Humanseat: semi–wearable seating concepts for vehicle control, medical, and wellbeing applications.

By

Patrik A. Künzler

Doctor of Medicine
University of Zürich, 1995

SUBMITTED TO THE PROGRAM IN MEDIA ARTS AND SCIENCES, SCHOOL OF ARCHITECTURE AND PLANNING, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

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ABSTRACT

This thesis explores how natural bodily movements can be translated into a control interface for vehicles. Focusing on the car, our goal is to increase human performance and wellbeing while eliminating the traditionally antagonistic relationship between comfort and freedom of movement vs. support, safety and sensing the car.

We will discuss seating, traditional controls, their origins, evolution, and their implications in the context of today's cars. Based on the physical demands of the vehicle environment, and on positive body experiences from sports and other concepts of movement, we will then explore how we could re-think the function, self-image, and presentation of the human body in the context of cars.

We will develop a seat prototype, which will encourage beneficial body sensations and -motions, taking into account the shapes, textures, and emotional significance of touch and movement in and by itself, and in the car environment.

The core of our concept will focus on natural movements of the lower back and hips, as experienced when walking or skiing. Building on the exoskeleton-like "Athlete Seat," which blurs the boundaries between wearing and sitting in, we will develop the core prototype out towards the upper body and limbs.

We will develop a second prototype, which will have pelvic movements in the frontal plane as done when walking, bicycling, or dancing, as the basis of its concept.

This prototype will be connected to a car simulator to investigate if good vehicle control can be achieved with our method. In a second stage, we will systematically evaluate the car control, wellbeing, and fun aspects in a user study.

Our modular design will be usable in parts and adaptable to various uses, in vehicles, for entertainment, exercise, wellbeing, and medical purposes, improving physical condition and the way we relate to our bodies.

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Introduction

In this thesis, a radically human centric approach to sitting is investigated that blurs the boundaries of sitting in vs. wearing and discusses its possible physical and mental implications for driving vehicles with a focus on cars. Other applications and radical car concepts will also be discussed.

Driving a car should be a physically and mentally positive experience, the same way athletic activities, dancing, lying on a sofa, or sitting in the lotus position are. The more one feels one's car, the better one should feel. Exposure to g-forces and vibrations should feel like a massage, and the best sensory mechanisms available should be used for vehicle sensing and control, in combination with our natural balance and reflexes,.

Even though seats in cars and have evolved considerably from seating in horse drawn carriages and the seats in homes that they originated from, a basic conflict remains between comfort and freedom of movement on one hand, vs. support, safety, and feeling connected to the car on the other hand. "Feeling the car," is often associated with discomfort or seen as invasive and therefore cannot be exploited in a way that would be conducive for enhancing the drivers capabilities to control the car.

Our goal is to overcome these contradictions by braking with the evolutionary path of car seat design, and seat design in general. Instead, we propose a novel, radically human-centric approach to seating and vehicle control. Designing from the human outward, we are taking advantage of areas of the body where touch is beneficial for wellbeing and for sensory performance, and movements and reflexes that are intuitive in the car environment.

Similar to car seats, car control mechanisms have evolved from origins that were defined by the mechanical necessities around the time the motorcar was invented, over 100 years ago.

Contrary to recent efforts to reduce the body movements needed for controlling a car, for example, by using joysticks, we explore how movements and the high levels of coordination that the human body is capable of, as demonstrated in activities like walking or skiing, can be used to control cars in novel ways. This could add to the parameters that can successfully be controlled with high degrees of coordination, and may be useful for urban and high performance driving, or in conjunction with Wheelrobots.

Self- display and self- perception are another important aspect to the driving experience. Skiing, surfing, and inlineskating are great ways of looking and feeling elegant. Similarly, heroically mastering a horse, a motorcycle, or a sportscar, instills a sense of accomplishment and projects an image of confidence and refinement. Our goal is to maximize this experience.

The humanseat design principle is based on the shapes, volumes, and textures of the body, and the sensory, medical, and emotional significance of touch, vibration, and movement of its parts. The base of the humanseat is designed around the movements of the core of the body - the hips and pelvis - that occur during activities like walking and bicycling, but are absent during sitting and standing.

Using this approach, the humanseat tries to resolve the fundamental contradiction of chair design, that is, to provide support, balance, and stability, while enabling freedom of movement. Other than voluntary movements, the humanseat also allows small, subconscious balancing movements that help muscle strength, posture, and balance. This avoids periods of immobility and constant pressure the lower spine that can cause symptoms like lower back pain. It allows for the body to be moving in various ways or to remain in relatively stable positions.

Prototypes were built of wearable parts and of whole seat concepts. The idea was not to use cushioning, straps, or fixed joints, but to use materials that would place more narrow design restrictions, in order to learn the most from the experience. Plywood was chosen for the parts that touch the body, due to its simple bending and fabrication properties, and because it feels good to the touch. Plastic flextures were chosen instead of ball joints, in order to compliment rather than imitate natural joints.

The prototypes were then tested for feel, support, possibilities of movement, and to test whether it was possible to reward movement through positive tactile feedback. The second prototype was connected to a driving simulator in order to test the feasibility of using movements on the hips and thighs for driving. Comparison tests were done with a regular game controller.

The Athlete Car investigated at the Smart Cities group at the MIT Media Lab was an initial exploration of how the athletic and recreational experience from sports like skiing and ice-skating could be transferred to driving a car.

Part I: Background

In part I of this thesis, the cultural, medical, and functional context of movement, seating, and car control will be discussed. We will also briefly mention wheel robots, which are essential elements in some of the designs that will be discussed in part II.

1. Movement: Effects on Body and Mind

Body movement is important. Not only can the lack of movement, or the lack of the "right" movements have acute and chronic detrimental effects on blood circulation, joints, muscles, and bones, it can also have negative effects on the human psyche.

Moving can serve as a release of energy, or to overcome tension. In dance, movement can be an explicit form of expression, while posture, gait, and gesticulation are often involuntary expressions in the inner state of a person.

Environments that are constantly in motion, such as, boats, require quasi-constant movement to balance the body, even when sitting down. Depending on the amplitude and predictability of these movements, we are consciously aware of them, or they fade into the background and our bodies make the necessary corrections for balancing without us noticing. Similarly, sitting in rocking chairs or on exercise balls, helps to distribute pressures and tensions throughout the body in a way that avoids any single part being overstressed.

1.1 The Physiological Need to Move

For physiological reasons, our bodies should be in quasi-constant motion, even if some of these movements are not perceived consciously. Examples of the consequences of the absence of these movements are patients with the rare condition CIPA, the absence of functional pain receptors. CIPA patients don't move while they sleep and as a consequence suffer debilitating spine and joint injuries at a young age. Interestingly, there was no report of having a child with CIPA sleep in an environment that provides constant motion, like a boat.

The physical importance of movement is further illustrated by the fact that only highly trained individuals in practices that involve both physical, and mental training can achieve sustaining voluntary prolonged periods of non-movement.

Non-voluntary extended motionless periods can result in skin ulcers if blood circulation in major blood vessels is sufficient, or loss of limb and life in the case of insufficient blood flow.

Apart from these extreme cases, we know from common experience that staying in almost any position for too long is uncomfortable.

1.2 The Psychological Need to Move

Conversely, physical activity can make us feel good, due to endorphins that are released during intense exercise, but also because the act of moving itself can have positive effect on the psyche. Movement and mind are connected by a psychosomatic/ somatopsychic two-way street. As discussed in section 1.4, our posture often expresses how we feel, how we perceive the world, and the levels of energy we have. Imitating another person's posture and gait tells us a lot about that person.

In humans, as in other mammals, the motivation to move declines with age. Anybody who has been around small children knows that sitting still for any period of time will result in a strong urge to release the pent up energy. Some stationary movements, like rocking back and forth, provide a lot of joy and relief to children, while adults prefer more complex and coordinated movements, which often have to do with locomotion.

Mental and physical benefits of movement are often hard to separate.

1.3 Athletic Activities that do not Require Equipment for Moving in Space

Athletic activities that do not require equipment tell us something about our bodies and minds, even though, compared to sports that require equipment, the speeds and ranges of movement are limited.

Running, for example, can focus on speed (sprinting), endurance (marathon), or on agility. Free climbing focuses on agility, strength, and endurance.

Simple objects that are interchangeable between individuals can turn these sports into team sports. A stick passed on between runners, a Frisbee, or a ball to be thrown or kicked within the rules of a game. Spectators can watch and participate in the experience.

As tools that enhance our natural abilities are added, like bats in order to propel a baseball, or golf clubs to propel a golf ball, the movements required to play a sport change and move away from natural movements that relate directly to everyday life.

If tools are used for propulsion of the body, like bicycles or skis, the major determinant of the body movement, along with the purpose of the sport, typically moving the athlete over a distance, they not only change the types of body movements we make, but also how we relate to space.

1.4 Athletic Activities that Require Equipment for Moving in Space

The weighing of the factors that determine how fast and how efficiently an athlete moves through space is varies between sports. In cycling, strength and endurance are more important that fine motor skills and coordination. In downhill skiing, strength and gross motor coordination are very important factors determining the success in a race.

In car racing, the weighing of strength, endurance, and fine motor skills for success, depends on the racing series, as does mental stress. Excellent physical fitness and mental training are crucial to perform well under the high physical and mental loads on racecar drivers in high-speed series, such as, Formula One (F1).

Interestingly, the combination of excellent endurance and great reflexes and fine motor skills is rather unique and poses special challenges, since the amounts of movement and blood circulation to the limbs during endurance training is higher than during racing. Because of vibrations and accelerative forces that can reach 3-4g, the body needs to be restrained in a manner that allows correct operation of the steering wheel and the pedals.

We will later discuss how it might be possible to provide more degrees of movement in order to increase driver wellbeing and endurance while enhancing vehicle control.

1.5 Riding, Gliding, and Flying

In the arts, riding, gliding, and flying have always been associated with freedom of the mind and the spirit. Some of this association relates to escape, while other aspects stem from the sensation itself. Experiencing these sensations usually requires moving in space, ideally at high speed, or being suspended in air that is traveling at high speeds around us. While mechanical bulls and motorcycle riding arcade games focus on fun as well as performance, stationary rides as seen in many shopping malls provide great joy to children by moving back and forth in an ellipsoidal motion, without any competitive components involved.

Figure I-1: Riding, Gliding, and Flying.
Athletic activities that involve fying or evoke gliding sensations. From left to right, Snowboarding; Paragliding; Skiing; Galloping along a beach; Flying.

1.6 Movements of the Pelvis

Pelvic movement is part of the basic activities the human body is designed for. It strengthens our posture muscles, while making sure that the stresses on the lower back are distributed evenly over time.

Movements of the pelvis are basic elements of locomotion, and, to a smaller degree, standing. While walking, the pelvis moves in the coronal (frontal) plane, tilting back and forth, and in the sagittal (lateral) plane, rocking sideways. Most of the time we are not consciously aware of these movements. During some types of dancing (Figure I-2) and during horseback riding, we are more aware of pelvic movements, since they are an active, determining part of the activity with which the associations typically are positive. Pelvic movements can also play an important role during intercourse, adding another positive association with these movements, although there are cultural complexities resulting from that association.

Figure I-2: Artwork postage stamp illustrating unison in pelvis- derived rhythmic motion.

When sitting, the movements of the pelvis are restricted mostly to movements in the coronal (frontal) plane, increasing or decreasing lordosis, allowing us to rock our pelvis forward, for an upright seating position, or backward, for a slouching position. The latter results in a C- shape of the spine. For many people, holding the pelvis in a tilted-forward

position in order to sit straight requires too much energy to be a comfortable position for a longer period of time. Therefore people tend to quickly revert back to a slouching position. In reclination, slouching can be beneficial if the angle between the thighs and the back is 135° rather than 90°, making the stress on single intervertebrate discs lower than when sitting upright at a 90° angle. Still this position is not ideal because unless we recline, it compresses our abdominal space and chest, making it harder to breathe, and because it weakens the posture-related musculature of our pelvis and back.

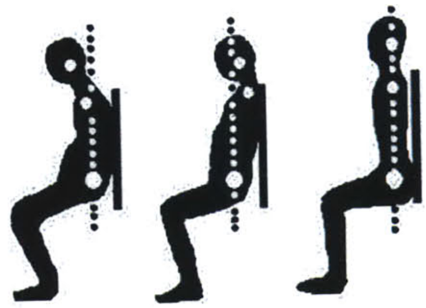


Figure I-3: Spine positions.
C-shaped slouching position (left), hyperlordosis (middle), "correct" position (right).

Movements in the sagittal plane are either not possible, for example, when the seat surface is hard and fixed, or only possible with great effort, when the seat surface is cushioned. It may be the case that the absence of pelvic movements in the sagittal plane is a major contributor to the medical problems associated with sitting in chairs, rather than incorrect degrees of lordosis.

Figure I-4: Sitting surfaces that make sagittal pelvic movement difficult.
Saddle seat (left) that is too wide; chairs with mild degrees of flexibility (middle); padded chair with "scientific" cushion to better disctribute load.

1.7 Self Display

Self-display is a pastime performed on the esplanades of the world, but it can go much deeper than that, influencing how we feel about ourselves and how our surroundings perceive us (Figure I-5). The way we perceive ourselves and the way we like to portray ourselves to others are strongly interconnected. We choose to reveal certain aspects of our personalities and our lives to some environments and not to others. Sometimes we do this because of social codes, protection of privacy, to make a statement, or to gain power in social situations. This can be a manipulative, but also a self-assuring and rewarding experience. Our presence, posture, the clothes we wear, the way we move, the activities we do and how we do them, and the objects we associate ourselves with are all tools of self-display.

Figure I-5A: Public self-display and body-image.
(Left panel). Surfing: Graceful motion in space is easy to achieve for experts and beginners alike on surfboards (middle), while more difficult to achieve with other means of moving in space (right panel).

Some objects, for example surfboards, make us look majestic and elegant; others do not. It is almost impossible not to look elegant while riding a surfboard, while other means of transportation make even experts look rather clumsy (Figure I-5). A beautiful sports car should therefore not only look good by itself, but the driver should also look good while mastering the car.

Seats can be majestic or simple; they can make their occupant look majestic or humble, empowered, or powerless. In some instances, like wheelchairs, caricaturized augmentation may not work. A better projected image has to come from the occupant through posture and movement (Figure I-5B).

Figure I-5B: Commanding presence in a wheelchair.
The result of posture (left panel) rather than caricaturized augmentation of mobility-related mythologies (middle right panel). Mobility-related mythologies: "Heroically mastering" a sports car (right panel).

1.8 Aging

In the industrialized countries, the relative number of aging individuals with respect to the overall population is increasing rapidly. Aging is accompanied by a complex interplay between physiological changes and their psychological effects. As the strength of our muscles and bones decreases, connective tissue becomes weaker and less flexible, and as our senses become weaker, the way we relate to our bodies typically also changes.

One principle could be termed reasonable caution: the fear of the greater consequences of falling due to frail bones and slower reflexes can have a negative impact on the motivation to walk. Another principle is avoidance of pain: painful joints can have a negative motivation on moving, sitting up, or doing other formerly pleasurable activities.

There is also a strong psychophysical component: On the one hand, the more a part of our body is necessary for survival and functioning in our daily lives, the more it gives us pleasure. The more it contributes to the image we want ourselves and others to have of us, the more attention we pay to it. If on the other hand, the opposite is true, we either try to change those aspects of our bodies, or worse, we start neglecting them.

A common example is the "diabetic foot:" reduced blood circulation in the lower limbs causes a loss of function, accompanied by a loss of sensitivity. Since the decay is gradual, patients have a tendency to ignore it or consider it normal until a state of high acute pain or other severe consequences is reached.

Typical measures, such as, walkers, surgery, and pain medication, take into account the first two principles. That is to say, walkers make walking safer by reducing the risk of falling and more comfortable by giving the opportunity to transfer some weight from the lower to the upper body.

The humanseat project aims to take into account these psychophysical aspects that have so far been neglected by making wearable pieces that improve the relationship to our bodies and increase the pleasure of moving through positive tactile and vibration feedback (ref Collins, BU).

Figure I-6: Reduced mobility and cognitive ability for the elderly.
Safe mobility that potentially depends on help (top); assisted walking with physiotherapist and walker (upper middle); patient with diabetic ulcers (lower middle); "Empathy suit" (bottom) to simulate loss of faculty and mobility in old age.

1.9 Human Augmentation

Modern prosthesis have made a new form of human augmentation possible – the performance of replacement body parts has gone beyond the capabilities of the biological parts they are replacing. Stronger ankles for faster walking at low energy levels, longer shins for better reach in rock climbing, and carbon fiber feet for sprinting are changing the functionality as well as the public perception of prosthesis.

There are other forms of movement-related human augmentation that supplement the function of the human body rather than replacing it. Skiing boots augment the rigidity of the ankle, and skis, ice-skates, and rollerblades can be seen as movement-related human augmentation. Cosmetic implants are often seen as augmentation (Figure I-8).

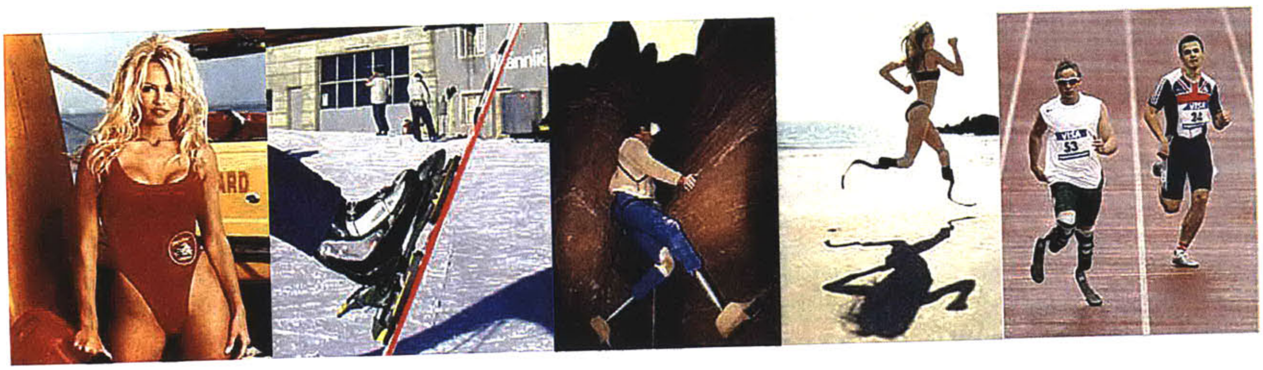


Figure I-7: Human augmentation:
Cosmetic alterations that can be seen as augmentation, a familiar and commonly accepted paradigm (leftmost panel); augmentation by enhancing natural function, in this case, rigidity of the ankle (middle left). Augmentation by replacement: enhancement of climbing performance by using longer than natural prosthetic shins (middle); sprinting beyond the capabilities of "able bodied" competitors by using high-tech replacement prosthesis (middle right and right).

2. Coordination

The human body and mind has an extraordinary capacity to coordinate physical and mental activities. Different sensory inputs are involved in coordination processes: Balance, proprioceptive (the position of parts of our bodies relative to each other), visual, auditory, and tactile inputs. The type of coordination needed for walking, running, skiing etc, is referred to as gross motor coordination; delicate manipulations of the fingers and the face, and activities for generating speech, are referred to as fine motor coordination.

