes from doing, manipulating, and examining.
- Learning is imitation.
- When multiple senses are involved.
- People learn visually, aurally, and kinesthetically.
- People learn through feedback.
- People learn through a loop of feedback and reflection.
- People learn from mistakes.
- People learn from playing.
- People learn when they are having fun.

The elements listed are only a few out of hundreds of reasons why computer games can be successfully used in the learning process. Before the age of the printed books learning was mostly done through questioning, storytelling, imitation, practice, and play. Today the same is happening, as computer games have the ability to put the players in direct contact with the world that they are so eager to explore. (Prensky, 2001)

18
Dr. Seymour Papert, the great edutainment pioneer, the inventor of Logo
MIT archive, 1999

Because computer games are so interactive, the player has a big say in what happens. Computer games are different from learning or training software, software is supposed to be taught, games should be designed to teach you as you go through them. This forces game designers to think about all kinds of possible interactions that players might have with the game environment; it makes them think of rules, topics, episodes, the story behind the game, etc. The games have to be completely user centered, innovative, and revolutionary to get the player's attention. This explains why designing an educative computer game is a highly complicated task.
According to Seymour Papert (fig. 18) from MIT, game designers have to have a better understanding of the nature of learning than curriculum designers.

While designing a piece of edutainment software, it is crucial that designers are well aware of the potential learning motivators. What will keep the players motivated enough to finish or at least try and play the game for a while?

Self-motivation through the game is among the least popular of motivators. The basic human motivation to achieve anything is relatively new to the world of computer games. SimCity from Maxis is one of the games where self-motivation plays a key factor in the game. The game has no obvious goal and is just an environment where the player is encouraged to plan and build.

To some degree players are motivated enough to play the game by seeing their virtual stock grow, however, it is believed that the freedom of choice in this virtual environment is the most important motivator that keeps them involved.

Fear is a traditionally important motivator for most of today's learners. You stop, you die; you don't study, you flunk the test. In computer game world fear is a rather questionable motivator. Fear tends to lead towards stress, and stress is not the best way to produce effective, long-term learning experiences.

Love, score, and money (greed) are the leading motivators and are important for those who need constant approval that they are making progress while playing a computer game. Lastly pleasure and fun also seem to be among the most powerful motivators in computer games when used in combination with any of the ones mentioned before.

Motivation, however, is not the only element that makes computer games interesting enough to play. The reason why computer gaming has became such a great learning success is that the computer games are enormously engaging. And computer games are engaging because they are (Malone, 1981):

- Fun, and fun gives us enjoyment and pleasure.
- A form of play that sparks passionate involvement.
- Interactive, they let players play and work.
- Adaptive, they change and give players flow.
- Problem solving, and they spark creativity.
- Conflictive, and that gives the players a sense of thrill.
- A representation of a story and are very emotional.
- Connected and enables group interactions.

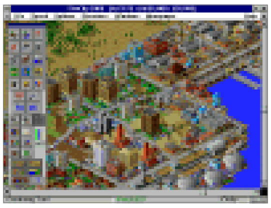
No other medium provides all the listed qualities of a computer game. Books and movies come close, but they are not nearly as interactive and are most of the times experienced alone. Computer games possess another great quality over the printed and television medium, they are active and require complete players dedication and attention in order to be played and finished.

Computer games are fun and playful. But why are fun and play such important elements in the learning process? If learning is fun, then learning itself can be a desire for the reoccurrence of the experience. It is also known that fun helps learners relax and face difficult tasks easier and it generally keeps them motivated for a longer period of time.

19
Jean Piaget, the pioneer researcher of development of intelligence in children
(1896-1980)

While fun is a rather simple idea, play is a much more complex phenomenon. It is an activity that is not obligatory, it is uncertain of the outcomes, and it has its own space and time. Play creates no material wealth, yet it is shaped by fixed rules (Caillois, 2001). In other words play is something that one chooses to do, play is intense and absorbing, and it promotes formations of social groups. It provides a venue for thinking and reflecting. With the help of play children are able to create their own knowledge by manipulating, experimenting, constructing, exploring, etc. (Piaget, 1926; fig. 19).
This is why people enjoy difficult tasks more when they are presented as play rather then work. Research in neuroscience even shows that when one is enjoying the activity of play or exercise, chemical changes occur in the body resulting in an increased state of alertness and openness to new knowledge (Jensen, 2000).

And as every form of play has its own sets of rules, so do computer games. Rules turn computer games into an organized play session. While most of these rules are obvious some remain hidden at first. Discovering new rules and pushing the limits of what one can achieve in a computer game, is often seen as a form of exploration and learning. Rules provide a structure for games, but goals and objectives are what makes games different from one another. Not all computer games have a clear goal; some of them (i.e. SimCity; fig. 20) are only simulations where the player has to set a goal for himself.



20
Simcity 2000
Maxis, Inc., 1999

In order to measure progress through a computer game a player must constantly receive some sort of feedback from the game. When he moves, the game moves, when he changes his state in a game the game adapts to it. This constant movement and change is what makes computer games so interactive and fascinating. It is from the feedback in a game that learning comes from. Via the feedback players can get rewarded for mastering something, and if they fail, the game has to provoke them to try again.
The art of providing feedback is extremely important and complex because too little or too much can quickly lead to frustration of the player. In a good computer game feedback has to be adaptable. The level of difficulty must go up and down depending on what the player does in the game.
This is how players are kept in the constant “flow state”

The “flow state” is a mental state of intense concentration, often to a point where previously difficult tasks become easy, and whatever a person is doing while experiencing flow becomes enjoyable (Csikszentmihalyi, 1991). In this state the challenges presented and one’s ability to solve them are almost perfectly matched. Often people are capable of accomplishing things that they did not know or believe that they could, along with a great deal of pleasure. Flow can be found in other activities as well; work, sports, learning, etc.

Previous paragraphs help us understand the enormous educational potential that computer games have, but the main reasons why they work are fairly simple. According to Marc Prensky, the author of the book "Digital Game Based Learning", computer games work primarily for three reasons:

20
Marc Prensky
from marcprensky.com, 2003

- The first and the most important reason is the added engagement that comes from putting the learning into a game context. This can be even more considerable for material people, as they seem to dislike learning more.
- The second reason is that interactivity and interactive learning processes are employed. This can take many different forms and approaches on the learning goals.
- The third reason is the combination of how the first two are put together.

However, in spite all the positive effects that computer games have on learning, the games will not teach a player anything new if they are not engaging enough to play. This is why when designing a piece of educational entertainment software one must be extremely careful to make the game feel just like a video game and not like a learning program. The context must be cleverly designed and the learning content has to be somewhat hidden from the player. In Ashley Lipson's words, "To be an entertaining and educational game, it must first be a game, and only then, a teacher."

2.1.4

Combining computer games and learning

»What is best about the best games is that they draw kids into some very hard learning.«

- Seymour Papert

Combining computer games and learning greatly depends on the audience, the subject matter, the technology available, even on the business and political context. Good edutainment software has to strive for both, engagement and learning, to be present at a high level. Not enough emphasis on learning will turn the product into a simple computer game, not enough play will make the product feel like a piece of computer training software.

To design an enjoyable educational experience we must provide a number of elements that will make a computer game both educational and fun. The game must challenge the player with its goals, variability, and levels, etc. It must include an emotionally appealing factor and use fantasy as a metaphorical environment for learning. Lastly it must be visually and aurally pleasing and it must stimulate sensory and cognitive curiosity (Malone, 1981)

For every type of content there is a preferred type of interactive learning. The following spreadsheet explains how the learning content is normally matched with various game styles (Prensky, 2001)

Learning content	**Examples**	**Learning Activities**	**Possible Game Styles**
Facts	Laws, specifications, policies	Questions, memorization, drill, association	Flashcard type games, quizzes, action and sports games
Skills	Interviewing, teaching, selling, managing, maintaining	Imitation, feedback coaching, continuous practice, increased challenge	Role-playing games, adventure games, detective games
Judgment	Management decisions, timing, ethics, hiring, problem solving	Reviewing cases, asking questions, making choices, feedback, coaching	Role-playing games, detective games, multiplayer games, strategy games
Behaviors	Supervising, exercising self-control, setting examples	Imitation, feedback, coaching, practice	Role-playing games
Theories	Marketing rationales, how people learn	Logic, experimentation, questioning	Open ended simulation games, building games, construction games, reality testing games
Reasoning	Strategic and tactical thinking, quality analysis	Problems, examples	Puzzle games
Process	Auditing, strategy creation	Problems, examples	Timed games, reflex games
Creativity	Invention, design, art	Play, memorization, reflection	Puzzles, invention games, responsive environments
Language	Foreign languages, jargon	Imitation, continuous practice, immersion	Role playing games, reflex games, flashcard games
Systems	Health care, markets, refineries	Understanding principles, graduated tasks, playing in micro-worlds	Simulation games
Observation	Moods, morale, inefficiencies, problems	Observing feedback	Concentration games, adventure games
Communication	Appropriate language, timing, involvement	Imitation, practice	Role playing games, online games, reflex games

One of the reasons why edutainment software is not impossibly hard to create is that it has up till now employed many learning and interactive learning techniques that have been used in non-game forms of learning. Among the most commonly described interactive learning techniques are (Pernsky, 2001):

- Practice and feedback
- Learning by doing
- Learning from mistakes
- Goal-oriented learning
- Learning through discovery
- Task-based learning
- Question-led learning
- Role playing
- Coaching
- Constructivist learning
- Intelligent tutoring

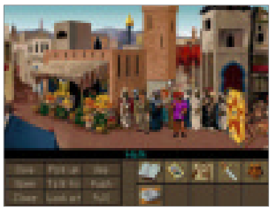
Practice and feedback are one of the earliest ways of using the computer for learning. Computers are great at presenting problems and keeping track of how well people solve them. Most of the edutainment software uses this type of learning, as often learning new things requires constant practice. Typing games seem to be among the most popular examples of practice and feedback learning (fig. 21).

Learning by doing is praised by many of those who reject telling as a learning methodology. Learning by doing an extremely popular way of communicating knowledge, as computers are exceptionally good at allowing us to interact with them. Learning by doing mostly results in adventure games or games where the player is instructed to explore a virtual world (fig. 22).

Learning from mistakes in spite of its evangelical nuance is another effective game based learning technique. Computer games excel at keeping the players motivated and engaged enough so that they want to try to play them over and over again. Players are often even tempted into making mistakes just to see the consequences of their misplay. Platform games and shoot-em-ups seem to be the types of the games where learning from mistakes is ubiquitous (fig. 23).

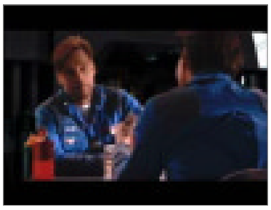
Goal-oriented learning seems to be more popular among the individuals that prefer to teach "how to do" rather then "what to do". A goal is the key element that turns play into a game. It provides a player with challenge that he wants to face and overcome.

21
Typing of the dead
Sega Corporation, 2000

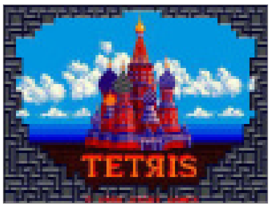


22
Indiana Jones and the Fate of Atlantis
LucasArts, 1993

23
DOOM
ID Software, 1993



24
Wing Commander III
Origin, 1993



25
Tetris
Atari, 1988

26
The Incredibile Machine
Sierra, 1992

Goals presented through an interesting piece of narrative help to keep players motivated enough to finish the game in spite of constant failure that might occur in the game play (fig. 24).

Discovery learning is based on the idea that you will learn something better if you learn or discover it for yourself. In edutainment software discovery implies some sort of a problem to solve. Problem solving through clues often does not appeal to those who are used to the linear type of thinking. In most cases discovery based learning is a key factor in adventure games.

Task based learning is another approach to computer game based learning. Through the game the player is first taught a task and then he is asked to repeat it for a number of times. The potential issue with this learning methodology is that users may learn less of the theory behind the skills (fig. 25).

Question-based learning is most often used as a form of a test, where questions are asked and answers are found with the help of clues. Questions are kept short and simple and are traditionally presented as type of trivia or a quiz game.

Situated learning is an approach in which learning is set in an environment similar or identical to where the learning material should be applied. For situated learning highly realistic and immersive environments are something most of the modern computer games do extremely well.

Coaching done by software agents or real tutors present physically or over a distance, is a growing element in interactive learning. Mostly coaching is found in military and technical applications.

Constructivist learning, built mostly on the works of Jean Piaget, has became increasingly popular over the last years, as MIT Media Lab's Epistemology and Learning group adopted it as a potentially most important modern learning technique. Constructivist learning is built upon the idea that a person learns best when he or she actively "constructs" ideas and relationships in their own mind, based on the experiments and actions that they do. In the computer game world constructivist learning is often found in various simulation games such as: SimCity and a variety of Tycoon games, or in simplified programming or explorative environments (i.e.The Incredible Machine; fig. 26).

When combining learning techniques and computer games we must be aware of the number of options and categories that we can choose from. Learning games are generally sorted in the following categories:

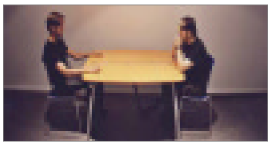
- Intrinsic and extrinsic games
- Reflective games and action games
- Synchronous and asynchronous games
- Single-player and multi-player games
- Session based games and persistent state games
- Narrative and reflection based games

Learning oriented computer games are split into two categories; intrinsic and extrinsic. In an intrinsic game the content is an integral part of the game structure. An example of such game is any flying simulator (fig. 27), where the game itself is about learning how to pilot an airplane. Most of the simulation games fall in the same category. Extrinsic games, on the other hand, are games where the content and the game structure are less tightly linked, or not linked at all (i.e. puzzle games). Some argue that intrinsic games provide the most powerful learning experiences technology can support today, others argue that extrinsic games are better for they spark creativity and reflection.

27
Flight Simulator
Microsoft, 2000

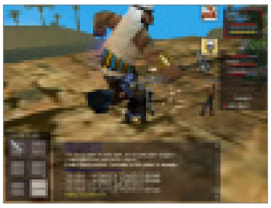
Non-stop action games offer less opportunity for reflection in themselves, while role-playing games, adventure, simulation, strategy, and puzzle games often proceed at a slower pace and offer more built-in reflective "space". This however, does not mean that we cannot use action in edutain—ment software; we must simply find the right balance between entertainment and speed, and education. Brainball (fig. 28), even though it is not an action game, is an interesting example how to combine reflection with non-stop action.

The distinction between real-time and turn-based games is quite important in game based learning. Most of the single player games have to be interrupted at some point, either to be paused or to offer time for reflection. In a turn based game the machine or the other player is instructed to wait for you unless you are playing a timed game.



28
Brainball
Autoreflective Biofeedback Game
Interactive Institute, 2002

The bigger the number of players that play the same computer game, the bigger the possibility for creation of social structures among the players. Collaborative play results in creation of social sub-groups and when gamers are playing the same game together, this commonly happens in a virtual space of the game. Lobbies, waiting rooms, or team radio are places where knowledge is transferred and where most of the learning happens.



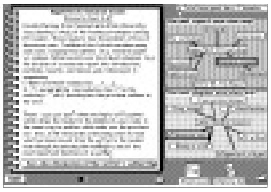
29
Everquest
Sony Interactive, 2000

Persistent state games are a recent addition to the world of computer gaming. They are often described as online worlds that are run on various synchronized servers around the world and never stop. The game continues to change even after a player logs of from the network. Games like Ultima Online or EverQuest are an excellent example how one can build up their own skills slowly over time and learn from eachother (fig. 29).

Another interesting question is how much story to include in the game. Although narrative and characters add emotional impact to a game it is most often that reflex not recall is important when playing a computer game. Narrative is often used to frame the game and set it in a certain context.

Selecting an appropriate learning style and matching it with the right type of the computer game is crucial to the success in edutainment software design. While designing and building it, the creators must ask themselves constantly if the game is fun enough that someone in the target audience would play it, if the game experience is addictive, does it encourage reflection, etc. When designing educational games, we must never forget that they must be entertaining and engaging first, only then they can teach.

2.1.5
Relevant examples of edutainment software



30
HyperCard
Apple Computer, Inc., 1987

While early computer games were already attracting large crowds of devotees, they were commonly not played by children or used for learning. The first computer to change this was the Apple II, which appeared in 1977. With the project »Apple Classroom of Tomorrow« Apple decided to penetrate the education market. Apple II was conceived primarily as a games machine by Steve Wozniak and is as such still used in many classrooms these days, good 20 year later (Apple, 2003).

When in 1984 Macintosh came along it opened a whole new world. Suddenly computer could talk and show pictures, and with the introduction of HyperCard, a huge wave of creativity and programming in the edutainment area was released (fig. 30).

During the 1980s learning games became increasingly popular. Being cleverly marketed as computer games titles like MathBlaster, Where in the World is Carmen Sandiego, SimCity, Tetris, various Quests from Sierra Studios and LucasArts, Sesame Street, Quin, The Incredible Machine, Adventures in Math, Beauty and the Beast, and Flight Simulator became over night hits that were sold in millions of copies. These titles have notably defined the edutainment space and were responsible for the introduction of a new type of software industry and research.

Among the most relevant asthma related edutainment titles found is Bronkie the Bronchiasaurus (fig. 31). An intrinsic asthma game geared toward children who suffer from asthma or other bronchial conditions (endorsed by the American Academy of Pediatrics). In the game a child plays the role of Bronkie, a dinosaur whose homeland has been assaulted by a meteor shower. Along with Bronkie's friends Trakie, Sam, and Kyla, a child has to clean up the air using a powerful wind machine. But first, he has to find the missing parts of the machine, while avoiding other dinosaurs and asthma irritants like dust, pollen, and cold viruses. Through the futuristic virtual environment children learn about the basic asthma facts such as pollen, respiration, hyperventilation, etc. Published by the Raya systems for Nintendo in 1994, this console game became a big hit in the asthma community. Appealingly designed with a rigid learning structure behind it, it found its use in private homes, educational institutions, and hospitals.

31
Bronkie the Bronchiasaurus
Raya Systems, 1994

Quest for the Code, another asthma related adventure game licensed by Starbright Company from the USA, makes the use of the advantages PC CD-ROM technology has to offer. This animation intensive computer game teaches children about the history of asthma, takes them on a tour of their body, introduces proper use of asthma medication devices, etc.

32
Quest for code
Starbright Company, 2001

With the introduction of the Internet and the broadband, edutainment software has become even more present in our daily lives. Health oriented educational computer games, in form of adventure games, puzzles, arcade games, etc. can be found with great ease all over the Internet.

Asthma Kids, a website sponsored by the Asthma Society of Canada (fig. 33), is just one out of many examples. It has a number of interesting, playful, and informative asthma oriented games. There are detailed explanations of asthma and other respiratory disorders, and an extensive online community is present as well.

33
www.asthmakids.ca
Asthma Society of Canada, 2003

2.2

Introducing biofeedback

The prefix "bio" from its Greek language origin means life. The word "feedback" means to return information to its origin. Biofeedback, therefore, is biological information, which is returned to the source that created it.

To insure its survival, the human organism maintains itself through various homeostatic mechanisms. The major way utilized to maintain this balance is feedback control (Ashby, 1963). For example, the human being must receive information about its behavior in order to control and alter it. This information comes through one or more of the senses. The simple ability to reach out and touch an object with the hand is mediated by the visual experience or feedback of the proximity of the hand to the object that is to be touched. This phenomenon is called a feedback loop (Gaarder, 1971).

In other words biofeedback is a technique through which individuals can acquire voluntary control over a physiological function, controlled by the autonomic nervous system, by monitoring its status (Sarafino, 1996).

Modern biofeedback techniques use various monitoring instruments to feed back patients' physiological information of which they usually are not aware. These devices enable patients to learn by trial and error how to adjust their thinking and other mental processes, in order to obtain voluntary control over bodily processes that were thus far thought of to be involuntary; such as blood pressure, temperature, gastrointestinal activity, respiration, heartbeat rate etc.

Next to being a successful treatment and training method, biofeedback is also an outstanding tool to facilitate stress control training. Over the last few decades more applications of biofeedback are being developed yearly.

In a biofeedback session a patient is required to wear various sensors (electrodes for galvanic skin response, muscular or neural activity, microphones or strain gauges for respiration, oximeters or stethoscopes for pulse monitoring, etc), which serve as an input to a sampling, and later on, to a signal-processing device. Data (also called biodata) collected from human body is immediately processed and fed back to the patient through a variety of output devices ranging from computer screens, small LCD monitors, speakers, headphones, head-mounted displays; to paper printouts, movable objects, and even responsive environments.

During most of the biofeedback sessions a therapist is present leading the patient through a series of exercises and helping them to reach a desired result. Biofeedback training for some disorders normally requires 8-10 sessions, however patients with long term or severe disorders require a longer therapy.

The goal of the training is obviously to teach patients how to regulate and control their own inner mental and bodily processes without the help of the biofeedback machine and the therapist.

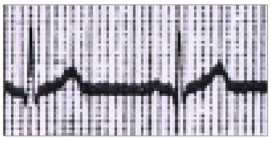
Although biofeedback is a relatively new scientific field that is seen as an alternative approach to medicine, it is already being recognized as a successful form of therapy and treatment by both physicians and specialists worldwide. Various successful studies indicate that biofeedback is extremely effective when it comes to very specific therapeutic needs such as; treatment of migraine headaches, hypertension, asthma, neuromuscular disorders, spastic colon syndrome, hypertension, stress, epilepsy, attention deficit disorder, muscle damage, etc.

People like and enjoy biofeedback training because it puts them in control over their disorder. It provides them with a sense of mastery and self—reliance over their illnesses and health.

2.2.1

The history of biofeedback

The scientific separation between mind and body was established during the 17th century. Originally it permitted medical science the freedom to experiment on the human body but at the same time it preserved the domain of the mind for the church.



34
The first electrocardiogram print
Einthoven, 1902

In the succeeding three centuries, the medicine that evolved from this focus on the body and its processes has presented us extraordinary discoveries about the nature and treatment of disease states.

However, this narrow focus has over the many years passed obscured the importance of interactions between our body and the mind. The interest of medical research has been biology, and the mind was left to non-biologically oriented researches such as: psychiatrists, psychologists, philosophers, theologians, etc.

With the introduction of eastern psychosomatic medicine and other healing systems such as yoga or tai chi, imported mostly from Asia in the beginning of the 20th century, the gap between the body and the mind began to grow smaller.

The introduction of the early biofeedback techniques date back to the beginning of that same era (fig. 34), when at the beginning of the century J.H. Schultz first developed a technique called Autogenic Training. In this method, verbal instructions are used to guide a person to a different; more relaxed and controlled, physiological state. The method, though still in use today, has mutated to a point where it is no longer referred to as Autogenic Training, but is treated as a very abstract form of hypnosis.

In the 1930's Edmund Jacobson developed a technique of Progressive Relaxation training, a series of exercises in muscle activity, to teach people awareness of tension and relaxation. The effect was to reduce muscle tension and to prevent the effects of stress.

As electronics were introduced in the field of experimental psychology n the early 1940's, Margolin and Kubic (1944) began to experiment with feedback on heartbeat and respiration. Although the subjects were not instructed to alter these physiological functions, the feedback of their biological system was used to affect their conscious and emotional state.

In the past 50 years psycho physiological research has examined the relationship between emotional states and physiological states and within the past 30 years numerous attempts have been made to affect these emotional states, as well as the states of consciousness.

35
An early polygraph machine
howstuffworks.com, 2003

In 1961, a milestone year for biofeedback, experimental psychologist Neal Miller proposed that autonomic, or visceral, nervous system is entirely trainable. His suggestion ran contrary to prevailing orthodoxy, which held that all autonomic responses (heart rate, blood pressure, respiration, etc.) were beyond voluntary control. Experimenting with lab rats and polygraphy (fig. 35) Miller managed to prove his theory that has been greatly expanded on over the succeeding four decades. More than 3000 articles and 100 books, describing biofeedback and its applications, have been published to date.

Even though biofeedback does not belong to any particular field of health care it has over the years found its uses in many disciplines, including internal medicine, dentistry, physical therapy and rehabilitation, psychology and psychiatry, pain and stress management, etc.

36
SenseWear Armband
Bodymedia, Inc., 2002

Today, in the digital era, biofeedback is thought of as a method of training and prevention rather than a way of healing. As we see electronic devices growing smaller and smaller the same thing is happening in the field of biofeedback; portable heart monitors are present in almost every gymnasium, on every other jogger. New devices that can monitor, display, process, and transmit multiple physiological factors are being developed and sent to the market at a rapid rate (fig. 36).

At the same time biofeedback is starting to mutate, biodata is being used to co-create digital bio-art pieces, feedback loops are being cut, our data is transmitted over networks to be analyzed, processed, monitored, or simply to serve as a way of bringing people closer together.

2.2.2
Measuring Bio-potential

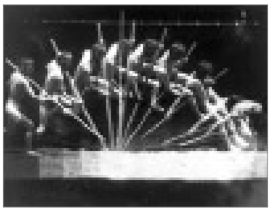
Man's interest in human body has been forever present. At first limitations of what it can do were being discovered through primal actions such as: work, play, competition, training, etc. As science and technology evolved over time biological, physical, and chemical studies to determine its limitations followed (fig. 37).

With the introduction of modern electronic devices, the number of ways one can measure various actions, which occur within or on the surface of the human body, seems almost infinite. After measuring temperature, respiration, heartbeat, galvanic skin response, pH balance, muscle tension, blood pressure, brain waves, neural activity, where can one go next?

Over the last few decades people have been pushing their bodies to the limits over and over again. Stellarc, Australian born cyber artist, experimented with exoskeletons (fig. 38), students from the MIT are programming affective computer games that shock them even more than regular shoot-em-ups, and wirelessly operated capsule sized swallow-able video cameras, that stream video to a computer screen are the next big thing to hit the market.

Biopotential measurements are everything but a simple task to perform. Complex electronic circuitry (such as amplifiers, filters, micro controller operated circuits, etc.) and sensing devices (electrodes, oximeters, strain gauges, etc.), have to be solidly built in order to provide clean and error free signals. Data acquisition is not the only problem that the engineers and designers are facing when it comes to creating biofeedback devices. Signal processing and data display require extensive mathematical and physical knowledge. Lastly the creators of such devices also need to be acquainted with the anatomy and the physiology of the human body.

The following sections focus on the most relevant physiological factors used in biofeedback training such as; body temperature, respiration, heartbeat, emotional arousal, muscle tension, and neural activity, as they study their relation to biofeedback devices.



37
Motion Study
Thomas Eakins , 1884

38
Exoskeleton
Stellarc , 1998

39
Swallow-able camera
Birmingham Hospital, 2002

2.2.2.1

Body temperature

40
Digital thermometer
from Bell Instruments

Thermal or temperature biofeedback is one of the easiest to conceptualize and to instrument. The tendency of the human body is simply to conserve resources when stressed (scared, shocked, surprised). Circulation is withdrawn from both the periphery and the gut, and is instead delivered to important parts of the body.

For instance when a person is being attacked by an astray dog their blood immediately gets pumped into large muscles, the heart, and the brain. At the same time other autonomic functions slow down, digestion can wait while someone is fighting for their life. Hands and feet consequently cool down.

This stress response mechanism is meant to be used only when needed. If stress is chronic our body suffers constantly. By providing body temperature feedback we can communicate actions that help the patient return to a better resting state. (fig. 40)

Body temperature is usually measured with a thermistor (thermal resistor) that is used to constantly acquire changes in the temperature of the subject. Thermistors are normally placed in subjects' ear or taped on to their fingers, hands, or wrists. Changes in the body temperature occur rather slowly and signals, if properly filtered, form gentle curves over time.

Next to medical reasons body temperature monitoring is also used to teach relaxation various techniques and is used extensively in polygraphy.