Our bodies and brains can coordinate extraordinarily complex movements into deliberate actions such as, balancing on one leg, running, horseback riding, skiing, and many other activities that machines still have not been able to replicate. Our hands, show tremendous degrees of precision and together with visual and oral input, can do such complex tasks as playing the piano. Gross motor coordination of the body and fine motor coordination of the hands and face can both be trained to handle and coordinate a large number of variables to generate precise motor output.

This of course raises the question of which system can do what best.

2.1 Gross Motor Coordination vs. Fine Motor Coordination

Fine motor coordination of the hand and digits, allows us to do very precise movements, which are aided by the great sensory capabilities of our hands and digits. Watch-making, delicate surgical operations, touching another human being, all require a delicate interplay of movement and tactile feedback. Reaction times can also be very fast. For example, it was found that Formula One (F1) drivers had better reaction times with hand-actuated clutches than with foot-activated clutches (ref). When stationary, sitting on a stool or standing, the number of spatially and temporally highly coordinated interdependent movements that can be achieved when auditory feedback supplements fine motor coordination, is astounding, for example, when playing a concert piano. The fine motor system is therefore well equipped for providing quick and accurate steering inputs to a vehicle traveling on a plane, like a motorcycle, a car, or a boat. Fine motor coordination is also used to steer vehicles in the 3D space, such as airplanes, helicopters in the air, and submarines in the water.

Gross motor coordination, typically does not operate at the high spatial resolution of fine motor coordination. Gross motor coordination has two very interesting features though: movements of our feet, legs, trunk, arms, and head are inherently and directly linked to our sense of balance, and a high number of input-output channels can be seamlessly and intuitively coordinated. Examples of this are walking on shaky ground, skiing, and ice-skating. Gross motor control thus may lend itself to quickly and intuitively deal with balance-related inputs. Using all extremities in parallel for controls helps to drastically increase the number of discrete output channels, for example, to control a car, or for more intuitive operation of vehicles that require complex steering inputs for moving in 3D space, such as, helicopters. The implications of these differences and their potential uses will be discussed in part III (Figure I-8).

Figure I-8: Gross-motor coordination vs. fine motor coordination. Gross-motor coordination allows for intuitive synchronization of many input-output channels in 3D space during activities like skiing (left panel); steering race car is combination of gross and fine motor skills in the 2D space (middle); joystick relies on fine motor skills (right panel).

2.2 Coordination and Feedback Through Sound

Through feedback sound can help in the coordination of fine motor systems, for example when playing a musical instrument, and for gross motor systems, for example, when dancing. Sound can also aid coordination between individuals.

Aural feedback is vital for performance of many different types of musical instruments. This is especially true for instruments without keys or frets, such as the violin, trumpet, or trombone, even for well-trained musicians, to make immediate corrections before the audience hears the sound (Figure I-9). Even with keyed instruments, where there is expressive tactile feedback and the musician can respond to how hard a key is struck and how long the key is held down. Thus, aural feedback still plays an important role in correction and coordination. In string instruments, tactile feedback is very important for playing, and for tuning the instrument. The importance of tactile feedback in string instruments depends on the interaction of the resonance frequency of a particular note with the body of the musician. Singing is interesting as well: what we hear is not only due to the sound coming from our mouth, through speakers, or headphones, but also from vibrations of the skull.

Figure I-9: Violinist receiving aural and tactile feedback while playing.

In car racing, the melody of the engine, besides being possibly tiring by being too loud or too constant, can aid performance self-assessment, precision, and endurance. The more monotonous sound of diesel racing engines initially caused performance problems for the drivers of the Audi R10, since they were lacking the more differentiated aural feedback of gasoline engines causes by their higher rev range.

2.3 Feedback through Sound And Cognitive Load

A great aspect of receiving information through background sound, or continuous tactile information, is that the attention the driver has to pay to it becomes minimal, allowing the driver to focus on other things. This has to do with cognitive load issues, which we will discuss later. In brief, cognitive load can be described as the amount of attention, or the amount of ad-hoc processing space that an activity or strategy requires. The more we concentrate, the more we are immersed in an activity, and the higher the cognitive load available for that activity. The driver only notices and reacts to deviation from the expected melody (ref). From a cognitive load point of view, sound is therefore almost-free information. The same is true for touch, although in a slightly different fashion.

2.4 Feedback Through Touch And Cognitive Load

Similar to sound, tactile feedback can give valuable feedback while requiring low cognitive load if given continually and below the threshold of being intrusive.

3. Chairs

Chairs are ubiquitous in modern western societies, and are making their way into societies where squatting is seen as more natural than sitting. Chairs are in our houses, in office buildings, in social places, in parks, even in vehicles, like cars, trucks, and buses. The oldest known witnesses of the use of chairs are figurines dated to Neolithic times (10'000-4'000B.C.) depicting people sitting in chairs. Chairs and stools were also known in ancient Egyptian, Greek, and Roman civilizations.

The cultural significance, the functional necessities, and the ergonomic challenges involved in chair design, have made designing chairs a welcome challenge for architects, artists, and ergonomists alike[1].

3.1 The Evolution Of Chairs: Status, Style, And, Eventually, Ergonomics

After disappearing with the end of the Roman Empire, chairs re-appeared in medieval Europe, evolving from and looking like storage chests that were fitted with large backs, expressing power and wealth. These chairs were heavy, significant, and unaffordable for most. In the 1600s, chairs started to become more commonly available, and started being decorated according to fashions of the times. This included designing chairs for women, taking into account needs of particular styles of clothing, touching the subject of ergonomics. The 'form follows function' ethos of modernists has, at least to some degree and certainly not in all instances, had a positive influence on chair ergonomics. As it has become more recognized that sitting the "wrong" way for extended periods of time is not only uncomfortable, but can have negative effects on productivity and cause chronic back- and posture problems, more research and sales efforts have gone in that direction. Still, status, style, fashion, and the personality they convey have not only been the major drivers of chair development, they also influence how we perceive chairs.

3.2 Ergonomics and Comfort

Posture, when standing, walking, or sitting, is not only an expression of our physical, but also of our mental state and constitution. This has to be taken into account when investigating the ergonomics of chairs and of the effects chairs have on our bodies and minds.

What makes a chair comfortable, is it its cushioning, padding, concave and convex shapes, support, or freedom of movement? Even though everybody has an idea of what being comfortable means to him or her, there is no universal scientific metric of what being comfortable is. It is still being debated whether there is a continuous scale from comfort to discomfort, or if those two are entirely separate concepts[2]. Some theories state that the critical determinant of comfort is the number of body parts that are comfortable vs. the number of body parts that are not[3]. Other theories state that there is a hierarchy of body parts for the perception of comfort: The back and buttocks are more important that the head and shoulders, which are in turn more important than the thighs and legs[4]. This illustrates the difficulties that arise when dealing with a system that consists of anatomical, physiological, psychological, and even cultural components[5].

There is a "right" chair for every type of person, depending on their sensibilities and their pre-conceived notions about what is comfortable, or, which process leads to a chair that accommodates their bodies best: avant-garde chairs, conservative chairs, chairs with lots of padding, etc. Additionally to long-term factors that influence the perception of comfort, short-tem factors, like mood and physical activity prior to sitting down are also relevant.

This can make subjective ratings of comfort, difficult, as the following example shows: Tests were conducted where subjects were asked to rate nine chairs according to how comfortable they were. When asked again a week or after the first trial[6], or only five later[7], the same subjects would rank the same chairs differently.

These factors had to be taken into account when conducting seating and movement trials with the humanseat, as described in part II.

There is a notion that 'relaxed' or 'comfortable' means, the body is not working, and i.e. its muscles are relaxed. This notion, although appealing to common sense, might not be correct, for two reasons. First, it is not muscular activity pre se that causes discomfort and stress, but too much activity of some muscle groups, and second, when we are lying down, or even sleeping, our bodies are in constant, sometimes unperceivable motion, distributing the load on muscles and joints in a way that is beneficial to the mind and body.

Figure I-10: Balans® kneeling chair

While typical chairs are designed to provide and angle of approximately 90 between the thighs and the back, there are claims that an angle of 135 is more natural and more beneficial, as in the Balans® kneeling chair (Figure I-10) design by Peter Opsvic. Others recommend perching, a posture halfway between sitting and standing[8]. Comfortable could therefore also be defined as load being distributed to different sets of muscles in a way that allows a person as a whole to feel relaxed.

Muscular tension can be measured using EMGs (electromyography); other methods measure pressure along the spine. This type of research can be very helpful when analyzing specific designs of chairs, and it can help avoid the difficulties that come with subjective evaluations of seating, although it is important to have internal controls measuring the baseline tension of a test subject, since this will depend on highly volatile factors. Although helpful, these highly scientific measurement methods have their limitations in so far that it can be difficult to address the mental and physical state of the subject as a whole. The workload and tension of one set of muscles may or may not correlate with how the person actually feels.

Holistic approaches, although not considered scientific by some, do not separate the mental from the physical aspects, but rather see the two as interactive, inherently intertwined systems. This approach might be very valuable when dealing with seating, movement, and even car perception.

3.3 Trouble Area: The Lower Back

Most seating-related chronic injuries relate to the lower back. Many efforts have gone into solving this problem, suspended seats in trucks and buses, adjustable lordosis support, massage functions, medical foams, and many more. So far, none of these solutions has achieved the desired result. They all rely on supporting the angle of the pelvis in the coronal (frontal) plane, not taking into account pelvic movements in the sagittal plane that naturally occur during walking. The humanseat project is taking a novel approach to this problem by allowing, even encouraging pelvic movements in the sagittal plane.

3.4 Holistic Approaches

The so-called somatic disciplines[9], like the Alexander technique, founded by Frederick Matthias Alexander of Australia in the late 19th Century, provide an integrated body-mind perspective that differs from medicine insofar that they "focus on the relationships between body and intellectual thought, cultural belief, individual feeling, and will,"[10] similar to Asian martial arts.

This leads to a postural and behavioral assessment of comfort. In his book "The Chair,"[1] Galen Cranz, an Alexander technique teacher, states that, "human beings are designed for movement, the important thing for posture is the coordination of movement." He also states that, "awareness of posture very deeply ingrained not accessible to verbalization"[11]. According to Alexander technique, the head initiates all movements, it is therefore important that the head be free to move. The technique sees itself as a re-education, thus un-training and re-training the body and mind my means of posture and movement.

"Posture influences world view; posture and attitude associated with that posture, you want the possibility of choosing either movement of the system at any time,"[12].

3.5 Remaining Issues

The inherent problem of chairs is that they have to provide stability and support while leaving room for movement and allowing the body to be in a position that is physiologically beneficial and comfortable. Additionally, chairs have to support the natural mechanisms for keeping our spines erect and our breathing free, but they should not replace these functions, because this would weaken our own posture-related musculature.

Stools provide support without replacing our natural postural apparatus, and sitting on exercise balls forces us to move and to balance ourselves, but both types of seats don't provide enough support and require a relatively large effort, especially for people used to sitting in chairs with backs. Kneeling chairs require less work to keep one's spine erect, but the cultural and psychological implications of kneeling and their social acceptance and adaptability to different environments, like offices, dinner tables, and cars, is very limited.

So far, the problem of providing movement and support simultaneously has been difficult to solve. Of course, we can always move into a new position to compensate for uncomfortable chairs, until that new position becomes uncomfortable, and we change position again.

Movement can compensate for the inherent shortcomings of chairs: We are never uncomfortable on our couches at home; because we can sit, lie down, or move around anyway we want. This is less possible, as social and functional constraints increase, making chair design more demanding. An environment with significantly more functional constraints than the home is the car.

4. Chairs In Cars

Car seats have to fulfill many requirements. Car seats have to allow proper operation of the vehicle; they have to be comfortable over prolonged periods of time, while providing lateral and longitudinal support and protection in case of an accident. All this has to be accomplished for a large variety of body types.

Addressing these problems in an evolutionary and additive fashion (Figure I-10), adapting chairs from homes to the increasing demands of the car environment over time, has not resolved some basic issues: Sitting more comfortably still means feeling less connected to the car, having more freedom of movement results in being less safe.

4.1 Origins

Seating in cars evolved from seating in the car's direct predecessors, the horse-drawn carriage, and from seating in homes. As car design moved away from that of horse carriages, and as cars became stronger and heavier, heavy, sophisticated furniture that matched or surpassed the quality and prestige of the furniture found in the owner's homes was installed. Similar to horse carriages, where driving was often relegated to the coachman, large luxury cars often had a clear division between the spartan chauffeur's workplace and the opulent passenger compartment. In cars that were meant to be driven by the owners, this distinction was less pronounced or absent.

Figure I-10: Evolution of car seats.
From seats in homes (left), through their almost unchanged adaptation in cars (left middle) to highly specialized car seats designed more for comfort (middle) or support (middle right), all the way to specialized seats in Formula One cars (right panel).

4.2 Evolution

With the advent of high performance cars, functionality became a significant driver of seat design, although the basic mindset of mastering the vehicle and therefore taking pride in adapting to adverse conditions rather than complaining about them, which would lead to improvements, was prevalent or at least present. Although there are bucket seats in some early cars, prestige, comfort, and the engineering necessities of the cars were the main drivers for car seats. Drivers were expected to ride the cars like jockeys rode horses, whose anatomy we cannot change, like cars can be redesigned. In some race cars, the driver was an afterthought, someone who had to make due with what he was given, a situation that can still be found in some racecars and teams today, aided by the driver's pride and their definition of mastery.

In order for people of different sizes to be able to operate the cars, movable seats, and movable controls were introduced. Seatbelts, although invented in the 1800s, were first used in planes, where they became commonplace in the 1930s. Three point seat belts were invented in 1959 by Volvo and became commonplace in front seats of cars in 1964, in back seats in 1968 (USA). In order to reduce discomfort caused by seatbelts and to improve compliance, self-adjusting seatbelts with inertia-reels, which would block the extension of the seatbelt only during sudden deceleration, were introduced.

In order to give support to counter lateral and longitudinal g forces, lateral contours of seats were enhanced ("bucket seats"), and the bases of the seats were constructed in order to prevent "submarining," a phenomenon where the occupant slips below the seatbelt during a longitudinal crash, making the seatbelt ineffective.

In racecars, four-, five- and recently, six point harnesses were introduced to safely connect the driver to the chassis (rather than the seat) for reasons of safety and vehicle control under the physically challenging conditions found in racecars. Additional functional and safety features in racecars relating to the seat and driver include helmets, fire proof clothing, neck- and leg restraining and –support devices, and seats that can be removed in one piece with the driver in case of a suspected spinal injury.

More comfort and safety features were added to the car seat, like cooling, heating, and massaging functions, active head rests against whiplash of the neck, pre-tensioners of seatbelts, and seat mounted airbags.

Other safety functions were relegated to the interior of the car, like safe plastics, buttons, and steering wheels, airbags, and crumple zones.

4.3 Relegation of Comfort and Safety Features to the Car vs. the Seat

The inadequacy of seats, even in combination with three point belts, to fully protect the occupants in case of an accident necessitates adaptations and therefore puts constraints on the design of the structure and of the interior of the car. Some of these adaptations are airbags, "soft" plastics, and other measures to minimize potential injuries.

Figure I-11: Mercedes Airscarf® puts function of keeping neck warm into car, freeing the driver from having to worry about a scarf and making the car appear more comfortable and "caring."

In interesting new relegation of functions is the Airscarf® introduced by DaimlerChrysler, which relegates the function of keeping one's neck warm in a convertible to the car (Figure I-11).

4.4 Remaining Problems

The fundamental issue of having constraints imposed by the necessity to control the car, by the movements of the car, and by the eventuality of an accident has thus been addressed in an evolutionary and additive fashion.

Some basic contradictions inherent to this evolutionary approach remain: Sitting more comfortably still means being less connected to the car, having more freedom of movement results in being less safe. Car seats also had to become heavy and highly complex in order to alleviate these contradictions.

5. Horse Saddles and Motorcycle Seats vs. Seats in Cars

5.1 Horse Saddles

Horse saddles were developed to make riding horses more comfortable and to give the riders more control. They are fascinating insofar that they have to give support and be comfortable while allowing the rider to control the horse with inputs from the thighs, heels, and holster. There are fundamental differences between horses and cars. Similar to boats, horses move in the x/y/z/ axes. Due to the fact that horses move on legs and not on wheels, and because the horses themselves are flexible, different types of movements, accelerations, and rhythms have to be dealt with. From a posture and movement point of view, sitting on horses provides a much better platform than sitting in chairs, although it can be tiring to the novice.

What is very interesting is the feedback loop between the horse and the rider: A team that knows each other well can anticipate each other's movements and interpret the slightest change in attitude, similar to an experienced pair of human dance partners. This can be a satisfactory experience of togetherness and harmony, or of mastery, even domination, depending on the type of the relationship, the intent and the situation. For example, even the smartest and most trusting horse will have to be pushed beyond its comfort zone sometimes because its natural instincts of stopping or fleeing have to be overcome in order to follow the intentions of the human. On the other hand, as rider and horse get to know each other better, the capabilities of the pair as a team increase, which is satisfactory for both sides. There are parallels of these aspects of horsemanship to driving modern vehicles.

Figure I-12: Evolution of motorcycle seats from horse saddles.
The degrees of freedom and types of motions are similar.

5.2 Motorcycle Seats

Motorcycle seating has evolved from seating on horses. There are significant similarities: we sit on horses and motorcycles, rather than in them, we hold both, motorcycles and horses, between our legs, and the angle between the thighs and the back is larger than in chairs.

The movements are also similar, there is a back and forth rocking motion, although to a lesser degree and in a more fluid manner on motorcycles than on horses. Motorcycles, in turn, lean sideways more often and to a larger degree than horses. The bigger width of a horse compared to a motorcycle forces the thighs to be at a more open angle.

The feeling of being intimately connected with a horse stems to a large degree from the fact that it is an intelligent, live mammal, whose' breathing, character, etc, we can feel and interact with. On a motorcycle, having the legs at a more closed angle and therefore feeling more like protecting the bike with one's body, might make up for some of this difference. It is also known that riders develop more affection to bikes with 'character.' Of course it is hard to determine to what degree this is due to the fact that riders want to project mammalian qualities onto their motorcycle, and to what extent it has to do with the history of the brand, marketing, and escapism related to any particular ownership experience.

5.3 Comparison

Comparing the two evolutionary pairs, the house and car pair, to the horseback and motorcycle pair, the latter are much more similar as far as degrees of freedom and types of movement, G forces, and habituation go. Another example that could be compared is seating in trains vs. seating in airplanes, but the underlying principle is the same as in the house/ car pair.

5.3.1 Horses To. Motorcycles: Origin And Destination Of The Evolutionary Process Are Similar, Freedom Of Movement And Constraints Remain Balanced

On horses and on motorcycles, the rider can determine and spontaneously vary the angle between the thighs and the back more than when sitting in chairs, and in both cases, the natural motion of the vehicle helps the lower spine and pelvis to be in motion relative to the back, with a reasonable degree of movement of the pelvis in the sagittal plane. This makes sitting on motorcycle seats, which are very simple compared to car seats, comfortable, while still appropriate for vehicle control. Between the horse and the motorcycle, there is no significant change in degrees of freedom of movement and constraints for control.

This is very different for the chair in a house compared to chairs in cars, where degrees of freedom are removed, and demands of control increase.