2.2.2.2

Respiration

Many symptoms, that are experienced by a patient as caused by stress, may in fact be due to false breathing. These symptoms include panic, functional chest pain, asthma, irritable bowel syndrome, migraine headaches, hypertension and many others. One quality that distinguishes humans from animals is the exquisite control of breath that makes speech possible; therefore, control of breath is not as "automatic" as other autonomic functions.

In 1975 Hirai suggested that lung action, if regulated by contraction of the abdominal diaphragm, simulates the vagus nerve. This nerve additionally stimulates the entire parasympathetic nervous system and causes general relaxation. At the same time it is a well known medical fact that temporary or chronic hyperventilation, accompanied by low blood carbon dioxide levels, can create its own sets of problems.

Emotional excitement and physical activity are reported to lead to a faster and deeper respiration; in contrast, rest and relaxation lead to shallower and slower respiration. A state of long-term stress is indicated by a higher respiratory rate, however when exposed to a sudden shock, our body tends to momentarily cease respiratory functions.

To prevent or stop respiration related problems, various techniques for teaching breathing skills have been developed, utilizing both biofeedback measures and behavioral techniques.

Usually a limited number of biofeedback sessions is required to teach the patients how to control their respiratory behavior, however, since we can be aware of our own breathing without instrumentation, much of the techniques can be rehearsed later on an individual basis without any help from the biofeedback device.

Respiration can be measured in many different ways. Among the most popular methods are; chest and upper abdominal mounted Hall effect sensors, strain gauges, even potentiometers (named pneumographs; fig.41). It is also possible to measure respiration with stethoscopes, nose or mouth-mounted microphones, and devices similar to inverted bronchodilators.

41
Respiration sensor
from Biocom Technologies

Signals and processing techniques in respiratory sensing vary greatly on the input device; however, they do have one important thing in common. The intervals between inhalations get prolonged and distorted if talking is present.

Biofeedback on respiration itself, or in combination with other forms such as; pulse oximetry or muscle tension biofeedback, is an extremely successful way to teach various relaxation techniques to those suffering from asthma, chronic stress disorders, and respiratory sinus arrhythmia.

2.2.2.3
Heartbeat

Human heart is one of the most important organs, and is at the same time an organ, over which we have very little actual control. In order for its state to change, our entire body must go through some sort of change physically or hormonally. It is known that our heart beat rate increases, while we exercise, and decreases, when we sleep or simply rest. It literally jumps if we get scared, shocked, or stressed in any other way. Through time it changes both very quickly and very slowly. So in order for our heartbeat to change, we must change, and we can do so willingly or not.

42
Heart rate monitor
from Polar

For instance let us examine the ubiquitous electronic athletic equipment. Chest mounted heartbeat monitoring belts (sometimes in combination with respiration but very rarely) are used to monitor athletes' physiological state (fig. 42). Based on the output of such a device an athlete can willfully decide whether they want to lower or higher the pace of their exercise. This kind of training is referred to as cardiovascular rather than biofeedback training. Prior to making conscious decisions on the pace of the exercise, athletes must familiarize themselves with various anatomical and physiological facts. While training they simply have to know at what pace they need to train so that they know whether their body is burning excess fat, training muscles, or is literally burning out.

43
ECG heart monigor
from FSI

Precise heartbeat measurements can be achieved in a number of ways. Next to stethoscopes and microphones the following two methods, accepted mainly for their simplicity, preciseness, and elegant way of fitting, seem to be most commonly used.

Electrocardiogram (ECG or EKG) is the first method and it is built on the principle of human body's conductivity (fig. 43). As the beating heart undergoes depolarization and repolarization, electrical currents are spread throughout the body. They are commonly measured with an array of electrodes placed on the body surface. Conveniently electrodes are placed on the end of limbs, or are mounted across the chest. Two types of ECG electrodes are being used lately, bipolar and unipolar. Bipolar set contains only two differently charged electrodes for measuring the polarity, on the other hand unipolar set contains more (usually 4-6) electrodes where one acts as a positive and the rest as a composite negative electrode. Being easier to implement bipolar sets are often used in the athletic equipment and other types of portable ECG devices.

44
Pulse oximeter
Biocom Technologies

Second, more mobile but slightly less precise method, is pulse oximetry (fig. 44). The principle of it is based on the red and infrared light absorption of oxygenated and deoxygenated hemoglobin. Hemoglobin filled with oxygen absorbs more infrared light and allows more red light to pass through it. Deoxygenated (or reduced) hemoglobin acts the other way around, absorbing the red light and letting infrared light to pass through it. According to this principle pulse oximeters are built in a standard manner. A light emitter with a red (sometimes in combination with infrared) LED is placed on the top of a reasonably translucent site with a good blood flow (typically over a finger, toe, or pinna (earlobe). On the opposite side of the site a photodetector or a photoresistor is placed. It serves as a receiver of the light passing through the site. Measuring its resistance provides us with the heartbeat signals. Pulse oximetry is slightly more complicated to implement than ECG, since light emitter and the resistor, as well as the spot over which the pulse is being measured, need to be shielded from any external light.

As mentioned before heartbeat display is usually used in combination with other forms of biofeedback, most commonly with devices for monitoring respiration, galvanic skin response (GSR), or electromyogram (EMG). By practicing other biofeedback techniques or exercises such as; breathing or progressive muscle relaxation exercises, while monitoring their heartbeat rate, patients can learn by trial and error how to affect their cardiac state.

2.2.2.4

Emotional arousal

Measuring emotional arousal with the help of electronic devices is alongside excursions in measuring temperature change, is one of the earliest research areas in the field biofeedback. Over the later half of the nineteenth century investigators (Tarchinoff in 1890) became aware that skin resistance varied all over the body. Although at first dismissed, it was later established that galvanic skin response varies systematically with the state of psychological arousal and even with mental processing. Devices for measuring galvanic skin response are built upon the principle, that autonomic nervous system activity causes a change in skin’s conductivity. A good decade later Carl Jung, a renowned psychologist, established through his work that galvanic skin response is an objective way of tracking physiological arousal and a way of tracking sympathetic part of the autonomous part of the nervous system.

Galvanic skin response meter is among the easiest biofeedback devices to orchestrate. It consists of a simple electronic circuit, amplifier, and a set of (usually 2) electrodes that can be mounted on the fingers, wrists, etc. When a person's emotional state changes, their skin becomes more conductive, and by using the electrodes correctly, one can pick up slight variations in skin's conductivity over very short intervals (0.2 – 0.5 seconds).

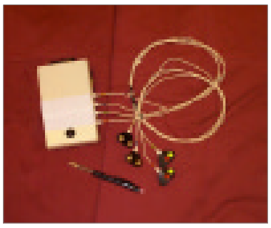
45
GSR meter
from Thought Technology Ltd.

Galvanic skin response sensing became increasingly more popular in the 1930's with the appearance of valve amplifiers. Once the psycho-galvanometer became easily available, the idea of measuring changes in emotional state was picked up with enthusiasm by criminologists. Further research led to the development of the polygraph also known as the lie detector. And with the birth of the polygraph the idea of cheating it became increasingly popular, leading mind related biofeedback research in using psycho-galvanometer in connection with meditation and relaxation in the 1970's.

The use of galvanic skin response feedback remained relatively the same to date. Although it is being used primarily as a relaxation technique, it is also used as: a technique to treat excessive sweating and other related dermatological conditions, a desensitization technique, and as an anger or stress management technique.

2.2.2.5
Muscle tension

Since its appearance in the late first half of the 20th century, electromyography, a way of monitoring electrical activity in neurons that control muscle tissue, has changed relatively little. Its primary use, that is rehabilitation, remains the same to date. The first prominent introduction of electromyography happened when in 1948 Kegel has successfully presented his method for urinary incontinence. Exercises for bladder control based on the use of an electromyograph may have been the first medically accepted method of biofeedback training. Soon after medical researchers started using it in posttraumatic rehabilitation and muscle training in general.

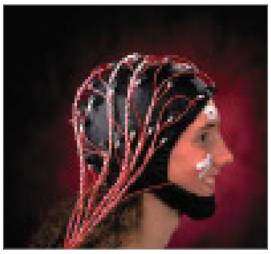


46
EMG electrodes and meter
from Team Ortopedteknik

Electromyograph (fig. 46) works on the same principle to that of the electrocardiogram described previously. When blood is rushed into the muscular tissue, changes in the polarity of the body are made almost instantly. For picking up such neural and muscular activity electromyograph uses detection and reference electrodes. Detection electrodes are placed between two motor (end) points of the muscle along its longitudinal midline, where muscle, if tense, expands the most. Reference, also named ground electrodes, are necessary for providing a common reference to the differential input, and are placed as far away as possible from the detection electrodes over a bony, electrically neutral tissue. For precise monitoring of the muscular activity it is very important that the electrodes are in a good contact with the skin. This is why they are rather large in size (normally 2cm x 2cm) and often a layer of conductive gel is placed between the surface of the skin and the electrode. Larger electrodes and conductive gel are used to lover the distortion levels of the noisy signal. Noise in the electromyography is consequential to all the friction that occurs during the muscular movement and the movement of the electrodes.

Measured and displayed with electromyograph muscular biofeedback training is among the most commonly used forms of biofeedback today. Electromyography is being used extensively in medical rehabilitation and in the field of sport, as a method of muscle training. In addition, it is also being used as a method to teach various meditation and relaxation techniques, particularly to those suffering from chronic or short-term stress, and intrinsic asthma.

2.2.2.6
Neural and brain activity



47
EEG electrode cap
from Med-Tech Systems, Ltd

Electroencephalogramic biofeedback got its start with the study of the alpha rhythm (Hans Berger, late 1920's), the rhythmic signal at about 10 Hertz, which appears in our visual cortex when our eyes are closed and the visual system is not very busy. This rhythm can be seen as the idling rhythm of the visual system. The results of the study were seen as controversial and were quickly forgotten.

Decades later, in his studies, Joe Kamiya successfully managed to demonstrate that altering of alpha rhythm was possible with the help of EEG. Kamiya's work further inspired research in related fields that led to interesting findings in monitoring of the brain activity. Today it is possible to measure various relevant types of brain waves or rhythms, among them: Beta (awake), Alpha (calm relaxation), Theta (light sleep), and Delta (Deep sleep).

Brain activity in microvolts is measured with the help of scalp-mounted electrodes (fig. 47). These are usually used in pairs and are mounted on the forehead, although experiments have indicated that brain activity can be measured all over the cranium.

For medical purposes electroencephalogramy (EEG) has been used since 1970 to trace brain activity and function deficit. In clinical psychology, EEG biofeedback is used to treat neuroses, epilepsy, insomnia, panic disorders, and attention deficit disorders.

2.3
Asthma, the life-long struggle

Asthma is probably one of the most common of all diseases. More people are being diagnosed with asthma daily, and it seems that air pollution and pollution in general are linked to it. Sadly most of the newly diagnosed cases are children. Statistics, taken from the National Asthma Campaign brochure, published in the year 2002 in UK, show that every 1 out of 8 children and 1 out of 13 adults is currently living with the condition. Statistics also show that children are more likely to require hospital care for their asthma than adults (NAC, 2002).

2.3.1

Medical facts

Asthma is classified as a chronic disorder involving a reactive airway. Living with the asthma condition means that patients' airway or airways, such as bronchioles or bronchi, occasionally become reduced in size or blocked when they react to certain triggers. The bronchial tubes can spasm, excess mucus can be secreted, or the mucosal membrane lining tubes can swell. All of these reactions can block a patient's airway.

Various kinds of asthma conditions exist, ranging from mild, to moderate, and even severe cases of asthma. Signs and symptoms of mild asthma include coughing, shortness of breath or wheezing after exercise or suffering from those symptoms once or twice a week without exercise starting them. Moderate asthma includes symptoms like shortness of breath, trouble breathing while resting and increased respiration rate. Moderate asthma attacks can last for several days and occasionally need to be treated with some sort of medicine. Severe asthma usually results in obvious wheezing and respiratory distress, and low blood oxygen levels.

Medication can be taken to reduce the inflammation in the patient's airways to prevent or reduce the allergic-type reactions that cause the swelling. If respiratory failure occurs, a mechanical respirator or inhaler drugs may be necessary to help the patient recover from the attack.

There are two distinct types of asthma know today – intrinsic and extrinsic. Extrinsic asthma is caused by the factors from outside the body. Triggers often include dust particles, animal dandruff, pollen, mold spores, air pollution, candle soot, fumes from cleaning products, and cigarette smoke. In order for the patient's health to stay stable, these triggers must generally be avoided in order to prevent an extrinsic asthma attack.

Intrinsic or idiopathic asthma is caused by internal factors, not allergens. This type of asthma usually begins after a severe infection in a respiratory system is tract, but triggers also include: stress, fatigue, extensive exercise, hormonal changes, heat, humidity, and other environmental changes.

However the distinction between intrinsic and extrinsic asthma is rather controversial, it is not completely clear that there actually are individuals whose asthma is completely unrelated to a certain type of allergy. (Siegfried, 2002)

2.3.2

Asthma and the children today

Asthma is three times more prevalent in children than any other kind of long-term respiratory disorder. Among adults today, the deterioration is particularly marked among those who first experienced asthma symptoms as children, pointing to the importance of early and effective intervention.

To date, there is no specific clinical test for diagnosing asthma in general in the early childhood. Doctors mostly rely on the treatment as their primary aid to diagnosis. And even when an asthma diagnosis is confirmed, symptoms may change over time. Most of the times children can be diagnosed for extrinsic asthma with the help of allergy tests, where they are injected with a small amount of allergen and their reactions to it are measured, in contrast, intrinsic asthma is much harder to identify.

To truly confirm the diagnosis the doctors need to know the child and the family history as well, as they need to monitor the child's progress through a longer period of time.

Over the years various self-care techniques and exercises have been developed in order to help children prevent and control their asthma attacks. These are thought to the patients when young and are often practiced by them through their adult life (Safarino, 1997).

2.3.3

Biopsychosocial factors in asthma

Although medical advances have greatly improved asthma treatment in recent years, it has been clear for some time now that the symptoms of asthma result from both; psychological and psychosocial processes (Safarino, 1997). The asthma condition is best understood by incorporating a biopsychosocial perspective in which biological, psychological, and social factors in patient's life are influential.