5.3.2 Homes to Cars: Origin And Destination Of The Evolutionary Process Are Dramatically Different, Leading to Less Freedom of Movement, More Constraints

At home, especially lying on a couch, the only constraint is gravity, and maybe holding a book, a remote control, or a glass of wine, making it easy to be comfortable. In situations where the functional and social demands increase, for example, when sitting at a table to eat, or while working on a computer at the office, the freedom to move around at will is reduced. This increases the need for chairs to be well designed in order to compensate for the lack of movement and the inappropriateness of certain positions required by functional and social needs.

In the car, not only does the driver have to be able to control the vehicle in a manner that satisfies the social responsibility of driving a car, there are also additional challenges in the form of vibrations, lateral and longitudinal g-forces, and the eventuality of an accident. Additionally, most car seats have to be designed to fit a large variety of body types. Sitting in chairs fixes the angle between the thighs and the back, and movements of the pelvis in the sagittal plane are not possible to a reasonable degree. These factors all increase constraints. Because excessive rocking movements of the car are not seen as comfortable, there is no relief to be found there (Table I-1).

	Functional Constraints	Seat Modifications	Modifications of Surroundings
	• 1 vertical G • comfort		
	• reach controls • cannot change position • cannot get up and move around • mild lateral Gs • potential high longitudinal Gs	• adjustable seat • cushions, etc. • massaging, cooling, etc. • side cushions • anti-"submarining", headrests	• movable controls • adaptable suspension • entertainment • cupholders • seatbelts, airbags, soft plastics
	• must reach controls • cannot change position • cannot get up and move around • high Gs laterally and longitudinally	• indiv. adjustment if possible • foam, ? • ? • make seat fit tightly	• indiv. adjustment if possible • ? • ? • thight cockpit if possible • helmets, HANS, 5 point

Table I-1: Comparison of constraints on seat occupant in home, car, race car.

Instead, car seats have evolved into heavy, highly complex and infinitely adjustable apparatuses that offer heating, cooling, and massaging functions. The problem inherent to this evolutionary approach due to the disparity of the origin of chairs and their use in cars has not been solved, leading development of car seats into a high-tech dead end street.

6. Clothing Commitment

When comparing seating on motorcycles to seating in cars, the issue of clothing commitment arises, that is, the necessity and/ or willingness to wear clothing specifically designed for operating a certain type of vehicle under certain conditions.

The main drivers for clothing commitment are protection and safety. Thus, the order of clothing commitment is as follows (Figure I-14):

Racing (Motorcycle>Car) > Motorcycle > Scooter > Convertible > Car.

Figure I-14: Clothing commitment.
The degree of necessity, money, or willingness to wear specialized clothing different means of transport, decreasing from left to right (Racing Motorcycle > Race Car > Motorcycle > Scooter > Convertible > Car. The technical need for higher clothing commitment also increases the potential for emotional significance of clothing, see below.

It has to be noted that there is no concept as of yet of specialized performance enhancing clothing, other than the obvious, general attributes of clothing, that is, giving protection, which can increase the willingness to drive closer to the limit. Still, there are no wearable parts as of now that add mew performance enhancing components rather that just reducing weaknesses.

Future developments might change this order, as clothing could incorporate sensors, energy storage, entertainment, heating and cooling functions that are part of the car now.

An example in the opposite direction is the Mercedes "airscarf", which moves an often-needed device in convertibles, the scarf, from being part of the driver to being part of the seat, freeing the driver from having to worry about wearing or loosing a scarf (Figure I-11).

Emotional factors also influence clothing-commitment. To identify with a group, a product, or an era, one might want to wear protective or otherwise functional clothing, within or outside its original context (Figure I-15).

Figure I-15: Emotional significance of clothing with vehicle-related functional origins.
Era-sensitive weather protection in high-profile vintage car race (left); customized motorcycle, customized clothing (middle left); highly individualized helmet (middle right); wearing motorcycle jacket while walking in city (right).

The complexity of this issue opens up interesting possibilities for the humanseat, which blurs the boundaries of wearing vs. sitting in, and is able to add new components to clothing, especially where clothing commitment is high.

7. Wearing vs. Sitting In

In this context, it is interesting to explore the boundaries of sitting in vs. wearing, and what is perceived as being part of the body. Work has been done in examining in what locations worn objects will be perceived as part of the body[12]. This will be discussed later in more detail.

The basic difference between wearing and sitting in is, that we can detach ourselves and move relative to something we sit in, as opposed to something we wear. We wear our pants, but not the seat we sit on. Another distinction is the time it takes to connect: Putting on clothing can take some time; sitting down and getting back up is quick.

Another criterion is relative weight and freedom of movement: a driver in a race car can barely move, is very connected to the car, and getting in can take some time, but the car is heavier and constricts the natural movements of the driver. Even in a kart, the driver can't just get up and walk around, and is closer to wearing the cart then sitting in it.

In some racing series, for example, F1, the seat can be extracted with the driver in case of a suspected spinal injury. This still does not make the seat wearable, since the driver cannot move in natural ways.

An example that bends this rule is the cow-milking stool, which is a stool that gets attached to the wearer with a belt and therefore becomes wearable, while still being a stool.

It is interesting to look at harnesses for mountain climbing and parachutes: the harness is worn, as is the unopened parachute. Once the parachute deploys it has dominance over the human's movements, even though the human controls these movements.

Another interesting thing about harnesses is that getting into the harness takes time and can be tedious, whereas the connection to the open parachute or a safety line when climbing can be disengaged quickly.

Skiing boots follow a similar concept. The time it takes to get into and out of the skiing boot is much longer than the time it takes to connect to or disconnect from the ski, which is instant. At the same time, while connected, there is a great amount of control and feedback from the driver to the ski.

This might be an interesting direction to go for car seats, especially for racing where clothing commitment and levels of protection needed are high, and where feeling very connected to the vehicle with the possibility of rapid extraction are crucial.

8. Vehicle Control

8.1 Input vs. Output in Cars

This chapter will discuss what the inputs are from the driver to the car, how the driver gets feedback, and what components influence this system.

8.2 Research at Ferrari SpA in Maranello

During a summer internship in June and July 2006 at Ferrari SpA in Maranello, the author conducted research with some of their test- and racecar drivers on car perception, car control, and comfort while driving. This research consisted of interviews and on-road and on-track observations. Drivers of different ages, personalities, statures, professional histories, and different levels of involvement in vehicle development and testing collaborated.

Apart from their levels of mastery and their sensibilities, another advantage of doing research with drivers from Ferrari, arguably the most influential "halo" car company from a cultural, performance, and experience perspective is that these drivers are less open to superficial suggestibility of what the ultimate car driving experience is. In other words, the "search for truth" component is very high.

It was important to use medical interview- and observational techniques in order to get drivers used to evaluating and composing the handling characteristics of cars, to talk about their experiences and their perceptions, shifting the attention to themselves, away from the cars.

Another important component of the interrogation and observational techniques was to shift the driver's way of thinking away from the tradition of taking pride in the ability to adapt to and compensate for a system' s shortcomings towards questioning the shortcomings of the current setup that they were used to compensating for. Well-established ways of self-perception had to be overcome, and information that the drivers themselves had, but were not aware of, had to be collected.

Depending on the level of relaxation and comfort or tension and discomfort, the ideal state to be achieved, and potential weaknesses of the current system could be observed, helping to re-think a system that had very little perceived problems for some.

Working with a highly diverse set of drivers was very important because of the influence of personality, experience, and stature on vehicle perception. For example, when asked, what their choice of road car would be for an early Sunday morning blast on deserted roads, the older generations would unanimously choose the Ferrari F40 (manual shift, raw, no power steering), except for head test driver D.B., who, along with the younger drivers chose the Ferrari Enzo Ferrari (F1- style hydraulically actuated manual gearbox, less physically involving to drive than the F40) but then, D.B. has been very closely involved in the development of this type of gearbox. Having information like this is important when developing a novel approach to driving that should lead to a maximum level of satisfaction. At this extremely high level of car perception, the personality of the driver has therefore to be taken into account when acquiring and interpreting data and creating future outlooks.

It was also important to do observations on the road and on the track, because of different levels of speed, cornering forces, predictability, rhythm, and mental workload the different environments provide. On the road, the drivers had to pay attention to potentially unforeseeable traffic and road conditions. On roads, their head movements, positioning of their bodies, and the sequence of accelerating, braking, cornering, and accelerating again was not as predictable as on the track, which provided a highly rhythmic, highly predictable environment, thus forcing the drivers to compromise more on their positions.

Results of this research will be part of the following paragraphs about the driving experience, car-perception, physical, and mental challenges of driving, and of related paragraphs in part III of this thesis.

8.3 Driving Experience

The driving experience is made up of many factors, some of which relate to the car, like the expectation towards it and the mental satisfaction it provides, the functional, physical, and sensual experience. These are factors that the owner chooses when buying the car. Other factors depend on the passengers in the car, the purpose of a trip, its length, and the time and route chosen within the limits of reason. The driver has some degree of control over these factors, depending on the situation. Weather, road and traffic conditions, and random external factors like accidents cannot be controlled by the driver, although sometimes choices can be made to avoid potentially averse conditions.

Drivers all differ in their abilities and their interest in driving a car with respect to vehicle control, correct assessment of road and traffic situations, and in their ability to handle stress and emergency situations.

8.4 Perception of the Car

Amongst four-wheeled vehicles, the go-kart provides the purest and most immediate driving experience. Initially, the driver controls three simple mechanical inputs: steering, throttle, and brake. Due to the simplicity of a go-kart's suspension, the immediacy of the experience and due to the ratio of vehicle weight vs. driver weight, drivers quickly learn to balance brake and throttle, and to shift their body weight in order to effectively drive the vehicle through different types of corners and on different types of surfaces. This experience is "fun," and helps honing the driver's skills of perceiving the vehicle's inputs and modulating his or her outputs for maximum speed and efficiency.

8.5 Controls in Cars

Driving a car using a wheel and pedals was established very early in automotive history, with slight variations of pedal and lever arrangements and assignment of functions in early cars. While the controls for driving road cars have become very standardized, some variations remain in specialized vehicles, like racecars, or adaptations for drivers with physical impairments.

The basic principle is simple: The human gives inputs that modulate speed and direction of a vehicle, and gets feedback from the vehicle about its state. Due to the variety of vehicles, the complexities of car suspensions and electronic driving aides, this "input-output experience" is vastly different for different people and for different cars and far from optimized.

8.6 Controls in Road Cars

In road cars the driver modulates the same three basic inputs, and the choice of gear. Compared to a go-kart, the driver is rather isolated from and typically incognicent of the more complex aspects of vehicle dynamics that determine the behavior and feel of the typical road car. Depending on the expectations and abilities of the driver, the car, and the traffic and road situation at any given time, more or less, and different types of feedback are desirable.

8.7 Vehicle Feedback in Road Cars

Amongst many other ways, vehicle feedback can be categorized according to whether the driver can choose to ignore them. This yields three types of inputs, those that the driver can easily ignore, like the speedometer reading, those that the driver can ignore at some cost, like moderate road and engine noise (turn up the music), and those that the driver is forced to feel, like steering input, chassis vibrations, accelerative forces, and loud driving related noises.

Another categorization is the attractiveness of inputs: Several factors determine the attractiveness of those inputs to the driver and other people in the car:

- The modality: visual, tactile, sound, balance
- The subjective qualities of the inputs
- Are the inputs helpful, necessary, or even fun
- Can the driver choose to ignore the inputs
- What is the cost of ignoring them (turn up music, less safety-relevant feedback, etc)

Ideally, these inputs are given to the driver when and how the driver wants or needs them, in a manner that allows the driver to react appropriately and precisely in as little time as possible, with as much or as little effort as desired.

Using traditional mechanical linkages in conjunction with traditional controls, this is hard to do, and there is a fine art to balancing inputs and outputs to generate a feel of a car that suits a certain type of car and customer. Electronic systems that allow to change suspension and gearbox characteristics, throttle response, and other factors, such as exhaust routes, have broadened the spectrum a car can offer considerably. The high art of chassis tuning determines the feel, the personality of the car, the way the driver perceives the road and the vehicle, encouraging different types of driving behavior and relationships between the car and the driver. The tuning of electronic driver aides has become an essential part of chassis tuning.

Systems modulate brake and driving forces, damping rates, and anti roll bar stiffness within fractions of seconds, have made it possible to optimize a vehicle's performance, correct driver error, and to increase efficiency of acceleration, deceleration, and directionality.

Electronic driving aides have also given the driver the choice between different settings for different moods and road conditions.

Although there is an ongoing discussion about the real-world safety value of driving aids, (for example, the pulsating brake pedal under ABS braking discourages many drivers from pressing the pedal hard enough for effective braking, and driving aids, such as, stability control, can result in a false sense of security, thus encouraging inappropriate risks), it is very likely that with technological improvements and a better understanding of the interaction between the human and the car, these difficulties can be overcome.

Even with traditional mechanical linkages, other ways of improving the driver experience could be explored. Touch, vibration, and movement of the body for vehicle feedback can be positive if they are given at the right place in the right modality and in the right quantities. This thesis explores a number of novel ways how this could be done in order to create a more positive driving experience.

8.8 Vehicle Feedback and Driver Performance in Racecars

The physical and mental wellbeing of the driver is paramount in racing cars, where heat, vibrations, g-forces and mental stress can take a significant toll on a driver's performance. We will discuss later how the humanseat approach could improve the physical and mental performance of racecar drivers.

In car racing, the discussion on how much driving should be done by the driver, and how much by the car, and to what extent electronic systems can be detected and regulated, has been ongoing ever since the advent of driver aides, which increase the range and/ or frequency of change of parameters relevant to vehicle dynamics. While some drivers argue that electronic driving aides enhance the difference in skills between drivers, most would argue that they have the opposite effect.

There is an ideal suspension, aerodynamic, brake force, tire, etc, setup for every corner of a racetrack. Due to the mechanical possibilities and the regulations given today several of these parameters have to be compromised to suit several different corners of a track or even several different tracks, depending on the racing series.

As far as vehicle-driver interaction is concerned, the goals a racing car should achieve are:

- Optimal performance of car
- Optimal performance of driver
- Maximum differentiation of skill levels between drivers

Having more output channels and being able to modulate the feedback types, levels, an separating them from noise might be valuable.

8.9 Cognitive Load

Cognitive load can be described as the temporary load on working memory, determined by the number and intrusiveness of sensory inputs, and the amount of concentration that is required for dealing with them.

Working memory is a type of short-term memory, which integrates sensory and motor inputs, and internal mental states, in order to generate motor outcomes. Driving through an intersection with heavy traffic, we observe other traffic, signaling, and the feedback from our vehicle. We anticipate the development of the situation and plan our actions based of this, but also on our mental state and on higher goals. The mental state of anger might influence us go through to intersection more decisively and more ruthlessly, the higher goal of saving lives and not damaging our vehicle might prevent us from doing so.

A practical example of cognitive load is that when looking for directions, drivers often turn down the radio, thereby reducing the impact of that input on working memory, in order to be able to focus better on finding the directions.

Studies have investigated the relationship between different types of vehicle feedback on cognitive load[12]. In brief, findings show that tactile and aural vehicle feedback, if not intrusive, can provide driving-related information at lower taxation of cognitive load than vs. visual feedback. In other words, hearing the speed of the car leaves more cognitive capacities for other aspects of driving than having to look at the speedometer.

Presenting vehicle feedback in a way that is pleasurable while requiring low cognitive load capacities will become more important as the demand for and availability of entertainment, navigation, and communication related systems increases.

8.10 Hand vs. Whole Body

In environments where drive by wire is feasible because cost and/ or safety issues can be overcome, such as, fighter planes, heavy construction machinery, or computer games, joysticks have been the mode of vehicle control of choice. Joysticks have many advantages: Not only do our hands have excellent temporal and spatial resolution for sensing and executing movements, their mass is also relatively low, which is conducive to precise movement in environments where there are high g-forces or vibrations. The muscle groups that control hand movements, and the motor and sensory brain areas are well equipped to do highly sensitive tasks, and are highly plastic, making it easy to train and improve operation by joystick. Since the wrists and the digits can be moved independently, multiple functions can be assigned to joysticks.

Joysticks have also been employed in car prototypes, with good results as far as operability and learning curves are concerned[13]. Various input/ output schemes have been employed, with two basic models, either using force/ pressure as input, or joystick movement. Theoretically, the human hand and wrist can move and rotate a joystick in three axes (x/y/z) simultaneously (there are six degrees of freedom in 3d space – movement in the three axis and rotation in the three axis). Pressure of the digits and the thumb can also be modulated. If the joystick is also responsive to pressure, 7 input/ output pairs are thus possible.

For a car, one could imagine that tilting the joystick forward and backward would modulate speed, tilting it sideways the steering angle. These are the basics, but as discussed above, more outputs could be desirable, for example, for camber of the front wheels, stiffness of stabilizer bars, and for brake force distribution front and rear. In a simple and intuitive graphic conversion, rotating the joystick around the y-axis could relate to turning of the front wheels, while tilting the joystick sideways could relate to front wheel camber.

As discussed in the chapter about coordination, it might be interesting to use the body's ability to instinctively and intuitively control many channels simultaneously through gross motor coordination. The challenges lie in the mapping and in the ability of the control movements to be performed correctly and intuitively during situations of high physical and mental stress.

9. Conclusions: Challenges and Limitations of the Current Setup

Current car seats have evolved from seating in houses, an environment with fewer constraints that allows more movement to the occupant than a car. This aggravates the problems caused by sitting in regular chairs, since sitting in cars is rather stationary and there are many functional and safety constraints to be met.

The inherent problem in current car seat design is that being safe, feeling connected to the car and getting good support in high-g situations is typically contradictory to being comfortable, especially over long distances, and having freedom of movement. In order to make up for their inherent shortcomings, variable cushioning, position adjustment, massaging, heating, and cooling functions have been added to car seats, adding weight and cost.

Furthermore, although beneficial from a cognitive load[12] and responsible driving, as well as entertainment point of view, feedback is not always presented to the driver in a way that is considered entertaining, otherwise beneficial, or even pleasant and sensual. This creates a conflict between receiving tactile and aural feedback about the driving situation vs. being comfortable.

These challenges are inherent to the evolution of car seats. In part II, we will discuss possible solution approaches.

10. Wheelrobots

10.1 General Concept

Wheelrobots are basically the re-introduction of the horse: autonomous, intelligent entities that can drive a vehicle, but are connected to it in a temporary fashion.

Wheelrobots are addressing the question of packaging and distribution of the powertrain in a contemporary vehicle, reaching back to earlier transportation such as the horse drawn carriage. Although such a concept might seem archaic it does have the most compelling feature of an autonomous, somewhat intelligent and detachable powertrain. Horses could be swapped out in an instance in case of an injury; they would not willfully run the carriage of the road and adapt their gait and speed intelligently based on very simple commands communicated through the reigns.

The author initiated the development of the Wheelrobot concept and researched its impact during the first few months of the design studio. In our search for modularity, the Wheelrobots represent the ultimate step in modularization, while taking full advantage of the opportunities provided by electrical motors and drive by wire. All the mechanicals required to drive the car are located in or right next to the wheels.

This Wheelrobot assembly is then connected to the chassis in a plug-and-play fashion, the connection providing mechanical stability, feeding of power to and from the Wheelrobot, and control input, unless the latter is provided wirelessly.