As a result various psychological techniques, ranging from relaxation, biofeedback, to systematic desensitization have been developed in addition to medical treatment, in order to lower the patients' medication use and at the same time lower the frequency and the severity of asthmatic episodes.

2.3.2.1

Biological factors in asthma

During asthma episodes airways become narrow because they become inflamed. The smooth muscles of the bronchial tubes develop spasms, and walls of the tubes constrict to produce mucus, which tends to plug the airways (Salvaggio 1981; Sinder, 1985).

These events are produced by the arousal of the autonomic nervous system at the start of and during an episode in reaction to one or more triggers that differ from one patient to the other. Triggers commonly include airborne allergens, physical activities, emotions, and moods (Cropp, 1985; Carrieri & Hudes, 1986). During an episode a series of chemical reactions take place allover the patients' body resulting in both muscle constriction and secreted mucus.

Development of asthma can also be caused by a serious of lung infections, lastly genetic and environmental factors that can rarely be influenced play substantial roles in asthma development.

2.3.3.2

Psychosocial factors in asthma

Various kinds of evidence, ranging from interview data to comparative studies, shows that stress and emotion alone can trigger asthmatic episodes. Because emotions and stress arouse the autonomic nervous system, they may produce the initial symptoms in an asthma episode or aggravate existing symptoms (Clarke, 1982; Schonell & Erskine-Millis, 1981; Spevack, 1978). Long-term stress can produce a longer period of increased respiration; on the other hand, short-term stress causes a temporary decrease in respiration. Despite some inconsistency in the evidence, most research supports a role of emotions in asthma and suggests that emotions can trigger or can make asthma symptoms worse. Lehrer, Hochron, and Isenberg (1993) have described that both asthma and emotion involve activation of the autonomic nervous system via the vagus nerve and suggested that emotion accompanied by the autonomic responses and vagal activity leads to respiratory resistance.

2.3.3.3

Cognition and asthma

The role of cognition in asthma suggests that cognitive processes may affect asthma episodes. Studies have shown that asthma symptoms can be induced by suggestion under placebo effects. Luparello, Lyons, Bleecker, in 1986 experimented with placebo inhalers and the patients showed signs of improvement.

In a different study patients were told that inhalers would worsen their breathing, so even though they inhaling pure water, they have showed respiratory resistance; Butler & Steptoe, 1986.

Studies demonstrating that emotion and suggestion can serve as triggers of attacks clearly implicate learning processes in the expression of asthma symptoms.

While analyzing cognition and asthma Lehrer, Isenberg, and Hochron (1993) produced evidence that showed that a distinction between large and small airways is important. Small airways may be more strongly influenced by activity in the sympathetic nervous system, and the large airways may be more affected by the parasympathetic nervous system and the person's current emotional state.

2.3.4
Asthma and biofeedback

Asthmatics, trained with biofeedback to increase their inhalation volume, report fewer emergency room visits, a lowered need for medication, and decreased instance of wheezing attacks. By learning how to adjust their inhalation volume they learn to control their breathing and continue to function normally even when wheezing attacks occur.

Throughout the last 40 years multiple alternative methods for treating asthma were proposed and tested. Ranging from respiratory biofeedback, systematic desensitization, to relaxation techniques using biofeedback devices, some of them were found to be more effective, some less. The following findings briefly illustrate various biofeedback methods or techniques that were developed to date, how they work, and why they are effective.

Most of the work described included psycho-educational training, next to the biofeedback training, and was generally designed to teach the patients to understand the disorder, cope with stress more effectively, and apply breathing and relaxation exercises when necessary.

Research also shows that self-care training and increased body awareness result in effective coping with the attacks. A meta-analysis pooling the results of research across all these methods confirms their value in treating asthma (Devine, 1996; Sarafino, 1997).

2.3.4.1
Findings in muscle relaxation biofeedback

Relaxation techniques are activities that enable individuals to reduce their levels of psychological and physiological tension or arousal. Emotion can play a substantial role in producing or aggravating asthma episodes. Researchers have examined the effectiveness of relaxation methods for helping asthma patients to reduce tension and anxiety. The main reason for using relaxation techniques in treating asthma, is to help patients achieve "diminished parasympathetic reactivity and therefore reduced bronchoconstriction of at least the larger upper airways" (Schwarz, 1995). Relaxation methods focus either on muscular on non-muscular involvement in producing relaxation.

One of the simplest and the most commonly used relaxation techniques in asthma treatment is called progressive muscle relaxation. It involves having patients sit or lie quietly and focus their attention on specific muscle groups while alternately tightening and relaxing these muscles (Safarino, 1996)

Alexander, Miklich, and Hershkoff (1972) have noted in their studies that having a patient sit quietly during an asthma episode helped to reduce wheezing. In addition to these results Alexander has also reported that relaxation technique worked much better on the subjects who reported having had attacks that were precipitated by emotional factors.

Philipp, Wilde, and Day (1972) also explored asthma treatment through relaxation training and have reported that the result data suggested that intrinsic asthmatics may have benefited more from relaxation training than did the extrinsics.

Later in 1987 Freedberg, Hoffman, Light, and Kreps reported that after a one month long progressive muscle relaxation training subjects were able to recall how to relax on their without a monitoring device being present. They have also concluded that patients suffering from moderate to severe asthma will receive the greatest benefit from treatment with progressive muscle relaxation.

However, relaxation techniques also include other ways of arousal reduction besides progressive muscle relaxation described previously. These are called non-muscular, or mental, or cognitive approaches for achieving relaxation. Most of them include some sort of meditation and tuning or listening to the bodily rhythms. Most techniques are practiced with the help of a monitoring device.

The results cited indicate that relaxation exercises can be a useful technique for treating asthmatic children and adults, especially if emotions play a strong role in triggering or worsening the attacks. In order for the autogenic training and relaxation techniques to work, patients must be trained to apply them in times of stress, especially as an asthmatic attack begins.

2.3.4.2

Findings in respiratory biofeedback

Providing feedback regarding airflow or simply monitoring chest movement is termed as respiratory biofeedback. Numerous studies (Staerk, and Bonk, 1973; Kahn, 1977; Vachon, and Rich, 1976; Janson-Bjerklie and Clarke, 1982) have shown that the utility of respiratory biofeedback training in treating asthma is a relatively effective approach. Respiratory biofeedback methods usually include simple physical exercise, relaxation training, or inhalation and exhalation monitoring, and are practiced over longer periods of time. Treating asthma with respiratory biofeedback methods enhances patients’ ability to control bronchodilation by teaching them to discriminate airway resistance.

Disconfirming reports also exist and from them it is evident that biofeedback can be an effective treatment for certain subgroups of asthmatics (Jurenec, 1988). One factor that may help to explain some inconsistent results regarding the effectiveness of respiratory biofeedback in treating asthma is the age of the subjects. Most of the studies that have shown support for using biofeedback in treating asthma have used children as the test subjects. Interestingly most of the disconfirming studies have used adults as the test subjects. Attanasio, Andarsik, Burke, Blake, Kabela, and McCarran (1985) have provided evidence indicating that children show faster and greater improvement than adults in their self-regulation or physiological processes with biofeedback training. Factors such as; greater enthusiasm, confidence in the biofeedback procedures, physiological liability, ability to succeed and control their physiological functioning makes biofeedback of respiratory behavior more effective when introduced in childhood rather than in adulthood.

2.3.4.3

Findings in non-respiratory biofeedback

In their studies Budzynski and Stoyva (1969) have noted that the use of biofeedback in order to reduce muscular tension in the frontalis muscles of the forehead seemed to produce generalized relaxation in their subjects. The goal of similar experiments and studies was to help patients' control the emotional factors that trigger or aggravate asthma episodes. In later years it was proven that reducing facial muscle tension alters vagal activity and consequently decreases airway resistance.

In 1976 Kotses, Glaus, Crawford, Edwards, and Scherr experimented with non-respiratory biofeedback. During the training sessions children in an asthma camp were asked to lower the voice they heard through the headphones. They had to do so by relaxing the frontalis muscle which tension was measured through a set of forehead mounted electrodes. Later children were asked to act as they did in the training sessions if an attack occurred. In only a few weeks visible improvements in attack control were noted.

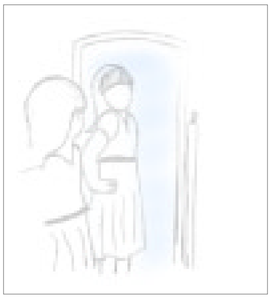
The studies by Kotses and others provide evidence that non-respiratory biofeedback (EMG or EEG) training can improve respiratory function in asthmatic children, at least temporarily.

Systematic desensitization is another important technique in asthma treatment and attack prevention. It is a technique where a patient is distracted during or prior to the attack. Systematic desensitization is an alternative technique to biofeedback that uses mostly visual and auditory stimuli. It is proven that systematic desensitization techniques work better with patients who suffer from intrinsic asthma and in cases where patients suffer from large airway obstruction and strong emotional influence (Moore, 1965; Milkich, Rene, Creer, Alexander, Chai, Davis, Hoffman, 1977; Yorkston, McHugh, Brady, Serber, 1974; Safarino, 1997).

2.3.5

Relevant examples of asthma oriented biofeedback

One of the simplest biofeedback techniques in asthma treatment is the mirror technique (fig. 48). It is taught to children with medium to severe cases of intrinsic asthma around the world at a very early stage in life. The children are asked to stand in front of the mirror, breathe in and count to 4, and then breathe out and count to 6. At the same time children are also told to relax their shoulders and the chest muscles. While performing this exercise for some time, children and parents participating in the exercise, are able to see their jaw lower and facial muscles relax. If this technique is practiced correctly over a longer period of time, usually a month, the children are found to be better prepared to deal with asthma attacks as they come. The severity and the frequency of the attacks can be reduced greatly as they learn how to control their respiratory behavior and avoid hyperventilation



48
Mirror feedback technique

A search for various asthma related biofeedback devices or software pieces has revealed that most of the software is written purely for medical or explorative purposes. Usually these games are only a mask over complicated biofeedback devices and are designed to simply hide the complicated biofeedback equipment from the children. Educational games in combination with sensors that pick up bodily signals are a recent addition to the fields of entertainment and biofeedback.

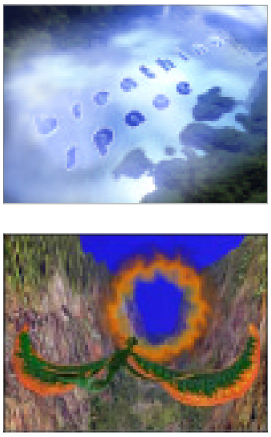
49
Tetris 64
Amtex, 1996

Amtex, a Japanese company, has developed a modified Tetris game (fig. 49) in the late 90s that was one of the first commercial console games to use biofeedback. The Nintendo 64 game, which was sold exclusively on the Japanese market, responded directly to the player’s biorhythm. This multiplayer game was sold together with a custom made device that served as a sampling device for oximeter clips. The oximeter clips were used to pick up the players’ heartbeat rate, which was used as an additional source of input to the game. As players became more nervous during the game play, their heartbeat rate increased and the pieces started to drop faster. The goal of the game was to stay relaxed while playing, and score as many points as possible in this intense multiplayer environment.

50
Hand Held Doctor
Vadim Gerasimov, 1997

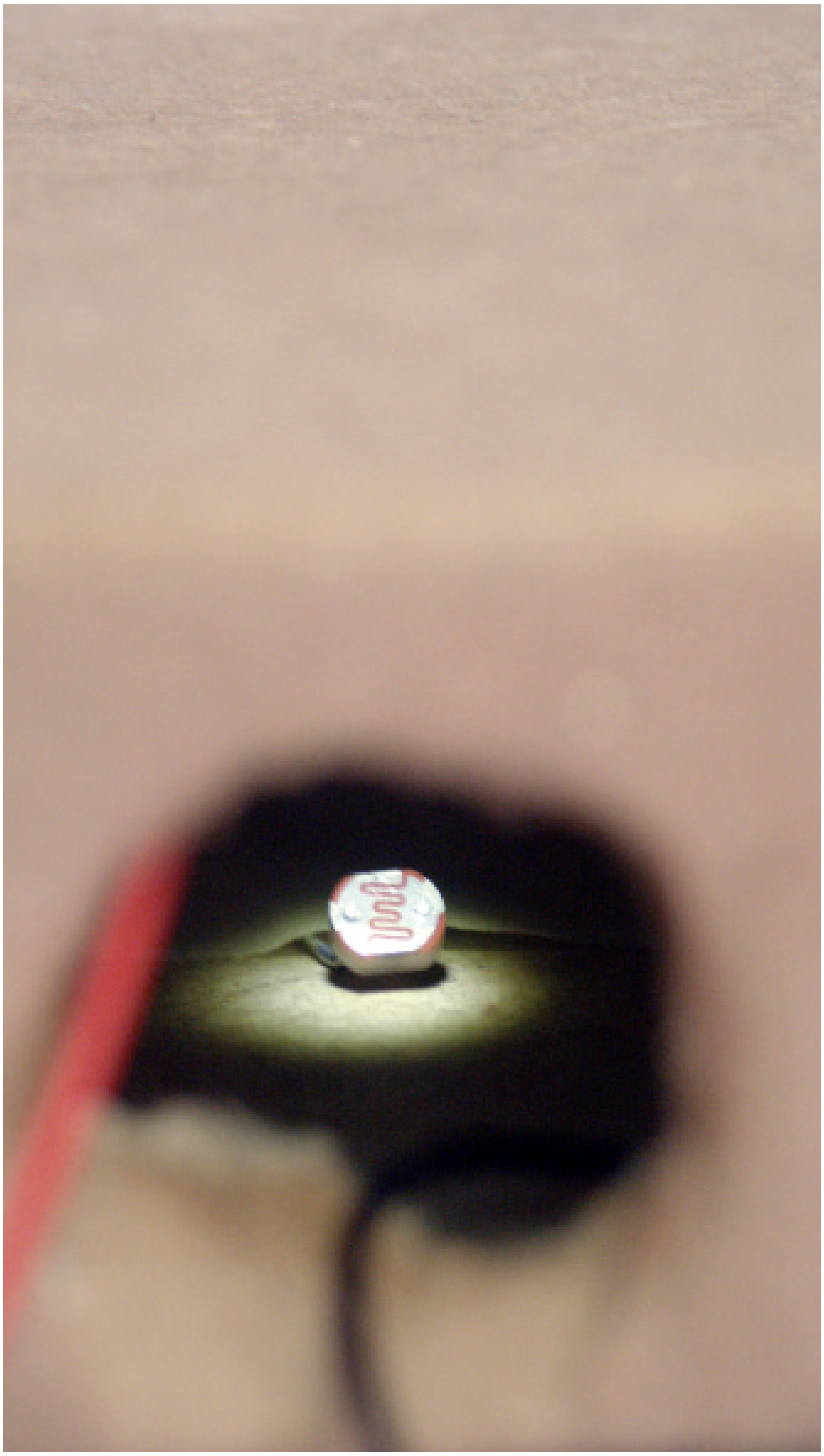
Among the most thought-provoking biofeedback related explorations of merging entertainment and biofeedback is undoubtedly the Hand Held Doctor project done by Vadim Gerasimov from MIT Media Laboratory. The project introduces a playful approach to biofeedback and body monitoring. In his studies Gerasimov uses game-like computer animation and robotic toys to represent body-data to children.