The original designs and explorations were based on the idea of the electrical motor not being part of the unsprung and rotational mass, of a perfectly vertical active suspension with adjustable camber, and a steering axis going trough the center of the contact patch. The principle is simple: an ideal geometry where all the parameters that influence vehicle dynamics can be adjusted independently of one another in order to optimize vehicle performance at any given time. Another option that comes with the Wheelrobot concept is Omnidirectionality, which can have a great impact on safety, performance, and traffic and storage contexts for cars. Imagine you can parallel park sideways. Used in a foldable, stackable platform omnidirectional steering could increase the number of cars parked over five-fold per city block, and over eight-fold for parking garages.

The Wheelrobot concept introduced here was integrated into several projects of the group and was developed further by Retro Poblano and by Peter Schmitt.

10.2 Implications on Chassis Design, Vehicle Production and Maintenance

The concept of putting all the mechanicals of the car into the space of the wheel and connecting the resulting Wheelrobots to the car in a plug-and-play fashion, not only greatly simplifies design and production of the chassis, it also separates production, usage, life- and maintenance cycles of the mechanicals from the rest of the car. It also drastically changes the investment and size requirements for car maintenance and production facilities.

The fact that Wheelrobots can react to the load and road conditions they encounter while taking into account the commands from the driver in a highly effective manner, just like horses can, has potential implications on chassis design: rigidity, which usually comes at a high cost in weight and money, can be replaced by intelligence.

The rider would never be strong enough to physically hold together the two horses he is standing on, yet, the autonomy and intelligence of the horses allows him to control them.

This leads to the opportunity of constructing novel types of chassis, one example being the "Athlete Car," that will be discussed in part II.

Part II: The Humanseat Design Principle

In medical school we were taught, "walking and lying down are good, sitting and standing are bad, for your lower back and for blood circulation of the lower limbs."

Apart from the fact that when we walk, we move our legs more than when we sit or stand, a major difference between walking vs. sitting or standing, is that when we walk, our pelvis rocks in the sagittal (frontal) plane, and this movement is transmitted to the lower spine, while during sitting and standing, the pelvis is mostly stationary in the sagittal plane. When lying down, on the other hand, the workload of our muscles is distributed temporally and anatomically in a manner that ensures optimal relaxation of the muscles, the joints, and the mind.

One goal of the humanseat project is to achieve the physical and mental benefits of walking and lying down for the position that we spend most of our awake time in: sitting.

The other goal is to enhance the sensual experience and the perception of movement, through touch and vibration, to improve vehicle perception, control, and wellbeing.

1. The Original Humanseat/ Wearable Seat Concept

The original concept of the humanseat, at that time referred to as the "wearable seat," was to provide a support and safety system with a large contact area with the occupant that would allow for the movements of the occupant while being as unobtrusive as regular clothing: hence the name, Wearable Seat. Other than "holding the occupant like a mother holds her baby" (William J. Mitchell), the wearable seat could also provide entertainment, well being, and diagnostic functions.

As discussed above, regular car seats tend to be either comfortable and provide freedom of movement to the occupant, or they tend to be safe and provide good feedback from the car to the driver. Additionally, restraint devices, such as, three-point seatbelts can safe lives in an accident but can be uncomfortable, and therefore are not always worn. And even if they are worn in an accident they can cause burns, liver ruptures, clavicular fractures, and other injuries. The belt geometry and the trajectory of the passenger in an accident necessitate design restrictions to the cabin due to the need for impact absorbing materials, airbags and the like, that can only work in specific spatial arrangements.

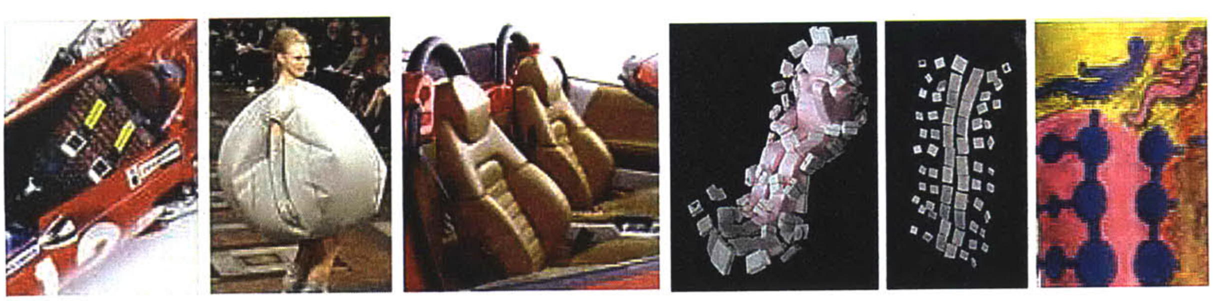


Figure II-1: Origins of the original wearable seat concept.
High levels of connectedness to car and safety in race car at the expense of comfort and freedom of movement (left panel); airbag-looking dress at fashion show (2nd from left); car seat with three point belts (left middle); foamcore model of wearable seat concept on figurine (middle right); foam core and wire model of wearable seat concept with ribs and double spine (2nd from right); original skech of concept (right panel).

The first iterations of the wearable seat were designed and built in collaboration with Axel Kilian. Segments were built, that were attached to a double spine. Geometric concepts were explored and prototypes were built of passive segments that would follow the movements of the occupant but tighten their grip if sudden large forces were to occur. One segment was made in foamcore, followed by two segments that were made out of acrylic.

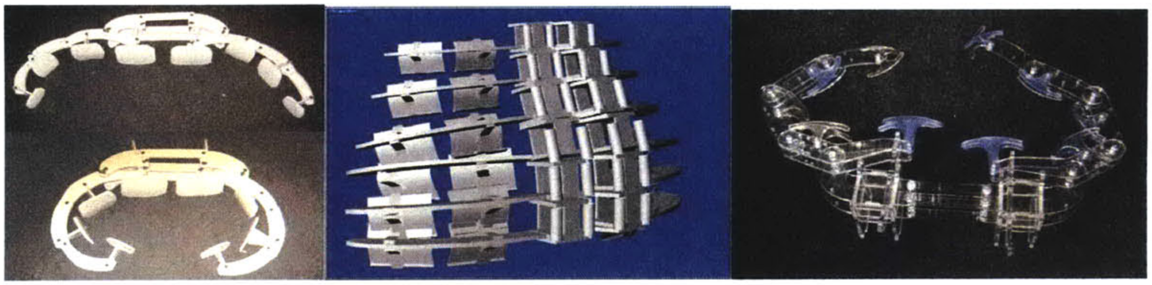


Figure II-2: Models of Wearable Seat segments.
Foamcore model of wearable seat segment (left panel); parametric 3D model in CATIA (middle panel); segment made from acrylic (right panel). Patrik Kunzler with Axel Kilian.

2. Combining Wheelrobots and the Wearable Seat: The Athlete Car

Combining the intelligent Wheelrobots with an intelligent, articulated chassis for collaborative driving – eliminating the distinction between driver and passenger, thereby making the act of driving itself a team sport – lead to the Athlete Car, based on initial explorations by Axel Kilian, who at that time was a PhD student in architecture at MIT. The Athlete Car was continued as a group project with the following contributors: was continued as a group project with Axel Kilian, Mitchell Joachim, Peter Schmitt, Luis Berrios-Negron, Kate Tan, Franco Vairani, and the author.

The idea was to translate the physical and mental experience from dynamic sports, such as, skiing, and ice-skating, into a vehicle, breaking away from the traditional notion of a sports car that consists of a rigid chassis with a large engine, large tires, and large brakes.

Using the BMW skateboard as inspiration, our design approach was to fragment the chassis into dynamically functional and efficient units that work naturally with human movement- and coordination capabilities to provide a thrilling and highly efficient sportscar driving experience. An iterative design process was used to investigate multiple angles of the sports car: Vehicle dynamics efficiency, maximizing the driver experience, and pushing the envelope at the level of technology, materials, and emotional driver experience and vehicle personality

Figure II-3: Collaborative driving using body movements (Axel Kilian).

2.1 Collaborative Driving Using Body Movements

Explorations were made on how the traditional chassis could be fragmented and put together in new ways that express complex but intuitive, coordinated body movements and maximize the thrill of driving without having to rely on lots of power to achieve this goal.

Instead, coordination of one' s body and with that of the co-driver, leaning, and movements of the parts of the chassis carrying each co-driver relative to each other were the aim as means for thrills. The car would move with the body, adopting and expressing the driver's personality and skills through its movements. The goal is to have a car that feels more like a surfboard or downhill skis that do not require high speeds for graceful elegant and joyful motion (Figure II-3).

The most logical path to achieve this goal was to conceive of an articulated chassis that would move expressively just as the human body does.

2.2 Articulated Chassis

From a performance point of view, an articulated chassis makes sense for a sportscar in many respects, especially in conjunction with Wheelrobots.

In brief, there are basically two mechanisms by which wheels can generate cornering forces. Change of slip angle ("steering" creating an angle between the direction of travel and the rotational axis of the wheel that is not 90 degrees), and camber (tilting the rotational axis of the wheel away from horizontal). On loose surfaces, like gravel and snow, there is an additional effect. A wheel traveling at an angle relative to the direction of travel, pushes up some of the material it travels on, similar to snow accumulating in front of a snow plow driving down a street.

Since the wheel robots are intelligent and can apply traction, braking, and cornering forces ideally for any load and surface that they are given, the ultimate goal of the Athlete Car has to be to distribute the weight and position the wheels relative to each other so that these Wheelrobots can perform optimally.

Continually moving the center of gravity, and varying the position of the wheels relative to each other could all make driving more efficient, but are impossible when using a rigid chassis. The effectiveness of these strategies can be seen in motorsports: In motorcycle sidecar racing, the co-pilot moves his body forward or backward to help acceleration and braking, and sideways to aid cornering. Adjustable wings for less drag in straights and more down-force during cornering and acceleration were employed in several racing series before they were declared illegal.

An articulated chassis (Figure II-4) could take these ideas much further. Making the car narrower and longer in straights, and wider during cornering would make the car more efficient. The center of gravity (CG) and the wheels could be placed according to the requirements of each specific corner, depending on radius, banking, and road surface. The longitudinal distribution of the wheels could change; making sure that every wheel is working under optimal conditions at any given time. For example, corner entry could be done by one wheel temporarily located in front of the other wheels, while the other wheels still focus on barking, traveling in a straight

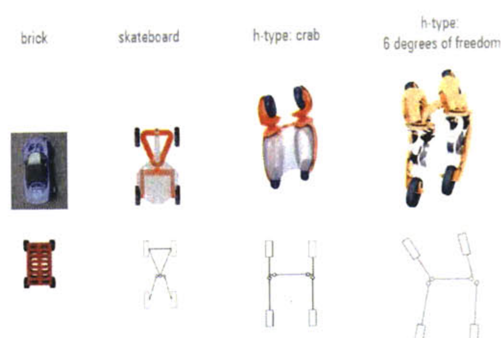


Figure II-4: "Escaping the brick." Geneology of an articulated chassis. (Axel Kilian[14]) line. All four wheels would subsequently change from a straight-line function focused mainly on braking into full cornering performance. At corner exit, the first wheel (inside front) would be in a straight line again before the other wheels, being able to fully focus on pulling the car out of the corner. The other wheels would follow. The swarmed vehicle was an exploration of the most efficient arrangement of four loosely connected wheels for cornering.

There is no place where this could be illustrated better than in the gravity and g-force free world of cartoons. Let's imagine Pluto speeding down a winding road on rollerskates. He can constantly move his center of gravity; he can move legs laterally and longitudinally

Our bodies are articulated, they consist of several parts that are joined together with joints and ligaments, and are actuated with muscles. Performing extremely complex coordination tasks while moving is natural to us. Our capabilities in doing so far exceed what is possible using artificial intelligence and smart materials, since even the most simple balancing acts are hard to achieve with machines, let alone movements as complex as skiing. It would thus make sense to use those capabilities to optimize the performance of our vehicles.

2.3 Flexible Skin

An articulated chassis would require a flexible skin. This can be challenging because there are no suitable materials yet that can provide flexibility and sufficient transparency for safely driving a car. Several concepts were explored with different assignment for flexible vs. non-flexible surfaces. Entry paths were also explored, some of which evoked interesting analogies with life.

2.4 The Muscle Car

The term muscle car in the sense of an automobile with excessive muscle, as in tangible, raw power and bravado, was born in the United States of the 1960s and 70s. Of course the association of muscles with strength, speed, and elegance, is much older and most likely pre-dates modern man. Using air muscles to move the articulated exoskeleton based chassis; we are going back to the roots (ref athlete paper, Axel's thesis).

Novel technologies are emerging that use the principle of linear contraction of flexible entities, similar to biological muscles in industrial settings. One of the companies at the forefront is FESTO®, who developed a technology of air muscles that contract as the air pressure inside them increases. This technology is lighter than hydraulics, cleaner, can be actuated very rapidly and precisely, and the pressure differentials required are rather small.

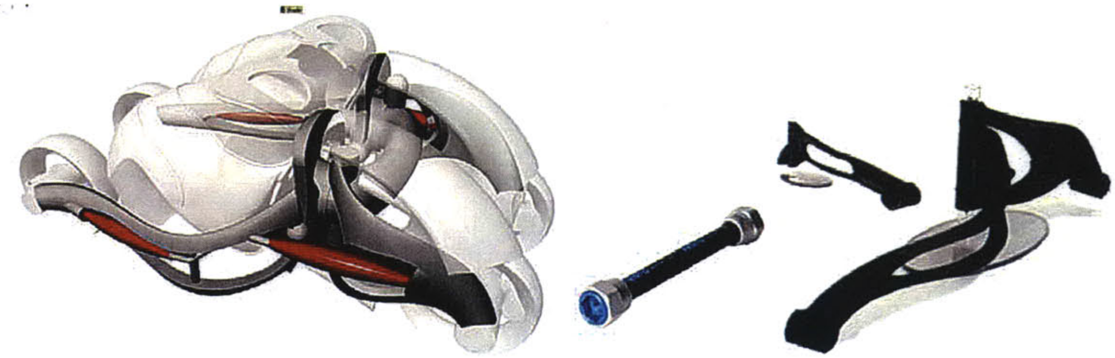


Figure II-5: Rendering of "Muscle Car."
An exoskeleton like chassis and actuated air muscles (left); FESTO air muscle (middle); 3D print wrapped in carbon fibre with inserted air muscles (right). (Axel Kilian, Peter Schmitt).

Combining these air muscles with our articulated chassis, we created a new type of muscle car that has muscles and bones, evoking or much rather, returning to the original notion of muscles on humans, horses and other animals that convey this idea (Figure II-5). It would even be feasible that driving and braking power is generated using air pressure. There are several projects in that direction all over the world, mostly for ecologically sound, non-aggressive city vehicles. For the Athlete Car, several personality scenarios were explored.
Vehicle Personalities

The Athlete Car is a novel vehicle concept and can therefore be developed in several directions as far as vehicle personality is concerned. A fundamental difference to regular cars is that the drivers become one with the car to the extent that their personality as expressed in their postures and movements, influence the shape and the movement of the car.

Traditional sports cars have carefully composed personalities that a potential buyer or the general public should be attracted to and should want to identify with. The car is meant to express something about the owner, thereby enhancing some, while changing other aspects of how the owner perceives himself or how others see him. The way the owner can influence the personality of the car is limited to customization, choosing engine and suspension specifications, color, wheels, exhaust system and interior trim, and by how the car is driven.

Like a musical instrument, which sounds different when played differently or by different musicians, experts can distinguish different drivers by the way a car is driven on a track. This can be difficult for experts and virtually impossible for the general public, so it makes sense to paint different driver's cars, or the driver's helmets, differently.

The Athlete Car takes this one step further. Because the relationships of its chassis components toward each other and the way they move are mapped after the posture and movements of the drivers, much higher levels of expressiveness can be reached.

Apart from the personality the driver gives the car; the car can also have a personality of its own, like traditional cars do. Scenarios were developed, expressing extreme characters and associations around sports cars, the emotions they evoke and their role in traffic and society. Designs were developed by Mitch Joachim and Axel Kilian that have hypermasculine and aggressive, soft, accommodating and feminine, or highly rational and technical traits (Figure II-6).

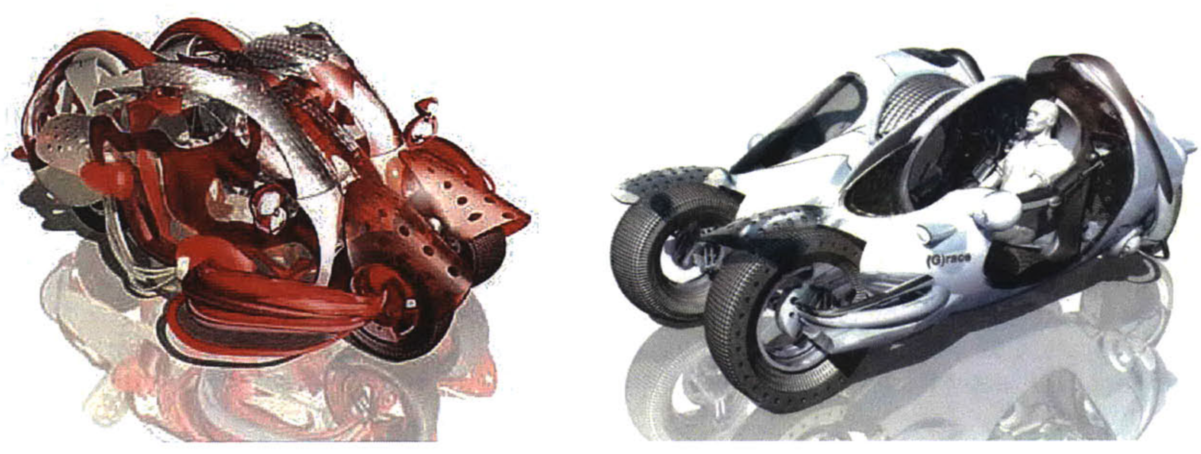


Figure II-6: Vehicle personalities for Athlete Car.
"Cerberus, car from hell" (left panel); (G)race (right panel). (Concepts, renderings: Mitchell Joachim.)

2.5 Movement Mapping Studies

A key aspect of the articulated car is that the mapping of the movements of the driver to the car allows for dancing- like collaborative driving by articulating the eight joints of the Athlete Car. The seating in the Athlete Car translates movements of the arms, legs, and the core of the body into leaning and other movements of the articulated parts relative to each other, thereby conveying a sense of speed, cornering forces, motion and emotion. There are instances where there are variations in mapping of mechanical driver inputs to vehicle outputs. In early automotive history, there was no universal understanding yet on the number of pedals and how they should be assigned to different functions.

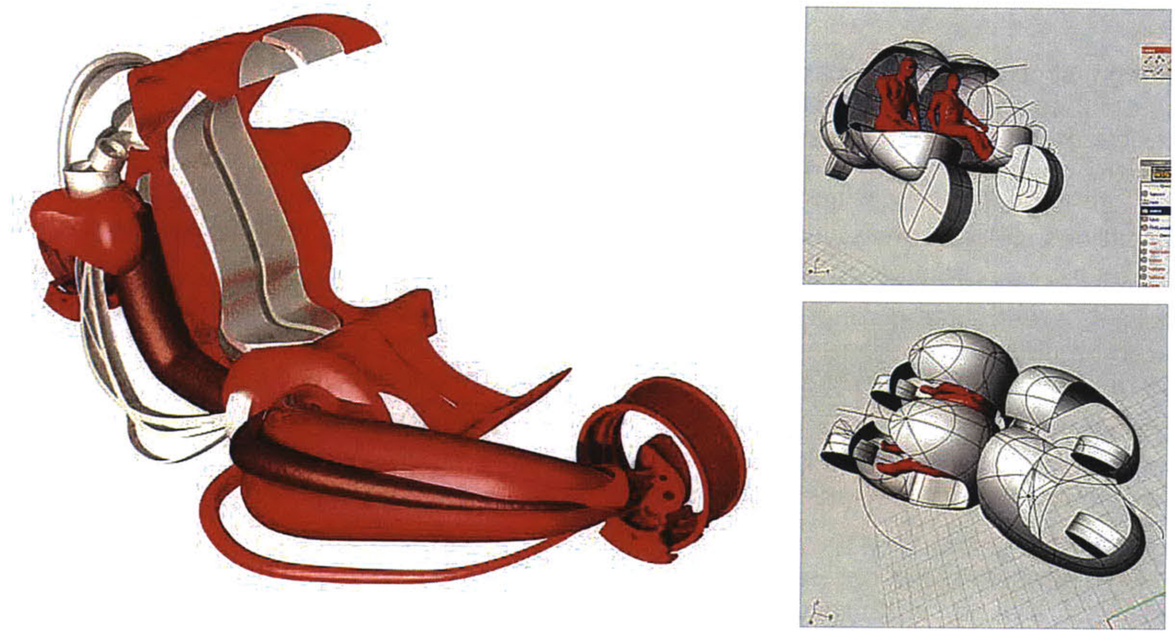


Figure II-7: Articulated seat connected to air muscles and Wheelrobots. (Left panel; rendering: Mitchell Joachim; Concept: Mitch Joachim, Axel Kilian, Patrik Kunzler); sythematid drawing of motion and banking of four sections of Athlete Car relative to eachother (right panel; Axel Kilian).

Several mapping options were discussed for a seat controlling an exoskeleton and a Wheelrobot (Figure II-7).

Drive by wire, that is, electronic transfer of input and their modulation to output signals theoretically means that any input could be mapped to any output. For a real-world road or track vehicle, this of course has to be done in a way that is safe. For good performance, it has to be done in a way that is intuitive and quick.

There are two extremes when mapping movements to vehicle outputs: Applying force to a non-moving (or barely moving) joystick, or using one's whole body to determine direction and acceleration of a vehicle. One could of course think of much more radical scenarios, like sensing input directly from the brain and translating it into output without taking the detour through the body.

Since the goal of the Athlete Car is to be involving, even demanding to drive, a whole body experience, we studied possibilities of mapping whole body movements to vehicle output. In our model, the basic functions are performed in a way that the CG of the body does not need to be moved: Acceleration and deceleration are done with a joystick, and the basic function of turning the front wheels left and right is done with the feet. This was done considering aspects of safety and fatigue, but also to insure that the skill level required for basic driving is low.

Movements of the hips and shoulders were assigned to more complex, secondary functions that would increase the performance of the car, the complexity, and the enjoyment.

Like in windsurfing or well-designed computer games, controlling the car for beginners is easy, intuitive, and fun. This leads to a steep learning curve to rapidly attract novices, and in order to encourage drivers to reach higher levels of controlling the car, having even more fun. At the highest level, both drivers will have to use their whole bodies and perfect coordination in order to drive the car at its maximum efficiency, because a driver can only control his/ her side. This will of course to encourage elegant and harmonious collaboration, like in dancing. How the seat would contribute to this driver-driver coordination will be discussed below (Figure II-8).

The maximum number of functions to control the Athlete Car is seven; the minimum required is three. The functions are designed for three categories of drivers: beginner, higher level, and expert.

Minimal functions (beginner):

- Movement 1: Simple push-pull movement of left and right foot to steer the front wheels.
- Movement 2: Joystick back-forth to control acceleration/ deceleration.
- Movement 3: Extension of legs for pre-loading the front suspensions.

  Our legs and the nervous systems relating to them, are the result of millions of years of evolution to perform well at suspension functions, can push the front wheels down or lift them up during lateral ad longitudinal weight transfer, or to make going over bumps more efficient by pulling up the wheels during the transfer from horizontal to uphill, and push them down during the transfer from flat to downhill, thereby making travel over undulations in the road more efficient.

Alternatively, the leg as a whole could act on the front and rear suspensions equally, while the angle of the ankle determines the pre-load of the front vs. the rear wheel, tiptoeing giving more pre-load on the front. Other intuitive movements bring driving to a higher level:

- Movement 4: Leaning the upper body left-right to lean the "eggs".
- To lean the eggs on one's side, one flexes one's upper spine sideways. This is intuitive and easy to do, a whole body involvement like on a motorcycle.
- Movement 5: Rotating shoulders to determine the longitudinal angle between the "eggs".

  Rotating one' s shoulders determines the angle between the front and the rear egg on one's side.

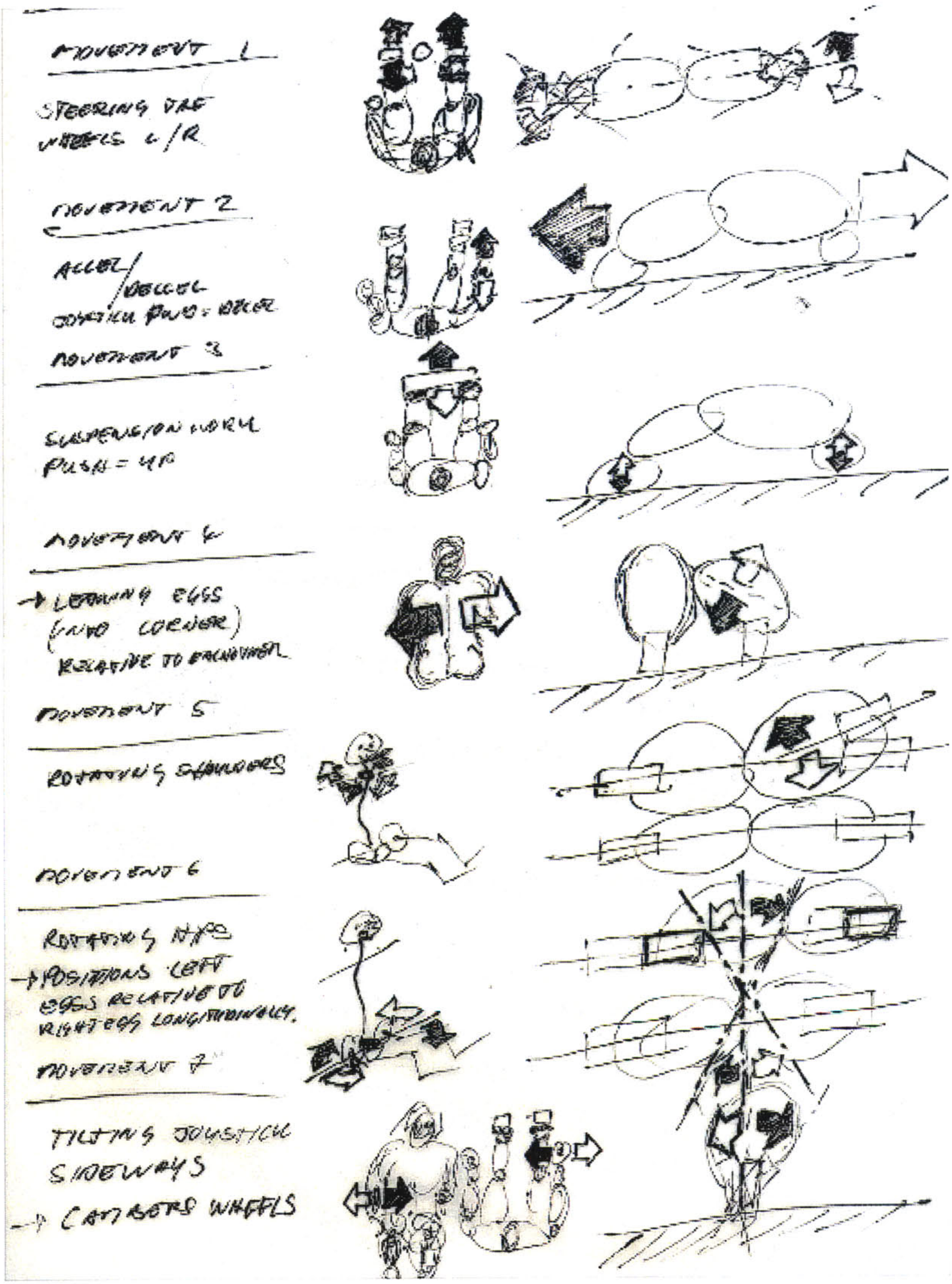


Figure II-8: Possible vehicle control strategy.
Combining joystick and whole body movement for safety, fast initial learning curve, and good differentiation between beginner and expert.

For experts, 2 more ways of controlling the car are available:

- Movement 6: Rotating hips to position "eggs" longitudinally (inner ski first effect).

  To get the inside eggs to go ahead of the outside eggs in a corner (like in skiing), one has to rotate one's hips so that the left hip moves forward and the right hip moves backward if one is sitting on the left for a left hand corner. So the right leg will actually be stretched more than the left leg, since, for left hand corner, the right foot goes forward to turn the wheel, and the right hip backward.

  It is also much more intuitive than foot and hip going parallel, it's anatomically easier to do, and allows for faster change of direction, as the diagonal axis of the body gets tensed up, ready to release like a spring.

- Movement 7: Tilting the joystick sideways to camber the wheels.

  This is light and delicate, and therefore more of a cerebral activity than the legwork; it requires smartness and understanding of driving dynamics. It should convey the joy of controlling a powerful horse with smart, well- measured inputs.

Communication Between the Co-Drivers

When two people are dancing or figure skating together, they coordinate their movements through visual and tactile signals and observations, while music helps for temporal and anticipatory coordination. Tactile communication can be purely observing, but it can also express readiness to receive commands or express the commands themselves.

For the Athlete Car, a hydraulic or pneumatic system was sketched out that gives non-imperative (the input does not force a reaction) tactile feedback between the two seats. A valve could regulate the flow of liquid or gas in the system to vary the dominance between the two co-drivers, for example, for training purposes.

This would add a tactile, communicative component for communication between the drivers, adding to the ways in which one driver can make the other feel good.

A lot of these movements are borrowed directly from a well-known complex body coordination paradigm, skiing: like the suspension work by the legs, the rotation of the shoulders and the hips. While some advanced driving functions involve the whole body, others are subtler, like tilting the joystick for camber control. In order to do the more sophisticated positioning effects of the eggs relative to each other, very coordinated whole body input is required, like in skiing, surfing, and horse back riding.

This is one of many possibilities of mapping body movements to an articulated chassis. Of course, simulator- and real-world tests would have to be done to determine what mappings are most successful in using our muscles and our bodies in a dignified, elegant, and joyful way to drive a vehicle.

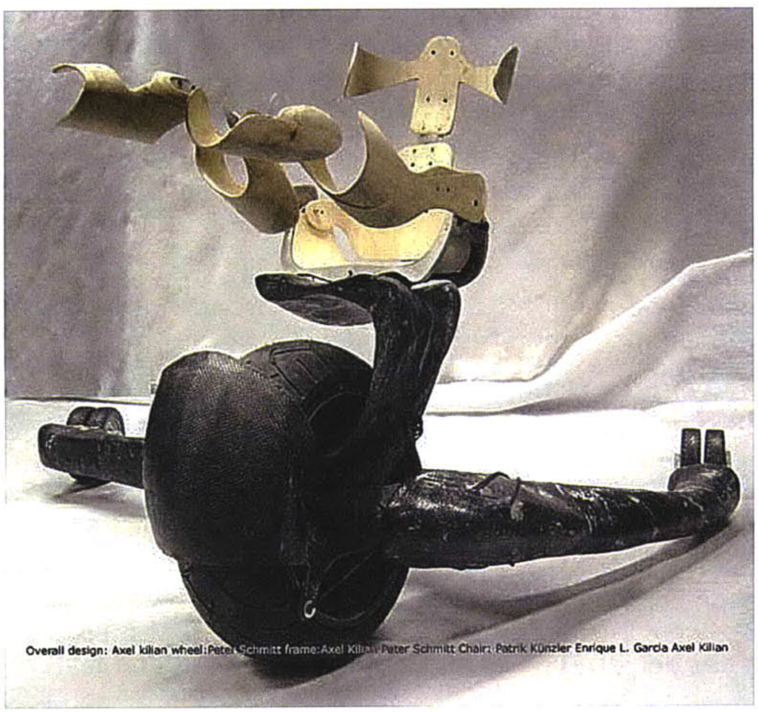
The simplest way of expressing the driver's personality and virtuosity in a vehicle is to let the driver be the vehicle, with the minimal element required for efficient moving on flat surfaces, the wheel.

3. The Mini Athlete

The most minimal and most radically expressive way of experiencing a sports car is, of course, to ride on top of a wheel with no protection, controlling it with one' s body movements, using the natural sense of balance and coordination to drive the vehicle.

Axel Kilian did initial studies of combining a Wheelrobot with the wearable seat: The Mini Athlete was born. After initial quarter- and half scale studies in cardboard and foamcore, and milled foam and acrylic, respectively, a full size prototype was produced in a collaborative effort between Axel Kilian, Peter Schmitt (wheel and base), and Patrik Künzler and Enrique J. Garcia (seat). The wheel mechanism was based on a later iteration of the Wheelrobot and built from carbon fiber. The other parts were made from milled foam core and wrapped in carbon fiber for stability. Four ropes, eventually to be replaced by FESTO air muscles, were attached to the Wheelrobot in order to control the longitudinal angle and camber of the wheel relative to the vehicle.

An extension of the base emanating from the center of the wheel and sweeping above it served as the base for attaching the humanseat (Figure II-9).



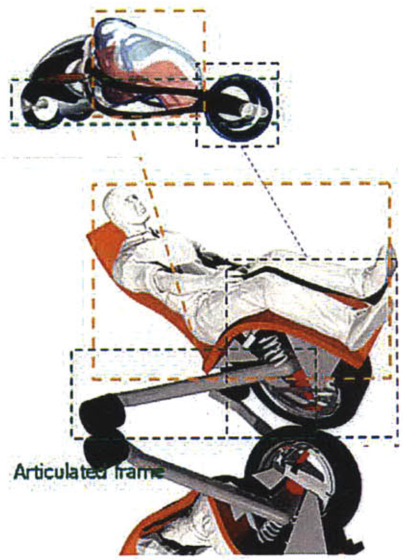


Figure II-9: Mini Athlete.
Left panel: The final Mini Athlete prototype, combining a Wheelrobot with the humanseat Mk1. (Overall design, Axel Kilian; Wheelrobot iteration, Peter Schmitt; Seat: Patrik Kunzler, Enrique J. Garcia); right panel: derivation of Mini Athlete concept from Athlete Car concept[15]

4. The humanseat Mk1

The first iteration of the humanseat (Figure II-10) was designed to allow and even encourage skiing- and bicycling-, or related movements of the body while providing support and protecting the occupant to generate control output when driving the highly agile and involving vehicle the Mini Athlete was designed to be. These movements were explored in real life and in 3D CAD modeling, and the seat was constructed around them.

This work was done in collaboration with Enrique J. Garcia, at that time a masters student in material sciences at MIT.

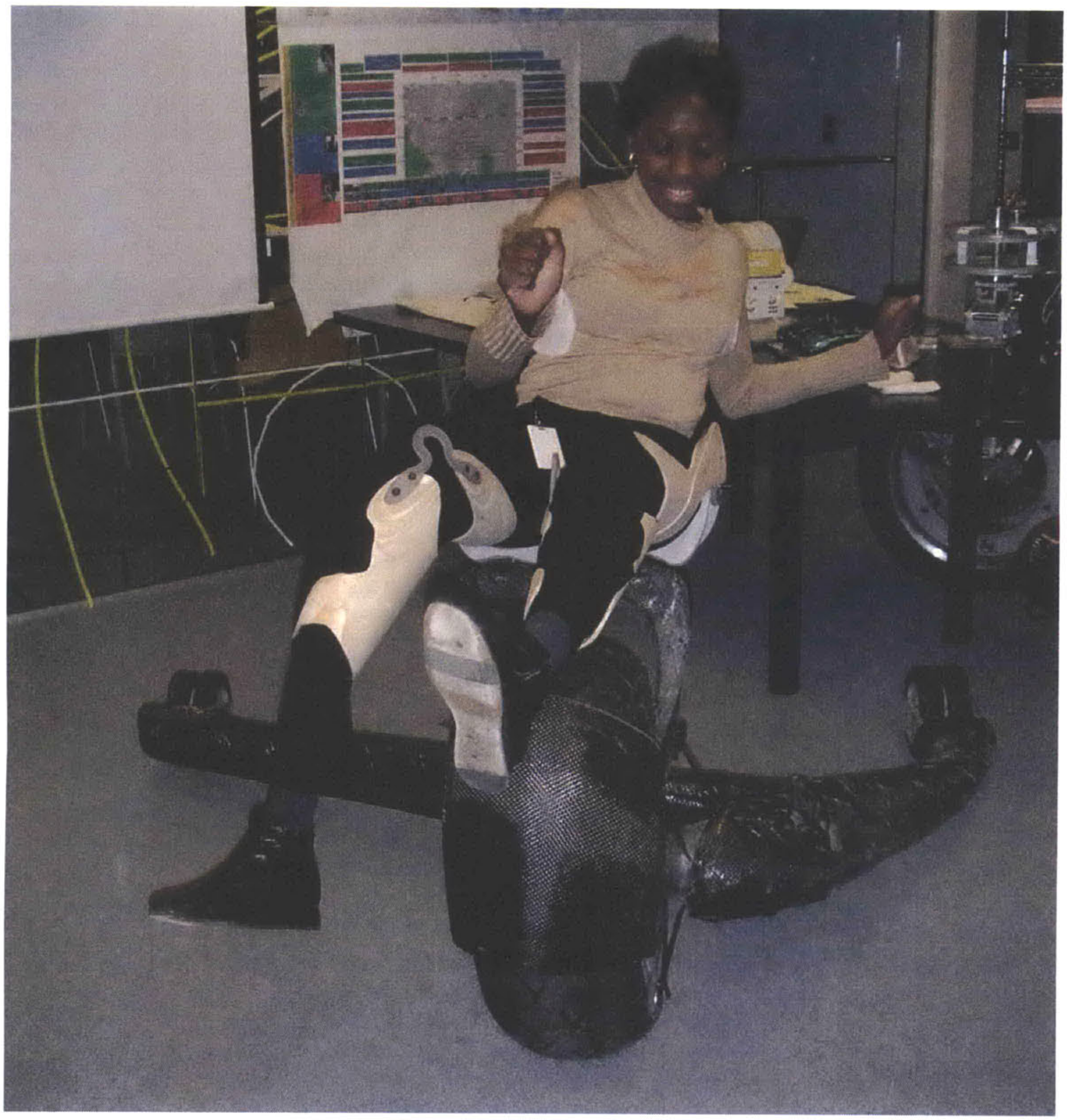


Figure II-10: testing of the humanseat Mk1 mounted on the Mini Athlete.
The subject – who does not ski – spontaneously started making skiing and bicycling movements showing visible enjoyment after a short period of familiarization with the seat.

4.1 Design Philosophy

The original concept was an evolution of the wearable seat. The goal was to design and build a sensual, elegant, intelligent and articulated, partially wearable seat that would not only allow, but also facilitate, reward, and encourage body movements, especially skiing- and bicycling movements. It had to be beautiful, fun, sensual, and, moving.