Newly founded Mindgames group, a part of the Media Lab Europe, is also investigating the possibilities of combining biofeedback techniques with video games and learning. Among many games developed a recently developed game titled Breathing Space (fig. 50) is the most relevant to this thesis. The player's diaphragm is constantly being monitored and the goal of the game is to force the player to relax. The player is asked to fly a dragon through a virtual environment using only his respiratory functions as a source of input to the computer game. As noted on the Mindgames website, deep breathing exercises, carried out when playing this game, can help children relax as well as restore their sleeping patterns.



51
Breathing space
MediaLab Europe
Mindgames Group, 2003

52
Oxymeter clip



Design and Implementation

To explore the hypothesis that fun and playful body monitoring devices are more effective in alowing people understand their disorders than established biofeedback systems, it seemed natural to design and produce a series of sensors for body-data acquisition, a device for interfacing them, and a device that would enable mobile, body-engaging game play. The following sections illustrate the design and implementation process of the Asthma Buster prototype, and the Bloop! video game.

3.1
Combining biofeedback, computer games, and asthma

53
Children at an Asthma Camp
www.corbis.com

The preceding chapters of this document indicate that the most relevant physiological factors for asthma related biofeedback techniques are: respiration speed, pulse rate, galvanic skin response, and muscle tension.

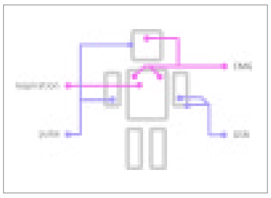
Feedback on muscle activity is typically used to communicate the level of stress to the participant in the biofeedback session; however, the level of stress can also be communicated through feedback on heartbeat, respiration, or galvanic skin response. At the same time, electrodes for measuring muscle activity normally involve the use of conductive gel. These findings have convinced me to discontinue investigating the use of EMG in the process of designing the Asthma Buster.

As the information presented in the Background section indicates, biofeedback techniques in asthma treatment work better with children, as they are more open to this way of training than adults; for this reason I set off to design for this very specific audience.

Staying at many asthma camps (fig. 53) when I was a child, made me aware of the importance that exercise plays in lives of those children suffering from asthma. While visiting them, I remember practicing breathing exercises, presented through play, every morning. Therefore I have determined that Asthma Buster should be as unobtrusive, portable, and as playful as possible. It should not in any way keep the children from moving or exercising.

Frustrated with the current state of the entertainment devices, I set to explore the most promising body-engaging computer game field, the wearable computing.

3.2
Designing for active play

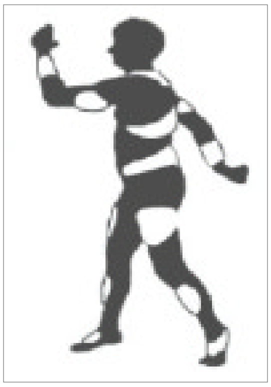


54
Biosensor positioning map
Jan Raposa, 2003

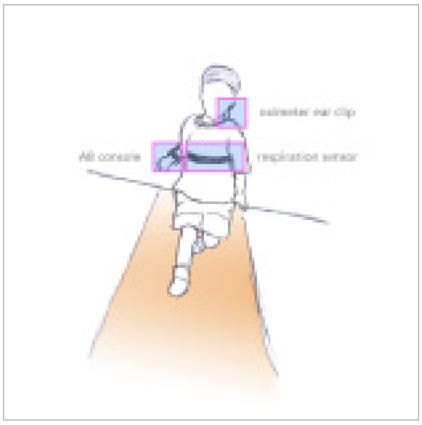
To better understand the design constraints posed by the devices for bio-data acquisition, I have developed a map of areas where relevant sensors can be placed (fig. 54). As the map illustrates, all the physiological functions can be monitored above the waistline. In order to make all the necessary sensors as unobtrusive as possible, I believe they need to be sown in to wearable garments such as jackets or tight T-shirts. Although heartbeat and respiration can be monitored with one chest—mounted device (as the pulse/respiration monitors from the Polar Company illustrate), I have for prototyping purposes decided to use pulse oximetry, rather than EKG, as it is much easier to orchestrate.

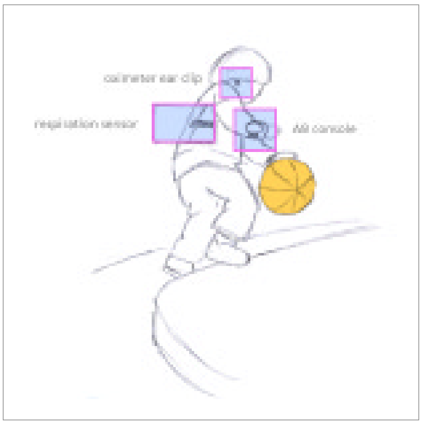
Studying the wearability map from BodyMedia, Inc. prefered the wrist worn console concept (fig. 55). Ideally, the console would be made removable, as interacting with a wrist mounted computer game seems rather awkward. Once removed, the console would use radio connection to communicate with the sensors. In order make the game play and the device feel as intuitive and simple as possible, I have decided to implement a tilt interface for playing the game rather than button controls.

The following sketches and renderings explore sensor fitting and device design possibilities.



55
Wearability Map
BodyMedia, Inc., 2001

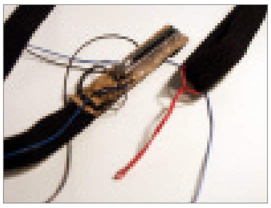




3.3
Building the Asthma Buster platform

To explore the qualities of small screen gaming devices I have used the existing commercially available technology. The Asthma Buster console is a modified GameBoy Advance (GBA) portable game console from Nintendo. This platform was selected for its low price and relative ease of use. GameBoy Flash Advance Linker and GBA flash cards from Visoly Inc. were used to store and run the developed game on the device. The developed sensors are connected to the GBA through a simple electronic circuit controlled by Basic Stamp 2 (BS2) micro controllers from Parallax. Inc. The following pages describe the development of the platform in detail.

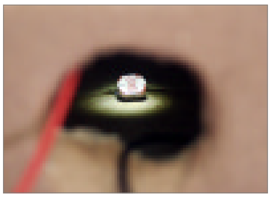
3.3.1
Respiration monitoring



56
Respiration sensor

This simple chest mounted respiration sensing element was made from very basic materials (fig. 56). A used backpack strap, elastic rubber bands, cardboard, hot glue gun, stapler clips, wires, and a simple potentiometer were used to create the sensor. The rubber bands are used to keep the potentiometer in place. As the player breathes in the rubber bands stretch and the potentiometer moves. The movement of the potentiometer is picked up and processed by the BS2 micro controller. As the player breathes out, the rubber bands force the potentiometer back into its original position. The sensor has turned out to be more efficient at monitoring the upper abdominal region expansion then at measuring chest (torso) expansion due to its relative insensitivity.

3.3.2
Heartbeat monitoring



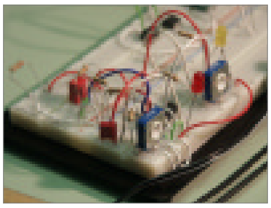
57a, 57b
Cardboard box and ear clip pulse oximeters

Designing a sensor to monitor the heart activity turned out to be a slightly more difficult task to complete, than designing a respiration sensor. The sensor (at first an equivalent of an oximeter finger clip) itself was rather simple to make. The major issue was hiding the extra bright red LED and the photo resistor from an external light source. To do so, I simply mounted the components in a small cardboard box (fig. 57a).

The complicated part of the design was monitoring the photo resistor's activity. A circuit diagram was borrowed from Keith Wilson and redesigned to fit the purpose. As the redesigned diagram illustrates, a photo resistor picks up the level of the red light that passes through an inserted finger. The signal is then amplified with the help of a standard LM358 operational amplifier, trimmers are used to adjust the sensitivity and the trigger level of the circuit.

The output from the circuit results in a high or low state, depending on the level of oxygenated hemoglobin in the finger or in the earlobe (fig. 58).

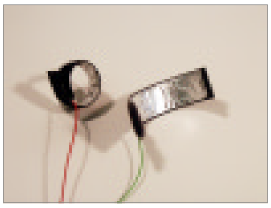
Later during the prototype development I successfully replaced the developed oximeter with a standard commercial oximeter ear clip (fig. 57b). Technically the only difference between the "homemade cardboard—based" finger clip and the manufactured ear clip is that the ear clip uses infrared light. Design—vise, the ear clip is a much better and portable solution.



58
Oximeter circuit

3.3.3
Galvanic skin response monitoring

The finger mounted galvanic skin response electrodes were made from Velcro tape, aluminum foil, wires, and staple clips (fig. 59). The resistance of the skin was measured with the help of a simple electronic circuit, powered only by 1.5V, mostly for safety reasons. While experimenting with the electrodes and measuring the resistance levels of my skin, I quickly realized that the changes in GSR are relatively slow. If processed correctly, the change in respiration and heartbeat rate can also indicate stress. This is why I decided to stop exploring GSR, as a source of input, and have excluded it from the final prototype design.



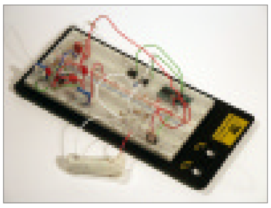
59
GSR electrodes

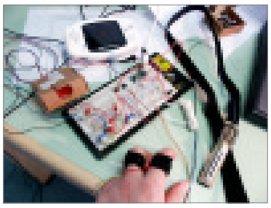
3.3.4
Signal processing and sensor—console communication

Two BS2 micro controllers individually monitor the sensors. Monitoring respiration is quite trivial, a micro controller and a very simple electronic circuit is used to simply assess the level of the potentiometer's resistance. By processing the resistance level, inhalation and exhalation can be detected.

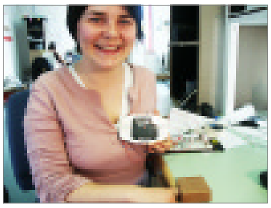
Monitoring the oximeter clip turned out to be slightly more complicated. The previously described circuit, when calibrated correctly, provides the BS2 micro controller with relatively clean digital signal (hi-low state), which is sampled at a 1000Hz. As the signal state changes from low to high, the sampling is simply paused for a few milliseconds to eliminate the bounce—back effect; later on the sampling is resumed.

After the body—data is processed, the BS2 micro controllers use standard 4N35 phototransistor optocouplers to communicate it to the GBA console. These components are used to simply "press" the buttons on the GBA console when heartbeat or breathing is identified. A function for monitoring these "button presses" was later incorporated in the developed game (fig. 60a, 60b).



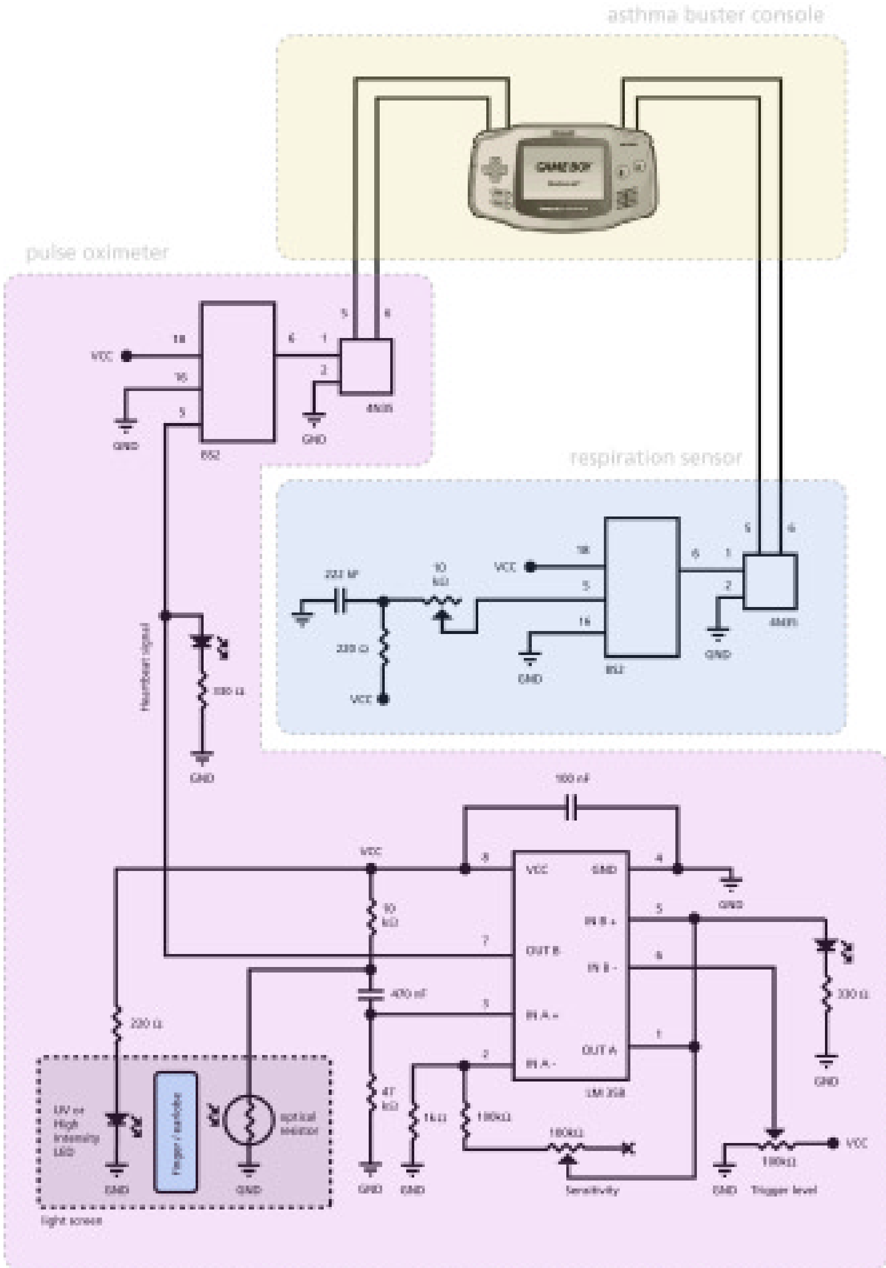


60a, 60b
Asthma Buster control board



61
The first system test

After the Asthma Buster platform (fig. 62) was completed, I wrote a short software piece to test it. As the heartbeat was picked up by the finger-mounted oximeter clip, processed and sent to the GBA in a previously described manor, the GBA intercepted these "button presses" and displayed an animation of a pulsating heart on the screen. The very first user test resulted in a wide smile, as the test subject realized that the beating heart on the screen pulsated in sync with her own (fig. 61).