Earlier we discussed common notions of comfort, fit, and wearability. The typical ways to satisfy these notions would have been to employ cushioning and straps in the design (Figure II-11). In order to learn the most from the process and in order not to restrict ourselves to preconceived notions of what a comfortable, sensual, and wearable chair is, we decided to not use this approach.

Figure II-11: Typical contemporary knee brace employs flexible materials, cushioning, straps, and a multi-axes joint configuration.

Instead, we decided to use hard materials, such as, plywood, metal, and polycarbonate to maximize the necessity for considering the actual shapes, textures, and movements of the human body in the design process. This turned out to be a big challenge design wise, as well as to our minds, since going the easy way is rather tempting and often the most logical way to do things. The constant comparison with traditional design solutions ensured that we would not succumb to the notion of being different just for the sake of trying new ways.

Figure II-12A: Connectiong piece from Mini Athlete to humanseat (top).

4.2 Constraints Given by the Mini Athlete

The part of the seat that supports the buttocks is connected to the Mini Athlete and was designed as part of it (Figure II-12). Contrary to the humanseat Mk2, the part of the set supporting the buttocks was fixed. The seat was then developed downwards towards the thighs, shins, and feet, and upwards towards the lower back, torso, and shoulders, to allow banking movement (Figure II-12B).

Figure II-12B: Skiing-like banking motion to steer Mini Athlete (below).

4.3 Wearing vs. Sitting In

We did initial explorations as to what parts of the humanseat for the Mini Athlete could be wearable, and what parts one would sit it.

Making parts of the seat wearable would simplify the act of entering or mounting the vehicle. The connection could be done with a simple snap-on mechanism, similar to ski bindings. Not only would this intensify the connection between the vehicle and the driver and increase the drama of the act, it would also reduce the time required to a minimum. The wearable seat would be comparable to a skiing boot, which is bought to fit the individual. While the act of putting on the skiing boot takes time, the connection and disconnection with the skis is very quick. This might be interesting for racecars, as we will discuss below.

Other potential advantages of a wearable seat are identification, and functional benefits. Apart from being potentially useful to the wearer when not connected to the car, the advantage of wearable parts is that they can provide better support and fit, while being smaller and weighing less than non-wearable parts. This is mostly due to the fact that getting in and out easily is not as much of a concern with clothing and wearable parts as it is when getting in and out of a vehicle. The next step exploring wearable parts lead to the Snakeseat.

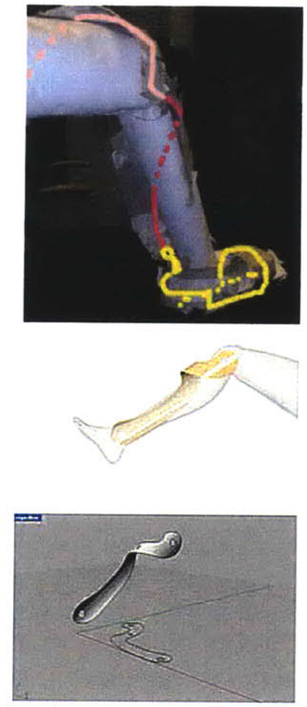


Figure II-13: Development of the Snakeseat. Support in all directions with minimal surface. Critical contact points in areas most consistent btw. individuals. From top to bottom: paper testleg; Poser and Rhino modeling; unrolling 3D part onto 2D surface.

4.4 Initial Studies of Wearable Parts: The Snakeseat.

The idea of the Snakeseat was that it would wrap itself around the leg like a snake, providing maximum support and tactile feedback with a minimal amount of material and covered area. A full-scale paper leg with an anatomically correct knee joint was made (Figure II-13) to explore the areas a minimal seat would have to touch in order to be able to fully support the leg in all directions. Contact points were chosen from a biomechanical and from a wellbeing point of view. Anatomical variation between individuals was also considered, since wearable parts of any given size should be comfortable for as many people as possible. Studies on what is perceived as belonging to the body and what is not for wearable objects were also considered[16].

Designs were then made using the Poser and Rhino software. Poser is a 3D modeling environment for human shapes and movements. People of different sizes and body types and their movements can me modeled. Modeling of movements from the start was important, since the end goal of the project was for the seat to encourage and reward movement (Figures II-13, II-14).

The designs were then printed out on letter-sized paper, cut out, and fixed together with scotch tape for trials on people. The advantage of the paper method is, that it allowed for quick and cheap adaptation and testing of shapes. Since the function of the seat was going to be supporting the body, we switched to a different, stronger material that has similar characteristics as far as types of curvatures that were possible, plywood.

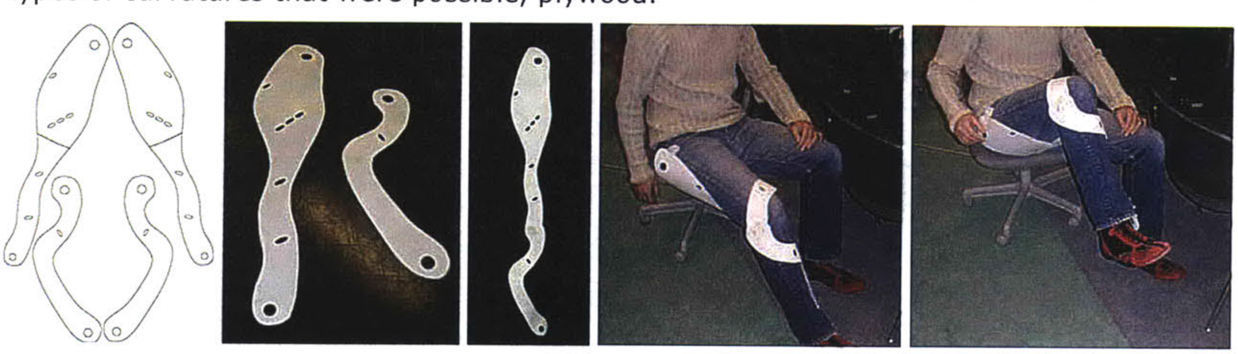


Figure II-14: Paper printouts of test leg "Snakeseat"
(From left to right); after cutting out, combining with knee joint made from masking tape; trial on author.

4.5 Structural Wearable Parts: Plywood

The next step was to re-produce the paper Snakeseat in plywood. Plywood was chosen because it is a cheap, readily available and easily customizable materiel using a lasercutter that can only be shaped in simple curves, forcing us the think more deeply about the body. Plywood, if untreated, is also very sensual to the human touch and provides the right amount of friction for this application.

Regular $^1/_8$-inch strength plywood was bent as described below. Initially, all parts were designed to be wearable, since it would be easy to subtract from them to facilitate getting in and out.

The initial parts were a development of the Snakeseat and consisted of single-layer pieces of plywood that were pre-tensioned, i.e. their radius was tighter than the leg they were meant to fit for stable attachment to the leg (Figure II-15). The attempt was to create positive tactile feedback during movement. This same mechanism could also be explored to aid venous blood flow in the lower limbs. Contrary to arteries, veins do not contract actively but have a number of valves instead. When the muscles flanking a vein contract, the blood gets squeezed out in the direction that these valves allow, towards the heart.

After the initial single-layer prototype, pieces consisting of two layers of plywood were made for greater strength and better stability and fidelity of their shape. The first pieces were connected with screws, followed by a test piece using screws and glue. Our initial pieces had cutouts for easier bending and lightness. The cutout also increased our precision when bending the pieces, since the inner and outer pieces were designed for exact alignment of the cutouts (Figure II-15). For greater stability, later pieces did not have cutouts.

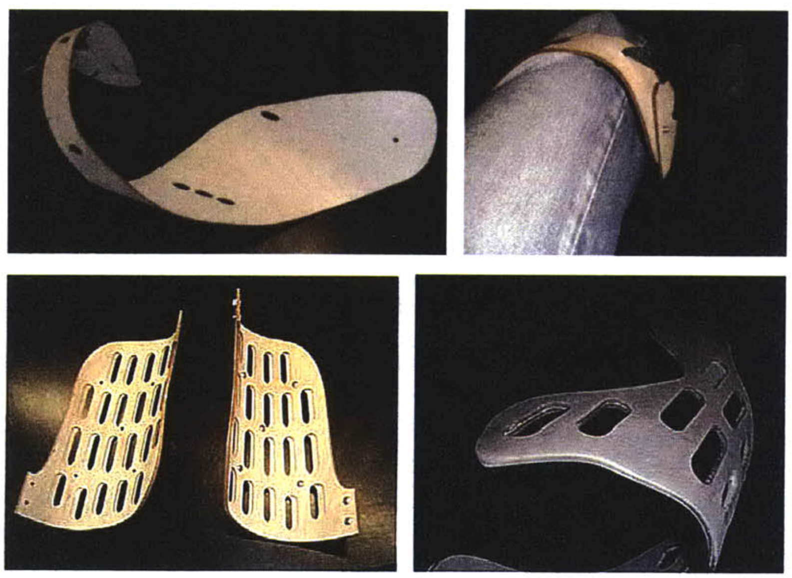


Figure II-15: Structural plywood parts.
Pre-tensioned single-layer plywood pieces were a further development of the snakeseat (top). For getter stability and for better accuracy and stability of bending, double layer pieces were made. The layers were initially bolted together (bottom left) and eventually glued using Gorillaglue®, which works well on wet plywood pieces. Gorillaglue® also expands slightly during hardening, filling out spaces were plywood layers were not perfectly laminar (bottom right).

4.6 Production of the Plywood Pieces

Designs were made in Rhino, transferred into Corel Draw, and cutout from $^{1}/_{8}$-inch plywood on a lasercutter. Techniques of bending plywood over steam and bending plywood after soaking in water were explored. Steaming allowed for tight curves in irreverent of the orientation of the natural bending direction of the plywood, and curing times were quick, but it proved technically and logistically difficult. Soaking the pieces in water restricted the direction in which the plywood could be bent to the natural bending direction of the sheet, and made bending with tight radii a little harder, but it was easily and efficient to do and proved sufficient for our purposes.

Bending the soaked plywood pieces was not trivial and it took several trials to get proficient. Throughout the project we used Gorilla® glue, which is water-activated and expands during drying, filling small gaps where the alignment between the sheets of plywood was not perfect. The soaked pieces were wiped off with paper towels. Gorilla glue was applied to the sides of each piece that would face the other one. The pieces were then put together and a mold made out of foam was put on top. As the pieces were gradually bent, zip ties and clamps were applied and gradually tightened until the piece had the desired shape. This was initially difficult to do because large forces had to be applied gradually, avoiding peaks that would cause the outer layers of the plywood to crack, and because the inner piece had to be actively pressed into the outer piece at the center point of the curve to avoid separation. In later designs, we took this into account and slightly altered the relative proportions of the inner and outer pieces to facilitate bending (Figure II-16).

The pieces were then left to dry overnight, cut into shape if necessary, and sanded. Sanding could create rather remarkable visual and tactile effects.

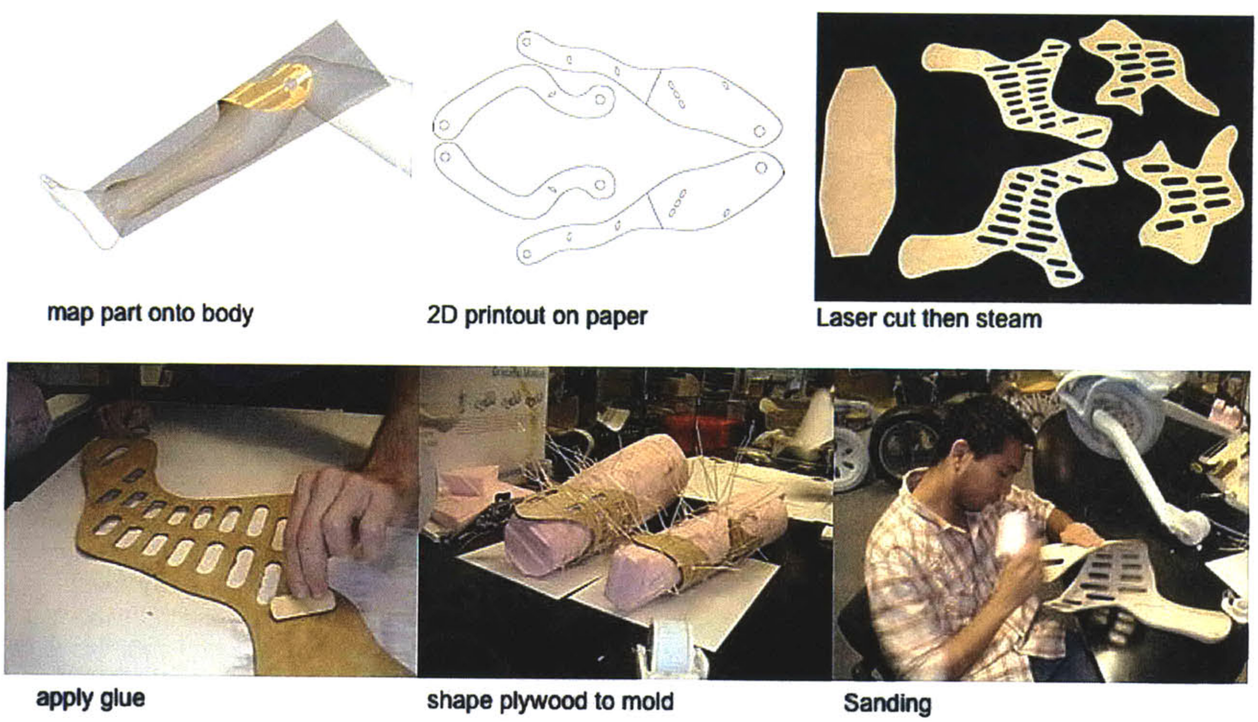


Figure II-16: Summary of production of plywood pieces.

4.7 Flextures: NOT Reproducing Joints

The goal when reproducing or aiding the function of joints of the leg from outside the body is, that the aides feel natural, working with the body and not against it. This might sound trivial, but is a difficult problem to solve. The difficulty stems from the fact that the joints of the hip and the knee, and the way we naturally move our legs and hips, are highly complex.

The knee joint allows rotation of the upper vs. the lower leg when bent, but not when extended. When we walk, and when we sit, we use this ability to rotate the knee to balance. Restricting this movement while making skiing or bicycling movements, as is our intention, would feel unnatural not only at the knee, but also at the hips. We therefore designed the flextures to allow rotation of the lower vs. the upper part of the leg.

The hip joint is, theoretically, a simple ball joint with a short extension that is attached to the femur at an angle. This makes it simple to get accurate function from replacement hip joins. But projecting a perfectly working hip joint from outside the body that allows natural movements of the leg to occur would require a rather complex apparatus, or a system that provides enough slack but still feels stable (Figure II-17).

Contrary to the strategy most widely used of employing single axis or ball joints, we decided to use flextures[17] made from a plastic material. For our purposes, we chose transparent polycarbonate (Lexan), because it was easily available and could be machined using the waterjet of the fabrication lab in our building. Carbon fiber would be another interesting material choice. The differences between plastic and metal flextures are, that metal provides springing, while plastic provides springing and damping. This was desirable for our purposes.

A number of designs for the hip and knee joints were tested before we arrived at the final designs. For the hip joint, it was important to project the horizontal axis of rotation of the hip with enough accuracy, but also allowing for changes in this axis due to anatomical differences and due to effects of movement of the legs and the pelvis. Another consideration was that the force required for rising and lowering the thighs should be perceived as roughly equal, in order for the intended movements to feel natural.

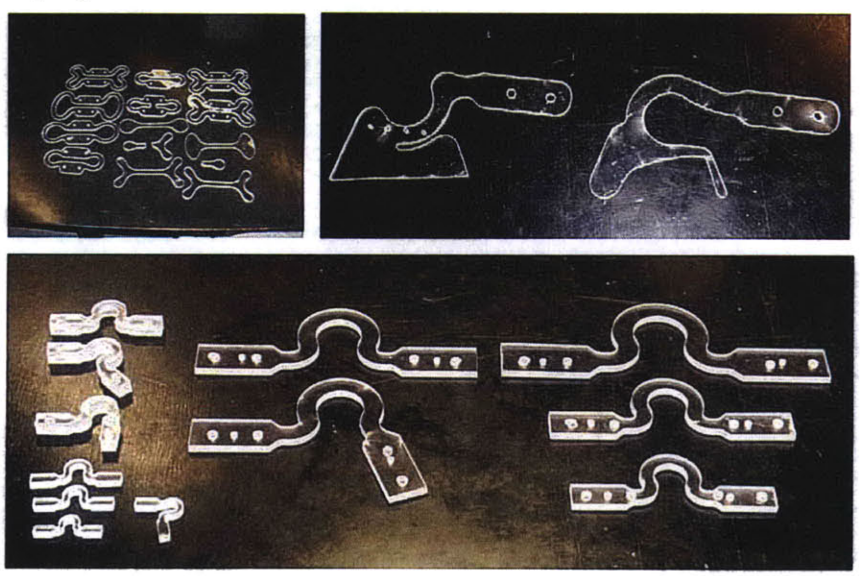


Figure II-17: Flexture studies. Flexture were used in order to support the body while best allowing and encouraging natural movement. Polycarbonate (Lexan) was cut with the waterjet cutter of the Media Lab. Different shapes and thicknesses were tested for pre-load, flexing, springing and damping, and directionality at different joints, mixing a systematic with an intuitive approach. Top left: Connection lower/ upper back; top right, hip joint; bottom, knee joint trials.

4.8 Developing the Leg

The development of the leg was an iterative process that involved designing, rapid prototyping, and testing doing leg-bouncing, leaning, bicycling, and other movements. Insights gained from these test would immediately be used for the next iteration. The process was a mixture between a systematic improvement approach, and trial and error. Due to the complexity of the system, trial and error often proved to be the faster way leading to the better solutions.

Since the base part of the seat that supports the buttocks and provides lateral support to the hips was given, we focused on the parts for the legs. Initially, pieces for a wearable design were made, as discussed above. After the decision was taken that the legs would be permanently fixed to the base of the seat, the development of new leg pieces started. This was far from trivial, since changes of any one part of the system would affect all the other parts.

First, we designed the plywood pieces for the thighs and shins. Initially, they provided a limited amount of lateral support. The pieces for the thigh and for the shin were connected with two flextures of slightly different dimensions and design, one lateral and one medial. This design proved supportive ad comfortable in initial tests. In the next step, the design of the plywood pieces was extended for better lateral support, and in order to stay on the leg during upward movements on the thigh. This proved challenging because a fine balance had to be found between ease of getting in and out and the function of the pieces. It was also found at this stage that support of the feed was not necessary, but uncomfortable and complicating the system (Figure II-18).

Next, the joints for the hips were designed and the thigh pieces were connected to the base using these joints Discussed in more detail in chapter II.4.10). Several joint designs were tested until a design was found that created equal perceived force for the up and down movement of the legs, while feeling natural at the same time.

The knee joints and pieces for the shins were connected next. To our astonishment, we found that contrary to our earlier results with plywood pieces that did not follow the leg during upward movements, having only one flexture on the medial side of the knee gave us better results.

Now that the basic system worked, we focused on the details: Which shapes would provide positive tactile feedback during rest and movement, how to find a good balance between fit and getting in and out, and how to calibrate the strength and flexibility of the actual flextures.

Figure II-18: Development of leg. 3D models; plywood pieces; movement studie; flexture joints for knee.