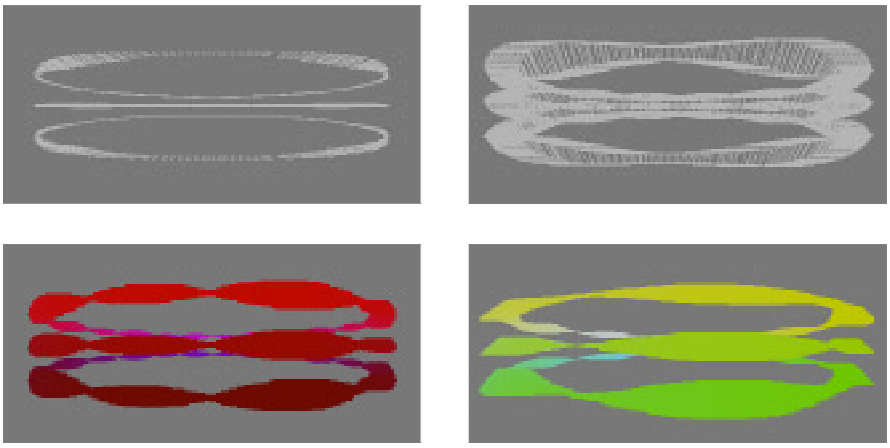


62
Asthma Buster platform

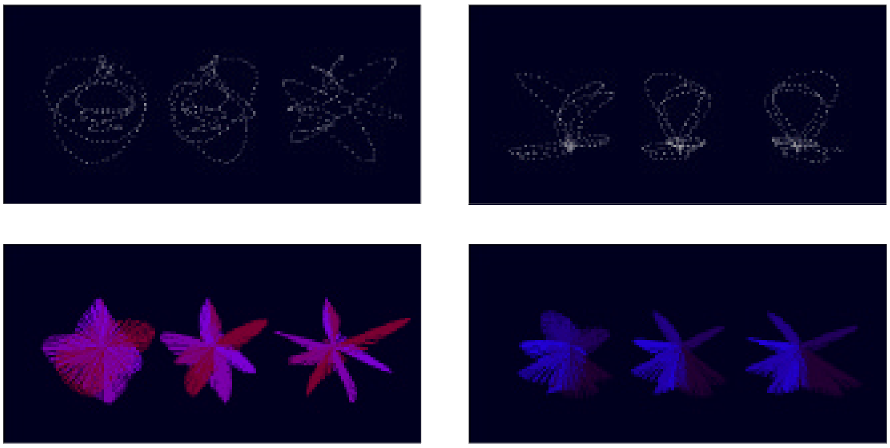
3.4

Visualization Explorations

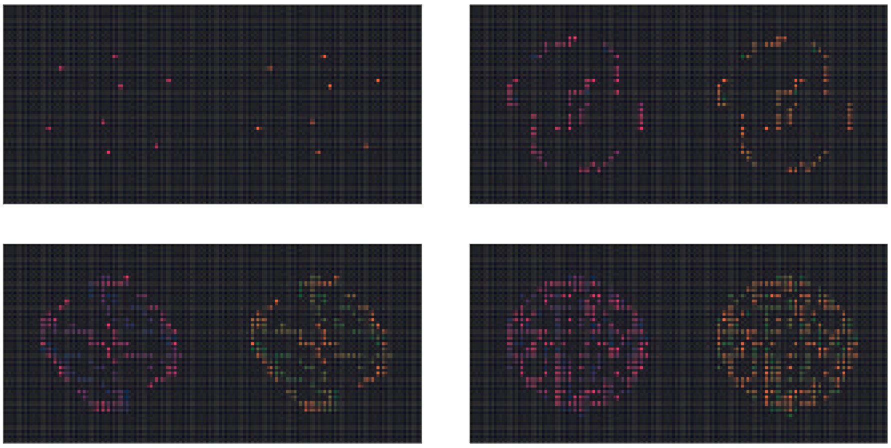
The following works presented are simple explorations of screen based form and interaction. Writing these short pieces of computer code was necessary in order to develop a greater understanding of the small screen medium, and to refresh my rusty programming skills, before moving on to the lower level languages, such as C++ and Assembler. The short pieces described were written in Processing, a Java based programming environment developed by Casey Reas and Ben Fry.



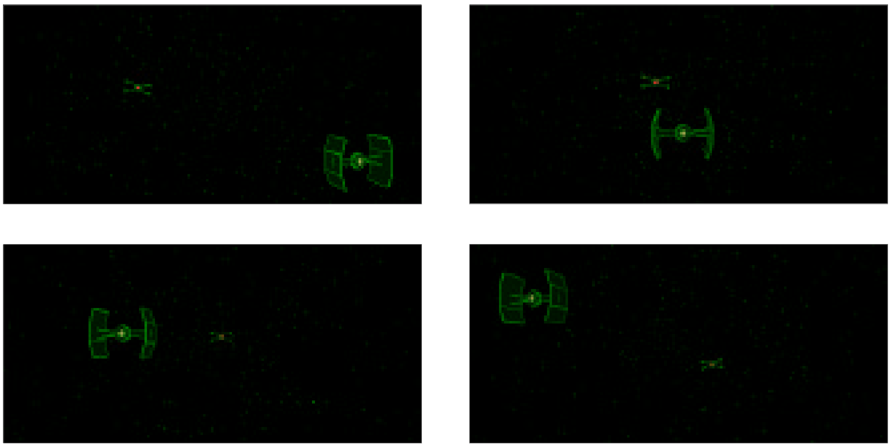
Tapeworms is a set of three individually colored circular bodies, constructed from a great number of squares. Constant sinusoidal scaling and rotation make these simple mathematical forms look vaguely life—like. Interaction with the applet through mouse movement and clicks changes the shape and colorization of the objects.



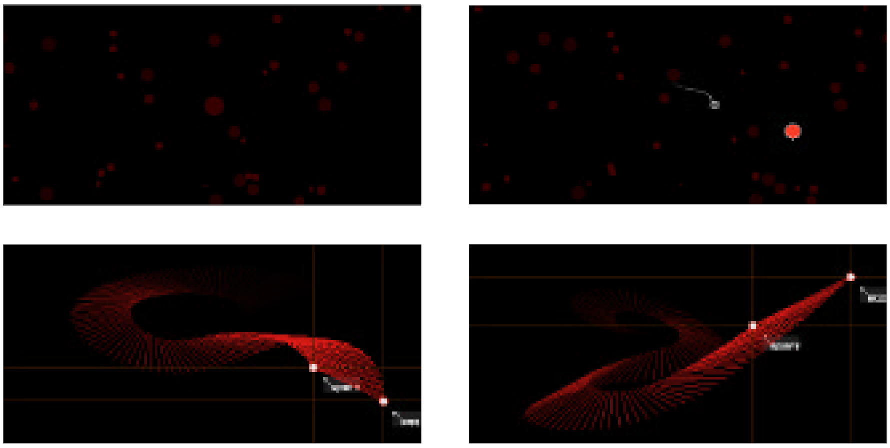
FlowerPower is a simple exploration of sinusoidal forms, movement, rotation in a three—dimensional space, and primitive shading techniques. Flowers' color, rotation, and petal position are mouse dependant.



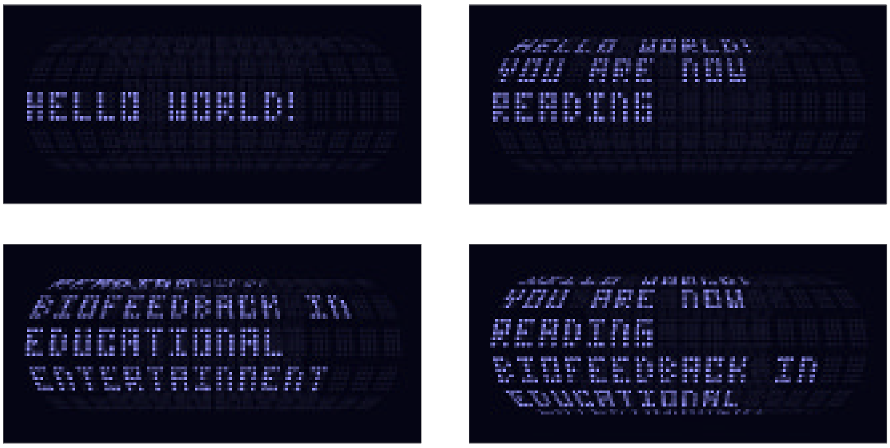
Sphere Illusion is a study of translation and rotation functions. Two cubes are simultaneously represented on the screen, each by a set of 8 corner points. As the interaction with the software piece happens, the cubes can be rotated. If the objects are rotated correctly, the corner points leave traces of color behind, which create circular and spherical impressions.



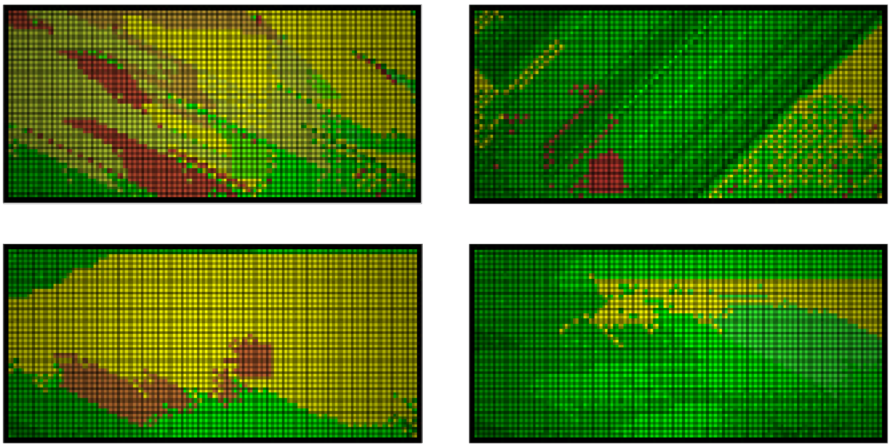
Return of the Empire is my homage to the Star Wars. This software piece explores the three—dimensional space, rotation, movement, dampening functions, and object oriented programming. Sadly I never had the time to finish the game, so the exploration remains simply a motion study.



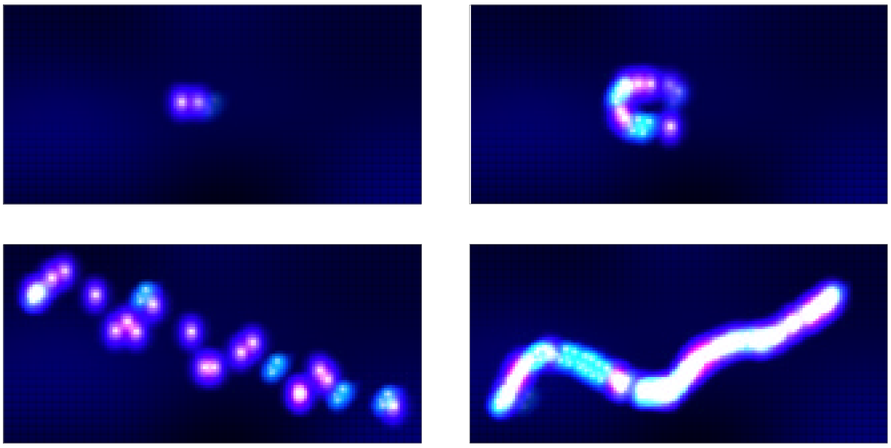
Egg Chase is an exploration of motion and tracking functions. The goal of this exploration is to move around the egg in order to avoid the insemination. With a click of the mouse a user can alter the visual representation of the mathematical rules, which are implemented in this visualization study. Although the main code remains the same, the visual representation of it is quite different.