Due to the interconnectedness of the system, this was often rather challenging and counterintuitive. The upside is, of course, that more could be learned from this process about human movement and the perception thereof (Figure II-19).

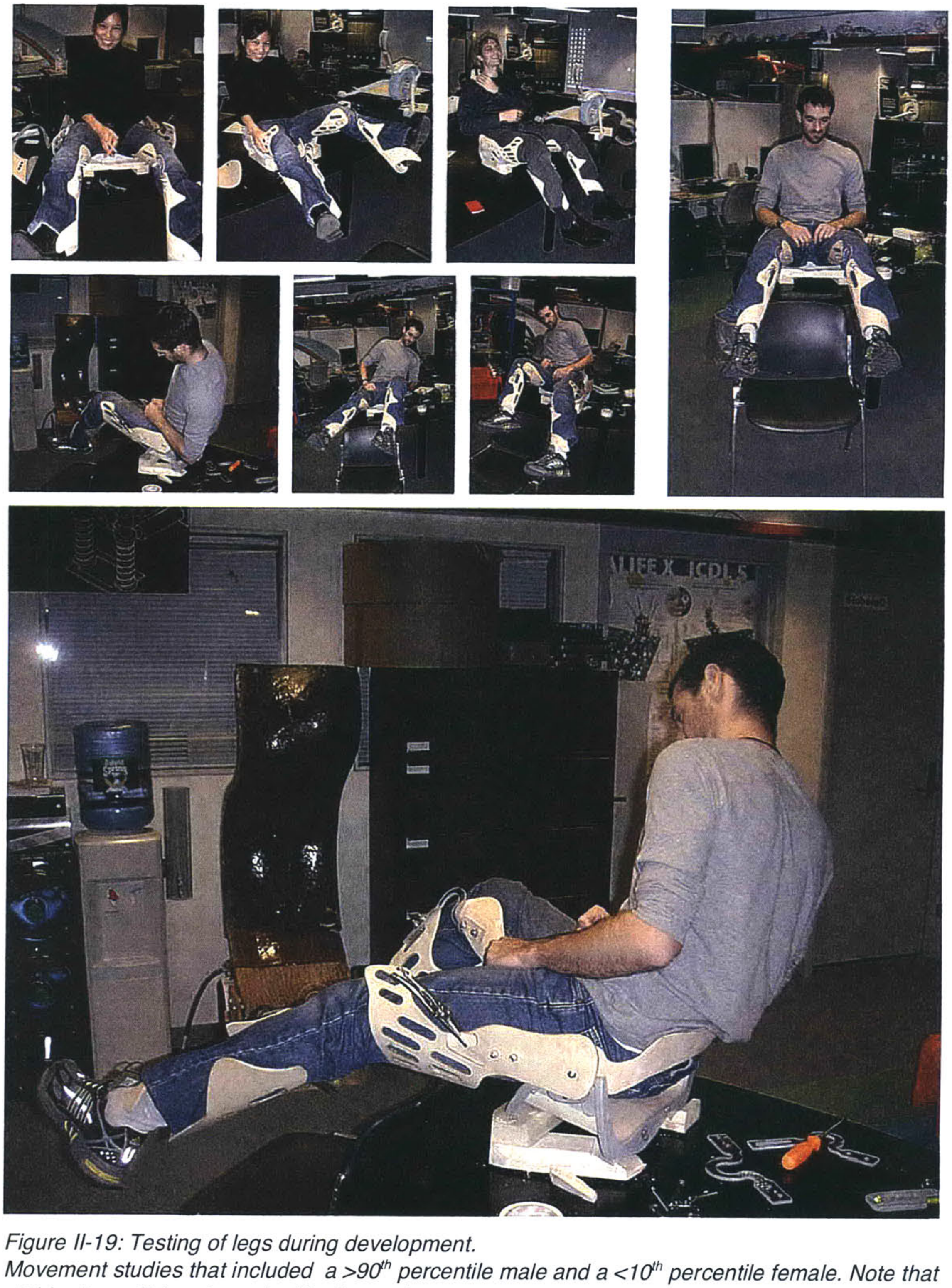


Figure II-19: Testing of legs during development.
Movement studies that included a $>90^{th}$ percentile male and a $<10^{th}$ percentile female. Note that at this stage, fit is not required for fun and movement.

4.9 Aluminum Pieces

Aluminum was used where there was a need for strong, rigid structures, as in the support for the buttocks and hips, and of the lower and upper back. 6061 grade aluminum was cut out using the Waterjet cutter of the Media Lab and sandblasted for visual and tactile reasons. Holes were drilled and threads were cut where necessary (Figure II-20).

Figure II-20: Aluminum pieces cut on the waterjet and sandblasted for the humanseat Mk1.

4.10 Developing the Hip Joints

The hip joints had to be designed in a way that people with different buttock heights could move comfortably and intuitively. Also, moving the legs up and down had to be perceived as equal in force. A mechanism to adjust the zero position of the hardstops (leg resting in seat) of the upward angle at the hip joint was designed to accommodate legs of different weight and to allow for adjustment according to user preferences (Figure II-21).

Figure II-21: Developing the hip joints.
Flextures made from 0.5-inch polycarbonate were shaped for the forces for moving the leg up and down to be perceived as equal. Hardstops were made adjustable using quick release pins.

4.11 Developing the Lower Back Support

The lower back is the area of the body most prone to chronic and acute damage induced by sitting. It transfers inputs, pressures, and movements from the upper body to the pelvis and the legs, and vice versa. The movements of the lower spine are quite complex and influenced by the position of the legs, the pelvis, and the upper body. Even breathing and abdominal muscle tension affects it.

We had to make a choice whether or not to encourage a slouching position, which in combination of an angle between the thighs and the spine of about 135° instead of the usual 90°, is better for the lower spine (135° as opposed to 90°, see above). We decided to go against the slouching position, since it is harder to use the abdominal muscles when slouching, which would make it harder to do skiing or bicycling movements while in the seat.

The structure of the backbone was made out of 0.5 inch strength 6061 grade aluminum, which was cut in the waterjet, machined for precise fit, and sandblasted for better feel and look. Several designs of the plywood and aluminum pieces and several articulation points and mechanisms were tested. Due to the interconnectedness of the system, this was done at the same time as f the hip flextures were developed. Once the basic design worked well, the hardstops that limit the degree to which one can lean back were developed. This also took several iterations of materials and design until a satisfactory solution was found. The most successful iteration of the hardstop was silicone cast into a mold whose layers were lasercut from acrylic and bolted together. Since the upper back heavily influences the forces on the lower back, both, for the seat, and for the occupant, the hardstops were developed in conjunction with the upper back (Figure II-22).

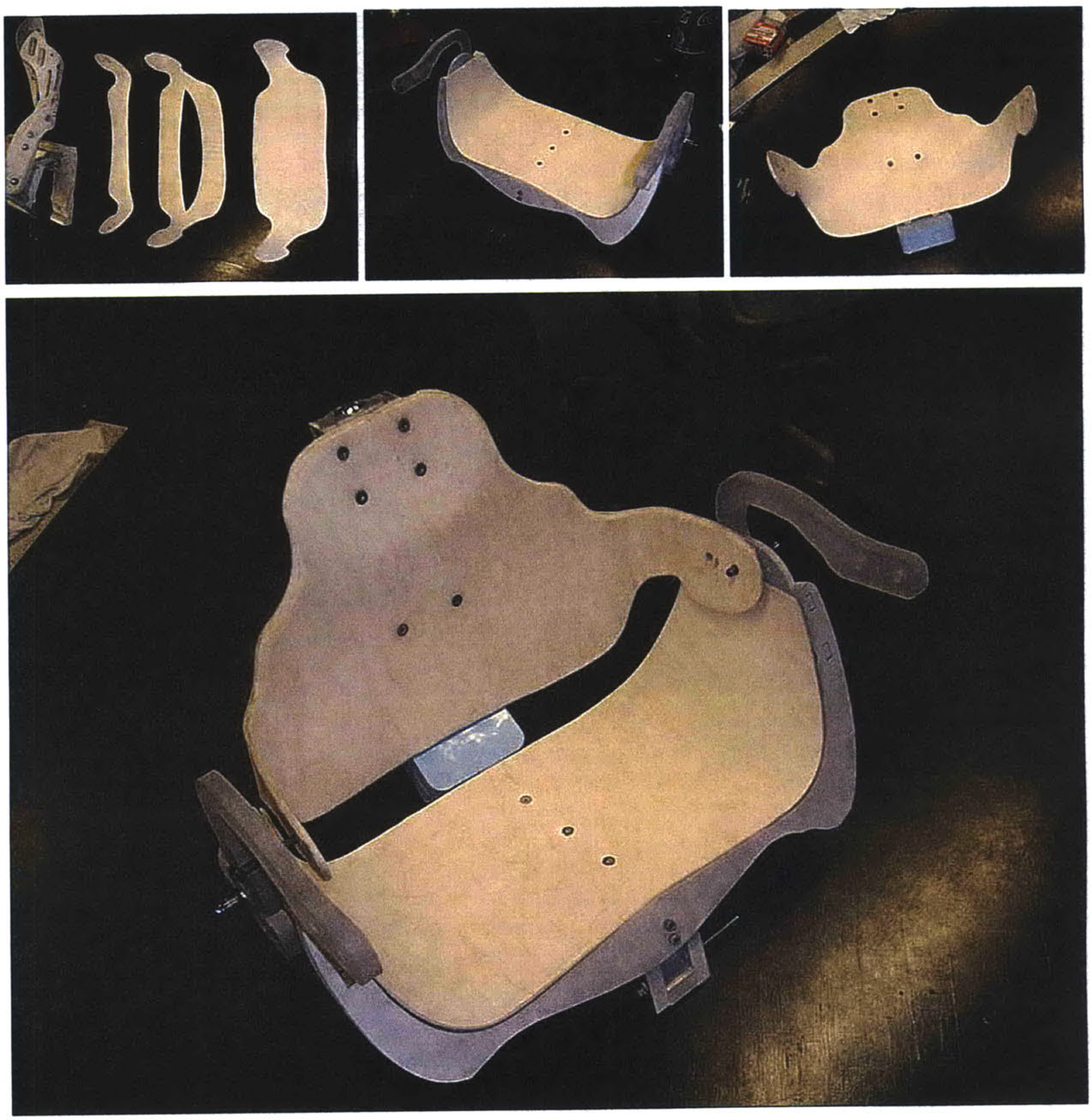


Figure II-22: Designing the lower back support.

4.12 Developing the Upper Back Support

There were several challenges when developing the upper back. Our goal was to design an exoskeleton-like seat that follows the movements while at the same time supporting the body. This meant that the joint between the plywood pieces for the lower back and for the upper back had not only to be able to rotate around the vertical axis, and tilt laterally and longitudinally, but it also had to be able to telescope, in order to compensate for the extension or contraction of the distance between the piece supporting the upper and the lower back when leaning forward or backwards. The problem was solved by fixing a ball joint to the top edge of the lower back support piece, and placing a rod connected to the upper back support piece in it that is allowed to travel up and down inside the ball joint, following the movement of the seat.

The next challenge was to provide hardstops and damping to this joint. Several flexture designs were tried, but none proved satisfactory during tests. The solution that worked was another custom designed silicone damper, in conjunction with a metal rod transversely inserted into the connector rod that supports the upper back.

We tested several designs for support of the shoulders and the head. Head support was quickly found to be unnecessary and uncomfortable. For shoulder support, we originally assumed that some sort of straps, similar to the straps of a backpack, were needed for the seat to be able to follow the body during rotation of the shoulders and while leaning forward and backward. Our tests showed that the straps were uncomfortable and even inhibit the desired movements. We also found that back support between the shoulder blades was counterproductive. Still, shoulder straps might be useful to limit forward movement during hard longitudinal deceleration, but they would have to be attached rather loosely (elastics, which would be ideal for comfort and movement, cannot be used for passenger restraint since they would store the energy of the impact and slam the occupant back into the seat with the same force).

The design process for the lateral support pieces for the upper back was rather straightforward. Several designs were tried, the best solution was a design that extends from the spine a few centimeters below the armpits giving lateral support curving from the back to the front until it reaches the most lateral point and extending straight forward from there on (Figure II-23).

Figure II-23: Development of the upper back support. Unless there needed to be a provision for sudden decceleration, there was no ergonomic reason to have shoulder straps or frontal chest support. A teleskoping ball joint with a silicone bushing ans a metal stopper provided all the degrees of freedom, damping, and the hardstops needed. Lateral chest support felt comfortable.

4.13 Aesthetic and Functional Customization

Some of the shape and material qualities of the humanseat Mk1 are a product simply of function, like the flexture joints, the metal pieces of the backbone, and the silicone dampers. These parts can easily be customized in a parametric model that takes onto account the dimensions, weight, and movement preferences on an end user.

The parts that touch the body, that is, the plywood pieces, allow for a large degree in design variation within the functional constraints of support, positive tactile feedback, movement, and ingress/ egress. Since these parts are to some degree wearable, or could even be designed to be fully wearable, it is natural that they should be customized not only for fit and function to allow for the desired degrees of support and movement, but also for character. While the earlier pieces have more of a hyper masculine Samurai-cartoon aesthetic, the newer pieces look more feminine. For purposes of customization, it would be relatively simple to make a parametric CATIA model linked to a table of input data from individuals. After setting the functional parameters and the boundaries within which aesthetic choices can be made, the designer or the end user could then create their own personal seat.

4.14 Results

The results from the humanseat Mk1 were not obtained in a systematic study, but rather by trials with random volunteers during the development process and of the final product.

4.14.1 Process

The design and fabrication process of the humanseat Mk1 was as challenging as it was interesting.

The development of the humanseat Mk1 was an iterative process that involved designing, rapid prototyping, and testing, re-designing, etc, in a very rapid cadence. The small investments of time and money of each round allowed not only and incremental, insight based approach, but also gave us the freedom to use trial and error. Due to the complexity of the system, the ladder often proved to be the faster way and lead to better results than well-thought out, linear development.

The interconnectedness of the pieces that make up the system, and the often-counterintuitive approaches that lead to the best results, provided an extraordinarily rewarding experience that has changed and shaped the way I think about design, about the functioning of the human body, and about man-machine systems in general.

Choosing the hard way, using plywood, a simple, hard material that is limited to simple curves, and using simple flextures instead of complex combinations of joints, and, refusing to use straps and elastics, forced us to really look into the dimensions, textures, and movements of the human body very carefully, and to constantly challenge our pre-conceived notions. In turn, the human body revealed a lot of its secrets to us that otherwise we would not have discovered. It was not a comfortable process, but a very rewarding one.

4.14.2 Initial Reactions

Initial reactions from looking at the seat or its pieces varied.

Predictably, the visuals and textures of the wood were met with positive responses. The purpose of single, disassembled pieces could often not be recognized, which caused much amusement. The effect of then putting on the pieces, especially plywood pieces for the thigh, was typically met with a slightly astonished, but very positive reaction. This was further enhanced when the subjects were asked to flex their hip joints to move their legs up and down with the thigh pieces on, since the pieces would follow the movements.

At some point the thighs were attached to the base facing up and slightly outward. This immediately evoked very negative associations of gynecological chairs in female onlookers. The angle was subsequently changed to a more parallel setting, and this criticism disappeared.

The final chair was met mostly with curiosity, and slight reservations about it being comfortable. The fact that getting in and out of the chair mounted to the Mini Athlete requires some balancing also caused some reservations amongst onlookers. Once in the chair, fit was the first aspect that subjects noticed.

4.14.3 Fit

Fit depended greatly on the amount of pieces connect to the system.

When only the pieces for the thighs were mounted to the base, a high percentile male (A.K, 190cm, 95kg) and low percentile female (L.W, 160cm, 56kg) alike felt comfortable and spontaneously started bouncing their legs or making leaning and skiing-like movements.

When the shin pieces were connected, the length and the diameter of the thigh had to be closer to the dimensions of the target person (P.K, 186cm, 78kg, male) for comfortable fit. The length of the thigh was much more relevant than the diameter. Even better fit war required for comfortably making skiing- or bicycling movements in the final seat assembly, although the spread of body types that could use the seat comfortably and successfully was larger than expected. The knee flextures and the shin pieces could cause uncomfortable pressure points in cases where there was a large discrepancy in size.

4.14.4Perceived Weightlessness of the Legs

One experience that was regularly commented on as very positive was the sensation that the legs could just weightlessly bounce in the air. Unless parts of the flextures or the shin pieces caused uncomfortable pressure points due to imprecise fit, this caused immediate bursts of relaxation and happiness, and led many subjects to spontaneously start moving their legs in a coordinated fashion.

4.14.5Movements

The polycarbonate flexture joints would at times make scratching noises during movement. In some cases, depending on the familiarity of the test person with prototypes, their personality, and their mental state at the time of the trial, a little reassurance could overcome the reservations about moving caused from these noises.

If the fit was good, many test subjects started spontaneously making skiing motions, while others enjoyed the movements once encouraged to initiate them. Coordinating movements of the upper body with movements of the legs was easy, intuitive, and was initiated spontaneously in conjunction with leg movement. Even subjects who do not ski, or hardly ever ride a bicycle, found that moving this way in the humanseat Mk1 was a very fun and rewarding experience.

4.14.6Reward through touch

One of the goals of this project was to reward movement using positive tactile feedback as a test bed for other applications of this principle, as discussed in chapter, aging. A significant number of subjects, again, depending on the fit of the humanseat, reported that the touch of the inner thing felt very positive and encouraged them to keep moving their legs.

4.14.7Spontaneous Remarks and Comments of During Trials

This is a short collection of spontaneous remarks and comments by people testing the seat: "Fun! - Like skiing! - I feel like I'm high! - Ouch, my shin hurts! - Do I have to get out? - Oh my god, my legs are weightless! - I like bouncing my legs!" Etc, etc.

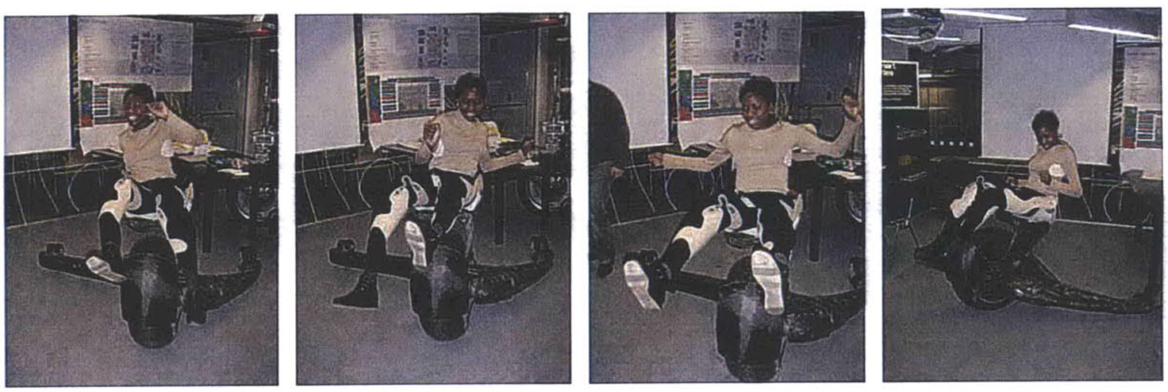


Figure II-24: A test person trying out the humanseat Mk1 for the first time.