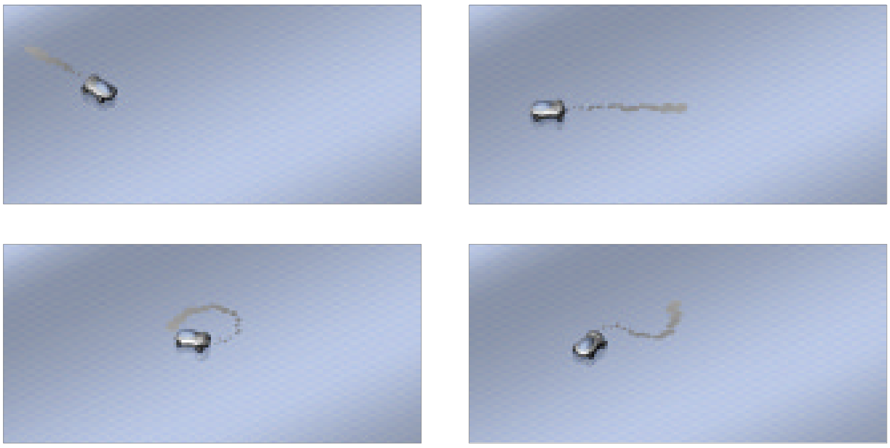
Text Tube is a simple text editor. It explores the advantages that a three—dimensional space has to offer to the display of textual data. The entered text is represented on the screen in a similar manner to that of a typewriter. When the user reaches the end of the line, the “tube” rotates so the text can be entered into the next one. After typing a few lines, the user can use a mouse to perform the “scrolling” action, which enables him to rotate the tube back and forward and view the entered text.



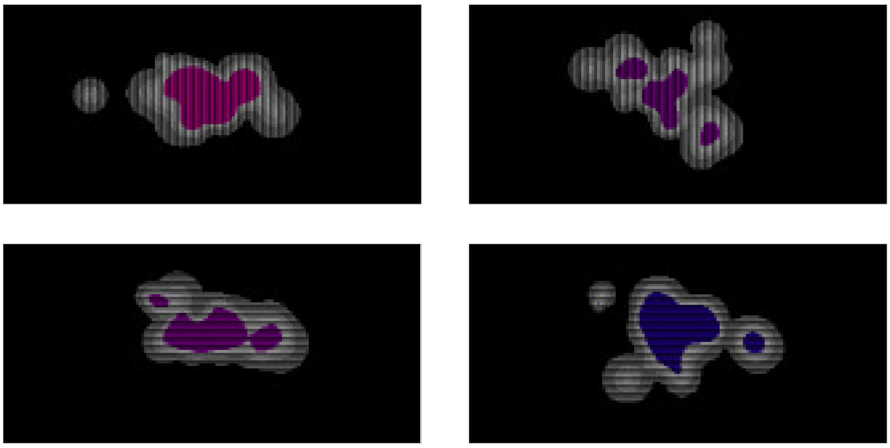
Ugly is a failed attempt to recreate the Conway’s Game of life. Even though I falsely implemented the rules of the game, the code resulted in an interesting visualization. Mouse input is used to interact with the system. The interaction results in colorful patterns similar to those known from the aquarelle painting.



Magic Stick is an exploration of pixel setting and double buffering. A mouse cursor is used to move the glowing flares around the screen. When the mouse buttons are pressed down, the flares leave trails around the applet area. Holding the buttons down for a longer time or dragging the mouse slowly, results in wider and brighter trails.



Ice Racer is simply an iteration of the Magic Stick. Slightly altered program code results in a playful, keyboard controlled, motion study of the isometric environment. The Ice Racer explores motion physics and bitmap graphics.



Funk Generator is a simple meta—balls study. To develop it I resorted to processing bitmap images rather than implementing complex walking square algorithms. Interaction with the visualization happens through mouse movement and clicks.

64a - 64f
Bloop! imagery

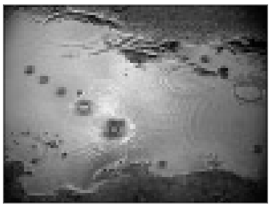
3.5

Designing and building the Bloop! game

Even though the goal of this thesis is to explore the potential of phisically—engaging computer games, wearable computing, and learning, it is not its goal to stimulate or monitor exercise in any way. The main focus is learning about the body from the provided physiological feedback; it is to create a playful digital equivalent of the mirror technique that is practiced by children with asthma.

Due to the design of the Asthma Buster platform, the player is required to keep relatively still during the game play, yet, this does not make the designed platform and the game any less body engaging. For instance, if the game is played after exercising, the player can easily monitor his physiological factors change over time, as he calms down.

As I learned from numerous conversations with friends, colleagues, relatives, interviewed children, and from my own personal experience, nature plays an enormously important role in lives of those affected by asthma. From asking which words they most commonly associate with the disease, I learned that air, sky, open spaces, water, sea, wind, animals, flowers, and trees tend to be the most reoccurring themes. This is why I decided to design a water theme game, as I believe that water is an interesting environment through which respiration can be presented (fig. 63).



63
Water
Jan Raposa, 2001

The Bloop! (fig. 64a-64f) game is a distant cousin of the Space Invaders video game, licensed in 1978 by the Atari Corporation. Here, the player plays a role of a fish (named Bloop), which is slowly followed around the screen area by the poisonous jellyfish. The goal of the game is to avoid the jellyfish and to eliminate them, by popping them with air bubbles, which are released by the Bloop every time when player's exhalation is detected. To avoid uneven or accelerated breathing, that might cause hyperventilation or dizziness, a control function, which monitors the respiration speed, is implemented in the game. The game simply stops if the player tries to breathe too rapidly. The speed at which the jellyfish move is relative to the speed of the player's heartbeat. In order to play the game for a longer time and reach a higher score, the player must learn how to control his breathing and how to keep the heartbeat rate low. I believe that a game designed in this way could function as an engaging and informative biofeedback training device. The speed and the action of the game can be customized so that they enforce propper-breathing techniques on the player. This playful yet rigid structure of the Bloop! game could potentially function better than merely reflective biofeedback exercises or non-goal oriented biofeedback games.

The elements of this bitmap heavy game were designed with bitmap manipulation (Photoshop) and illustration (Illustrator) tools from Adobe Systems Incorporated. The Bloop and the jellyfish were designed and rendered in 3D Studio MAX (from Discreet / Autodesk, Inc.).

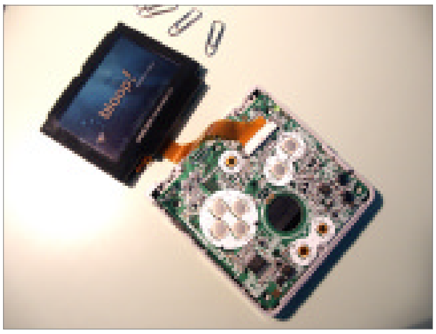
The game was developed in the Visual HAM, a visual C++ programming environment developed by Peter Schraut. To complete the game, various libraries provided with the VHAM were used to display and animate the game sprites, set backgrounds, and monitor key presses, as they have attested to be significantly faster than the ones we have developed. The attempt to enhance the gaming experience with a selection of under—water sounds has failed due to the lack of processing power that the GBA has to offer. The game turned out to be extremely demanding on the processor because of its large sprites and bitmap animation. After the game was completed and tested on the emulator, it was compiled for the GBA's ARM processor and uploaded to the Flash Extreme cartridge, which was subsequently used by the GBA console to run the developed game.

3.6
Building the Asthma Buster console

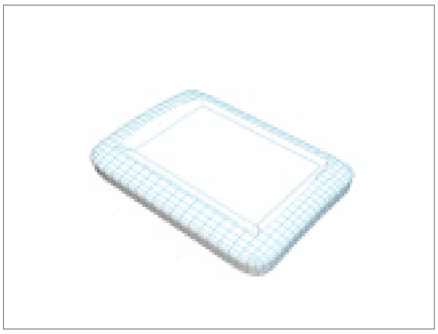
To explore the qualities of a wearable wrist-carried gaming device I selected to use the GBA SP handheld console. When working on this project, the GBA SP was the only commercially available and straightforwardly programmable device with a relatively small high-resolution color display (fig. 65).

After I removed the 2.9” TFT screen from the console I cleaned all the excess plastic from it. Based upon the dimensions of the display, I designed a fairly simple CAD model of the cover, which would hold the removed display (fig. 66). The cover was designed in a way analogous to the design studies presented in the Designing for active play section. (fig. 67). It was later produced from CibaTool, an advanced vinyl ether/acrylate-based resin material and fitted over the display (fig. 68).

Since the GBA SP display cable is no longer than only a few centimeters and as there is no way of prolonging it, I determined that it was best to present the Asthma Buster console concept by creating two visually identical models. Thus, one model was used to explore and study the Asthma Buster console as a game display device; the other model was used to study the tilt interface to the game and to explore the physical and portable qualities of the object (fig 69).



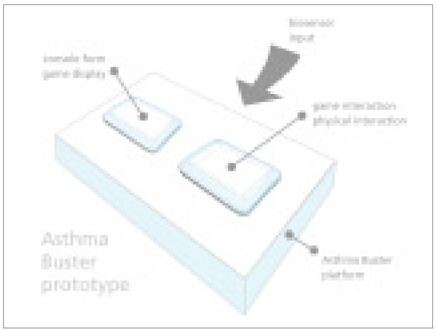
65
GBA SP opened, running Bloop!



66
CAD model of the Asthma Buster console

67
Asthma Buster console concept

68
CibaTool-based shell



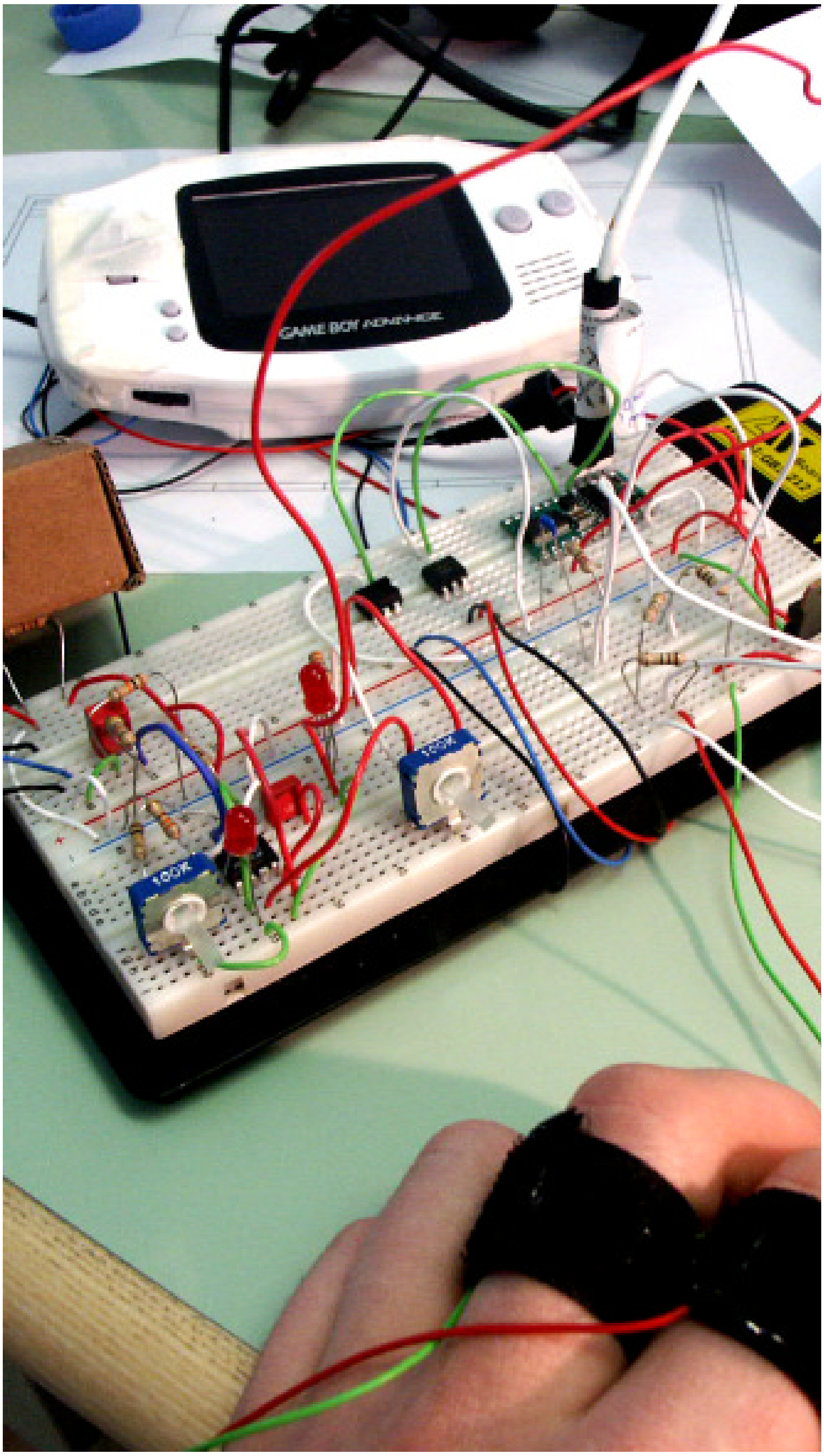
69
Presenting the Asthma Buster concept

70
The Asthma Buster console

The first console (fig. 70) was mounted on top of a foam core platform that contained all the necessary electronics to run the game (GBA-SP console, the Bloop! game cartridge, and the biosensor control board). The second console was made removable, as free movement was necessary to study the embedded tilt interface.

Although the Asthma Buster concept suggests that relevant biosensors should be embedded into wearable garments, the prototype was, mostly for technological restrictions, designed in a different way. The objective of the developed prototype was to study the biofeedback approach to computer games, rather then explore wearable computing in depth.

70
Asthma Buster platform
(early version)



Discussion and Analysis

This chapter discusses the suggested approach to biofeedback and educational entertainment, by studying the interactive qualities of the developed platform, console, and computer game. Alternative uses of the presented concept are explored, and the possibilities for its commercial applications are investigated. The Asthma Buster concept then is compared to some of the relevant works in the field of interaction design, and at the end of this chapter future steps of the project are introduced.

The environment in which this project was undertaken has not permitted me to suitably analyze the developed prototype. In order to determine the significance of the proposed concept I believe that the platform and the game should be systematically tested by a group of specialists from relevant fields such as: medicine, affective and wearable computing, human factors, and edutainment over a longer period of time.

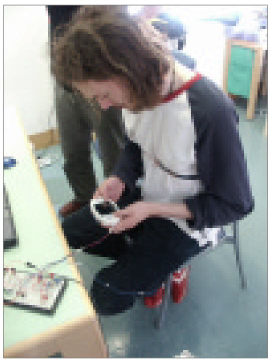
Being limited to the domain of the interaction design I believe I am only fit to study the interactive qualities of the proposed concept and the developed prototype. The attempt to test the developed prototype with children was to my disappointment unsuccessful, mainly for bureaucratic reasons. Thus, I was forced to using my peers as the test subjects in an observation-based analysis.

4.1
Interaction

71
Studying pulse oximetry

From observing the users who have experienced the Asthma Buster prototype I have learned that the developed platform functioned well. The implemented oximeter clip (fig. 71) worked satisfactorily with the developed circuit, which gave out a relatively clean heartbeat signal. The major flaw of developed oximeter was that the electronic circuit had to be recalibrated for every user that tested the platform, as it was overly sensitive.

In contrast to the oximeter, the respiration sensor turned out to be rather insensitive, mainly due to the slow travel speed of the embedded potentiometer and the stiffness of the rubber bands used in the sensing element (fig. 72). For anatomical facts it also worked better on men then on women, as their upper body expansion caused by breathing is much greater. Even though the developed biosensors and the sampling devices were crude, the data that they provided were suitable for the exploration of biosensor affected computer games.



72
Studying respiration

To thoroughly evaluate the Asthma Buster concept in its relation to portability and wearability I believe that commercially available wearable monitoring devices, such as chest mounted pulse and respiration monitors should be implemented in the Asthma Buster platform in the future as they are sturdily built and are able to provide the processing unit with clean and filtered data remotely.

Studying the proposed wrist-worn console concept resulted in the emergence of numerous issues. Most importantly, the chosen Gameboy Advance (GBA) TFT display turned out to be simply too big (fig. 73) to implement in such a device. The developed casing for it is awkward to fit onto the players' wrist. To better explore the advantages that wrist-carried display devices offer I believe the Asthma Buster console should be redesigned with a smaller and higher resolution display in mind.

The GBA's display cable was simply too short to make the designed console freely moveable the game was tested on a standard biosensor and tilt switch equipped GBA console.

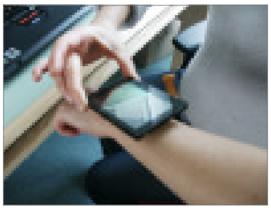
A side step in the prototype development, an exploration of the button-less interface to a portable computer game, was found very successful (fig. 73). Even though the display quality of the GBA console is rather poor (its screen is overly reflective) the users have described tilting the device (to move the Bloop around the screen) and shaking it (to change the state of the game) as a "cool" and "interesting" way of interacting with the portable computer game.

On the other hand, the heartbeat biosensor input was not found as engaging as I believed it would be. The input device worked fine and the users understood the relation between the movement of the jellyfish and their heartbeat, however, little attention was paid to the heartbeat-dependant movement of the jellyfish.

At the same time the respiration sensor did not work as smoothly as I have planned for. Although the users were able to make the Bloop blow bubbles they had to put a lot of effort into doing so. This observation confirms the need to implement commercial respiration sensing devices in the future versions of the Asthma Buster platform.

But to my surprise the failure of creating a faultless respiration sensing element has resulted in a very positive note. The players quickly realized that to blow bubbles they needed to exaggerate in their breathing. Although this fact could be potentially hazardous for asthmatics, it has confirmed my assumption that computer games are extremely motivating and possess the power to force the players into performing the desired tasks.

While observing the players interacting with the Bloop! game I have realized that the game itself is slightly too complicated. Even though the users described it as “fun”, it was also referred to as “difficult to play” or “hard”. I believe it could be somewhat improved by resetting a few variables (such as the number and the movement of the jellyfish) but to fully explore the medium of the biosensor-affected computer game more biosensor-affected games should be designed and tested.

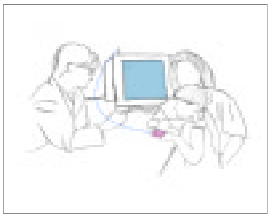


73
GBA display

74
Tilt sensor interaction

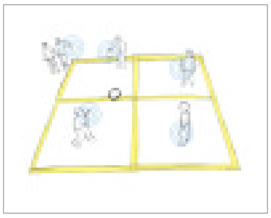
4.2
Beyond the concept

While building the Asthma Buster platform I became aware of the enormous potential that wearable devices for body monitoring offer. This section presents my thoughts on alternative uses of the Asthma Buster platform, as it explores, how wearable biodata processing devices designed in this way, could potentially improve asthma monitoring and treatment. Although the Asthma Buster platform was primarily designed as an edutainment device, the proposed wearable garment for bio-data acquisition and the portable processing device could be used in entirely different ways. This would be achieved by redesigning the software part of the platform and by adding wireless communication capabilities to the proposed platform (e.g. BlueTooth).



75
Biodata analysis

76
Remote monitoring



77
Augmented exercise

78
Remote monitoring

Through providing a series of different (possibly downloadable) biofeedback games, the players would be kept interested in playing with the proposed device over a longer period of time. As a result, the platform could hypothetically assess and store players' physiological information in greater timeframes, which would make the platform an outstanding bio-analytical tool. The collected biodata could be analyzed while visiting the doctor's office (fig. 75), monitored daily by the patient's parents, or perhaps even amusingly displayed in an online community.

Remote patient monitoring is another intriguing idea for the use of the Asthma Buster platform. For instance, a doctor could access the patient's information monthly to monitor the progress of the disease, a parent could check up on their child to determine if he is getting enough physical exercise when they are away (fig. 76).

I can envision the Asthma Buster concept being used as a variety of ways to augment athletic activity and monitor the participants' well being while exercising. The concept could easily be applied in physical education classes or asthma camps, as the coaches often aren't closely familiar with children's disorders. In addition to student/patient monitoring, the Asthma Buster platform could be used to facilitate multiplayer games or encourage group exercises in a physical space (fig. 77).

In wirelessly networked environments, such as hospitals, educational institutions, or homes, the Asthma Buster could be used simply as a playful display console or as a learning device. In the hospitals children could use it to explore their body in relation to other disorders, it could be used to explore the space of the hospital, or to compare the physiological data to the data of other patients. At home the console could serve as a playful display of relevant statistical information such as pollen concentration reports (fig. 78).

These few short scenarios illustrate the enormous commercial potential of the developed approach to bio-informatics. Their overview shows that treating biosensor technology as edutainment devices rather than medical equipment could positively result in a large array of applications ranging from very specific products to services.

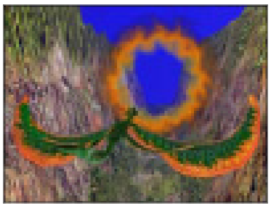
4.3
A new approach

Numerous explorations of merging edutainment and biofeedback were concluded since the introduction of computer gaming. I find the following three projects most relevant to this thesis: Brainball (from the Interactive Institute; fig. 79), Breathing Space (from the Mind Games group at Media Lab Europe; fig. 80), and Every Sign of Life (by Vadim Gerasimov from MIT Media Lab; fig. 81). All these projects illustrate and describe that it is possible to merge asthma-related biofeedback training and game-based entertainment successfully in order to create physically challenging and informative computer games.

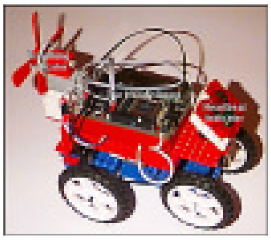
My approach to this problem is similar to the approach that Gerasimov introduces in his doctoral dissertation. He explores biofeedback training through physical objects and computer games. The scenarios he introduces illustrate that players must be absolutely unlimited in their movement while exercising or playing. However, the nature of his approach to bio-informatics is more bio-analytical and encourages reflection after exercise. At the same time, it is oriented towards the adults.

The concept I introduce focuses on children. It encourages extrinsic learning about the current state of the player's body through a portable and wearable computer game. I believe that this way of providing feedback on the physiological information is more engaging and informative than game-augmented reflective learning.

79
Brainball
Interactive Institute



80
Breathing Space
Interactive Institute



81
Every Sign of Life
MIT Media Lab

4.4
Future steps

As mentioned earlier, I did not have the opportunity to test the developed prototype with children. In order to successfully conclude the first part of the design process of this project, I am aware that I need to participate in a well-structured user testing session. Only the children can truly point out the fundamental flaws and the positive elements of the developed approach to biofeedback training and edutainment.

I believe that before such a study can be undertaken a sturdier, more portable, and entirely wearable version of the Asthma Buster must be built. In addition to the improved gaming device, more biosensor-affected games need to be designed and developed as the Bloop! game probably is not the optimal piece of edutainment software to analyze the qualities a biofeedback game.

After the propper user testing, iterations in the development of the prototype must be completed. Subsequently more rigorous testing and interaction with children is necessary to refine the Asthma Buster concept.

The physical form of the console and the wearable approach to biosensor part of the concept needs further research, as the final form of the Asthma Buster must allow free movement and physical exercise.

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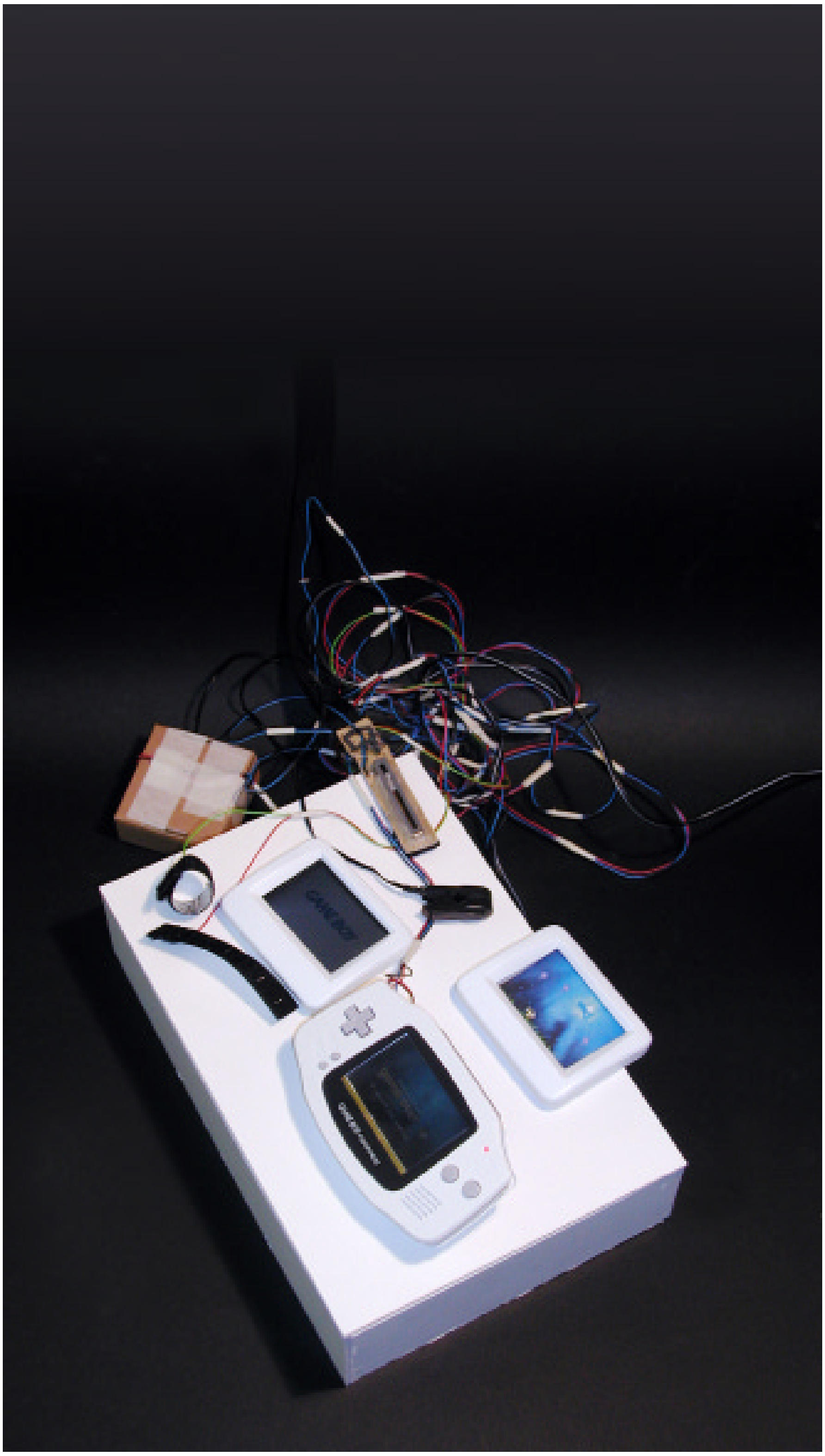
Asthma Buster Platform
(final prototype)



Conclusion

This thesis introduces a new, playful, and mobile approach to the design of body monitoring devices. To frame this ambitious task, I have chosen asthma, as the focus of my exploration. I have developed a detailed scenario and a prototype that illustrate how a wearable biosensor-affected edutainment device could be used to facilitate asthma related biofeedback exercises and learning.

Throughout this project I have explored the design and prototyping of a wearable computing device, developed a portable biosensor-affected gaming platform, and implemented an educational computer game with a well defined learning structure.

One of the assumptions of this thesis is that wearable devices for body monitoring designed in this way could affect the users' knowledge of the physiology better than the established biofeedback systems. While I cannot substantiate this claim, I believe this is possible due to the portability and playfulness of such devices. This document illustrates a need to further explore wearable computing for edutainment in relation to bio-informatics.

The most important conclusion of this thesis is that biofeedback exercises can be more fun when they are combined with computer games, perhaps even more fun than the established biofeedback training techniques.
I believe that visual and auditory representations of bio-data introduced through a computer game carry a great educational value.

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Interaction Design
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