4.15 Conclusions

The humanseat Mk1 was a difficult, but rewarding project that showed that an iterative design process that used the usual linear and incremental, but also unusual, intuitive and non-intuitive trial and error strategies could solve a very complex design problem.

Other crucial decisions to restrict ourselves to materials, such as, plywood for the parts that touch the body, and the decision not to try to precisely reproduce the functions of human joints, but instead use imprecise flextures, also helped us reach this result.

Together, these strategies lead us to solve a tremendously complex problem, that of comfortably fitting an exoskeleton the human body in a way that encourages and rewards movement while giving support and protection.

Designs derived from the humanseat Mk1 can have applications in environments where support, protection, and movement are required, as discussed in part III.

5. The humanseat Mk2: The Evolution Lies in the Core

While the humanseat Mk1 incorporated the principles of no padding, smart, "imprecise" flexture joints, facilitating and encouraging movement and rewarding it through tactile feedback, it still adhered to a principle that has been perpetuated in chair design since the first chairs known to mankind: fixation of the pelvis in the sagittal (lateral) plane.

Although the skiing- and bicycling movements encouraged by the humanseat Mk1 caused individual movements of the thighs, the points where the buttocks make contact with the seat were stationary and therefore counteracting the sideways rocking motion of the pelvis that would naturally accompany or be the root of those leg movements. This was due to design restrictions imposed by the Mini Athlete Car.

The humanseat Mk2 allows, even encourages movement of the pelvis in the sagittal plane, while providing stability. This can lead to a relaxing, fun and sometimes rather wild movement experience (Figure II-25).

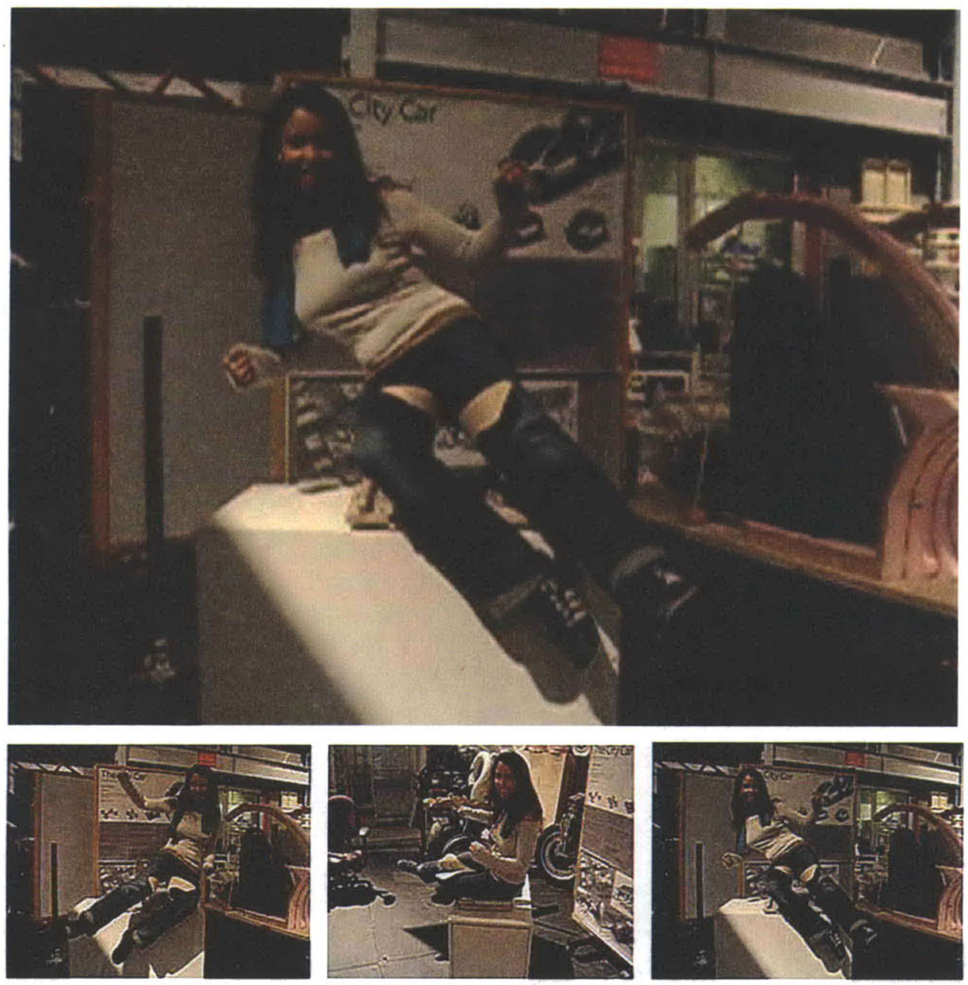


Figure II-25: Simulating Skiing and flying motions in the humanseat Mk2. (Still images from movie.)

5.1 Rocking of the Pelvis Sideways in the Coronal Plane: A Natural, Healthy, and Fun Motion

The lower back is also most affected by posture problems and strain injuries arising from sitting. Chair manufacturers have gone to great lengths to improve how seats relate to the lower back. Typical measures are adjustable lumbar supports or massaging functions. The Leap chair by Steelcase® goes a step further by offering training to companies on how to use it in order to obtain the gains in productivity shown in some of their studies[16]. The question has to be asked of course how natural and intuitive a chair is if the occupants have to be trained in order to use it correctly.

Following the humanseat design principles to allow and encourage natural and beneficial movements in any position, including sitting, it was evident that the humanseat had to give the occupant the opportunity to make the same movements of the pelvis and lower back that occur during walking, dancing, bicycling, skiing, and other healthy physical activities.

The movement that is notably absent from known chairs is the lateral rocking motion of the pelvis in the frontal plane, as it occurs during walking bicycling, etc. Another type of movement that is conspicuously absent in chairs is balancing- and micromovements that occur when standing, walking, or sitting in non-steady environments, such as, boats. Micromovements are small movements of the body that may or may not be consciously perceived or executed.

All these movements are important, since they cause the pressure points in the spine and the workload of muscles to move constantly, strengthening the muscles of the lower spine, improving the sense of balance, and reducing undue stress on intervertebrate disks, joints, muscle fatigue, while improving blood circulation.

Our experiments showed that in order for the body to feel balanced, the virtual axis of rotation of the pelvis when rocking sideways has to lie above an imaginary line connecting the bottom points of the buttocks, similar to a bicycle seat, rather than go through that imaginary line.

The second prototype of the humanseat was built around these principles.

5.2 Reduction to the Core: humanseat Mk2 Prototypes

The core of human locomotive movements is located around the body' s center of gravity, the lower back in conjunction with the pelvis, and the thighs. Following the design principles discussed for the first humanseat prototype, pieces that support the left and the right thigh and buttock were produced. These pieces were then attached in a parametric manner t two types of support mechanism, using hinges (type 1) and a combination of hinges and flextures (type 2).

The assembly was designed so that the geometry could easily be adjusted in order to allow, encourage, or simulate different types of movements and evoke different sensations. Rails were machined out of 6061 aluminum using the waterjet and milling machines, with holes set 1cm apart so that the hinges or flextures could engage the seat pieces at different points. Pins[15] were used to form rapidly exchangeable connections with the support pieces.

5.3 Functionally Parametric Assembly of the humanseat Core: Hinges

Semi-circular support pieces with a hole for connection to the seat piece and several holes for hardstops were cut out of 0.5" plywood on the waterjet and assembles (Figure II-26).

Although the suspension with hinges was thought only as an intermediary step before testing flextures, they provided us with quite encouraging results (see below).

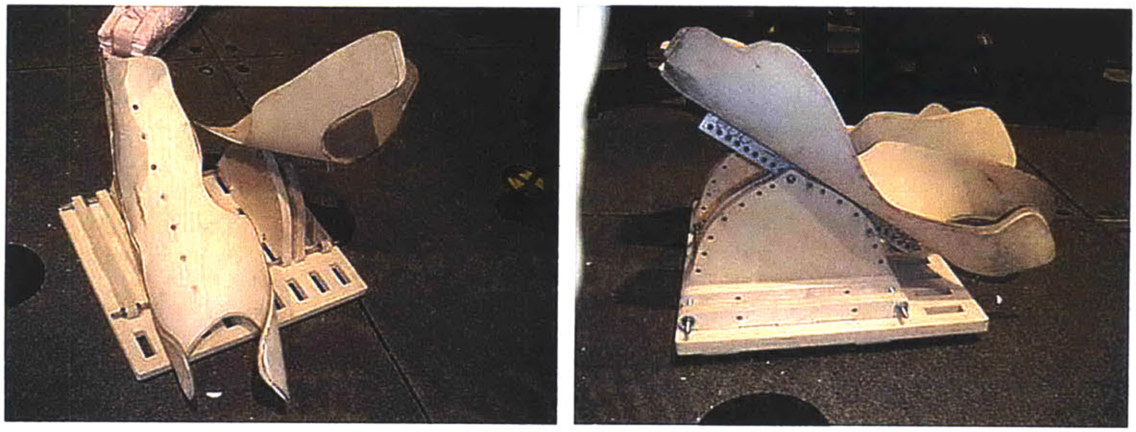


Figure II-26: The first parametric assembly of the humanseat Mk2 using hinges.
A parametric setup for longitudinal variation of the attachment point of the axis of rotation to the plywood pieces.

5.4 Functionally Parametric Assembly of the humanseat Core: Flextures

As demonstrated with the hip- and knee joints of the first humanseat prototype, flextures provide support, springing, and depending on the material, damping. Furthermore, flextures as we are using them here are not precise joints and therefore do not restrict the motion of the seat and therefore the body to directionally precisely pre-defined movements as the hinges do.

A parametric assembly was built for the flextures as demonstrated in fig. The rail that is connected directly to the seat piece has 24 holes spaced at 1cm intervals. This allows varying the attachment point of the connectors from the upper part of the flexture(s) to be chosen amongst different locations along the longitudinal axis of the thigh. A second pin or bolt can be inserted into the connector piece that is bolted to the flexture(s), so that a pre-set angle between the flextures and the seat can be chosen. The bottom end of the flextures is connected to the base via the same mechanism mirrored on the other side of the flexture. Flextures were cut out of polycarbonate using the waterjet. Different types of one piece and split flextures were tested, varying in length and strength (Figure II-27).

This setup allows testing of different geometries, resulting in different levels and types of support and movement. The base rails were connected to a base plate in a way that allowed for the lateral distance between the left and right piece and their angles relative to the longitudinal axis to be adjusted continually.

In the first iteration the assembly of the bolts and the mechanism connecting the base rails to the base plate had too much play. Also, bolts tended to loosen after some use. This made it difficult to separate out the contribution of the flextures vs. the looseness of the system to the effect felt by the occupant. To solve these issues, the bolts were replaced by quick release pins, except for the connection bolts of the flextures to the base rails, which were in a fixed position all the time, which were fitted with stop nuts with nylon inserts to prevent loosening during use. Still, valuable data about the movement experience and with the driving simulators could be gathered.

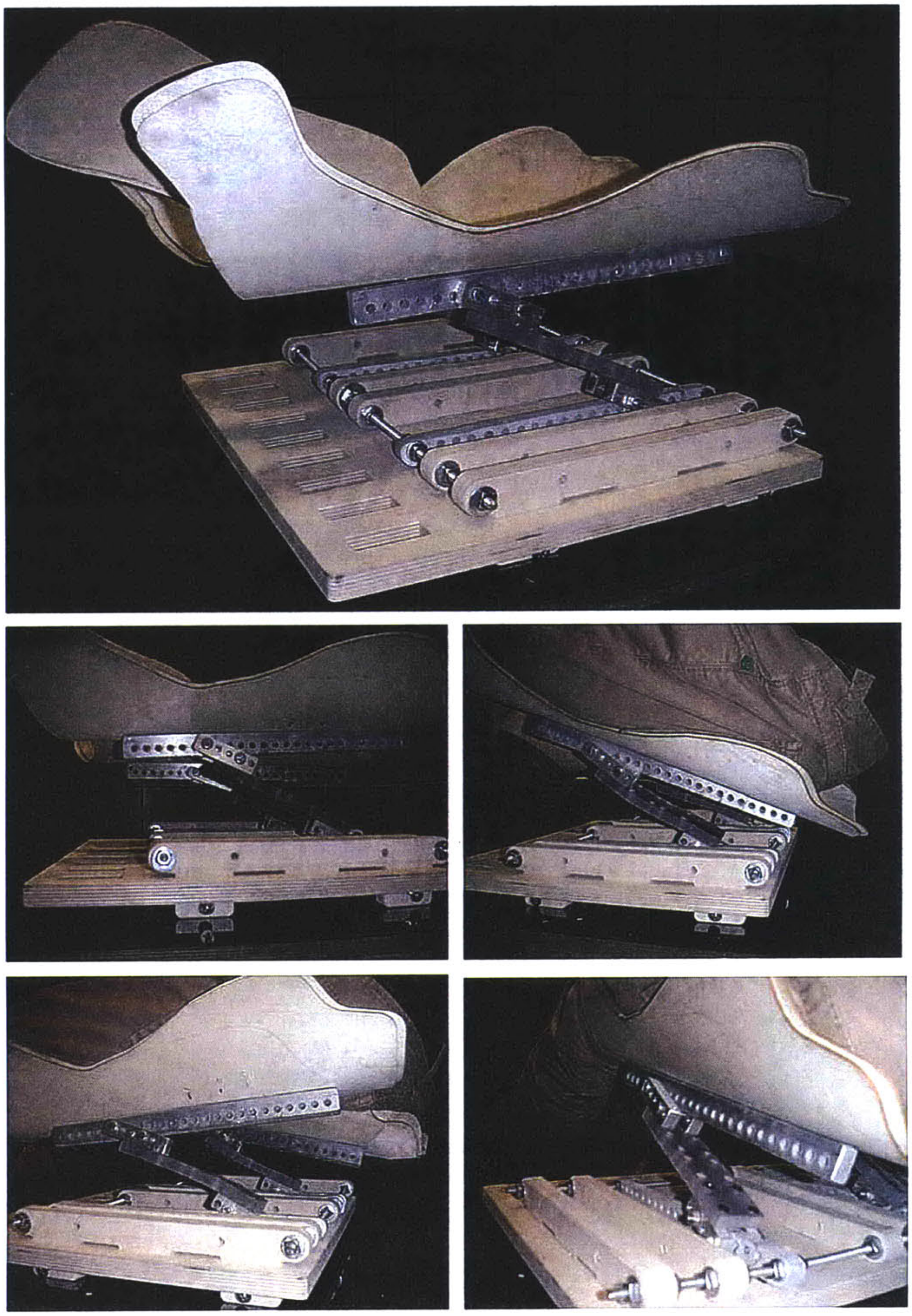


Figure II-27: Movement apparatus using parametric assembly of flextures. Flextures were installed in a manner that the preset angle to the base rail can be varied. The preset angle to the plywood seat pieces can also be varied, as can the longitudinal attachment point. Flextures allow movement in all directions, note movement pattern pepending on load. Flextures longitudinally split in the middle with a gap of ca. 1mm were employedat a later stage for better torsional deformation (bottom right panel shows torsional deformation).

An improved mechanism was constructed out of 80/20 materials for higher stability, and to allow convenient raising and lowering and longitudinal positioning of the seat. An additional degree of freedom was introduced by allowing the fixtures to rotate at their attachment point, permitting the user to determine the relative angle of the thighs. The resistance of this degree of freedom was high enough to provide a sense of stability (Figure II-28).

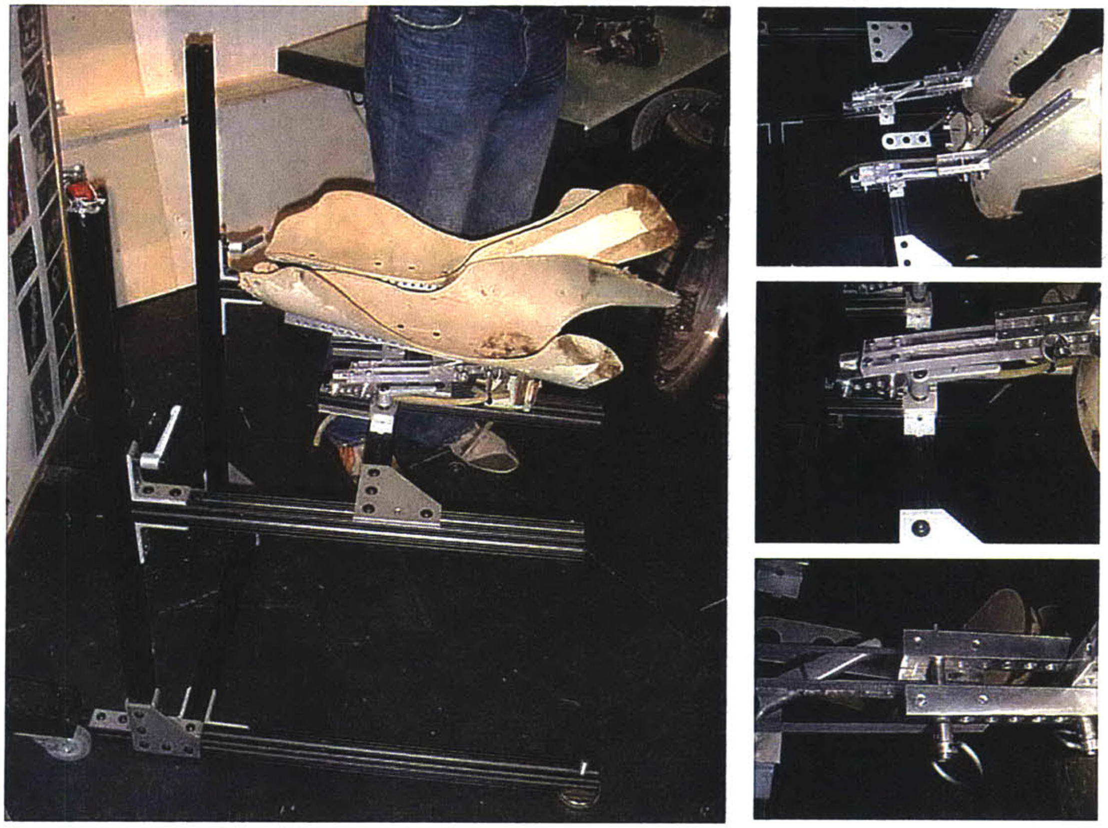


Figure II-28: Improved stand using 80/20 materials.
The height was made easily adjustable, facilitating test for different angles at the knee and heel support (left panel). Longitudinally split flextures for lower torsional resistance to facilitate "rolling" movements of the hips. Relative strength of medial and lateral part of flextures on each side can create bias toward more (weaker medial) or less (equal or stronger medial part) lateral stability. Variable longitudinal angle of flexture ancors allows occupant to vary angle between thighs, to close and open legs. Use of stopnuts to prevent loosening during use and quick-release pins for easy change of parametric settings (panles on right).

5.5 Fabrication of Plywood Pieces

Basically, the same techniques were used as for the fabrication of the plywood pieces of humanseat Mk I (Figure II-29). The shape of the previous pieces for the thighs was adapted to also support the buttocks, so that one piece would support one thing and buttock. Lateral support was added at the level of the hips, and longitudinal support was added in the back. As found previously, the slightest addition or subtraction of a support area changed subjective perception of balance, comfort, and safety dramatically, similar to changes of the actuation points and preset angles of the flextures (see below).

Figure II-29: Fabrication of humanseat Mk2 plywood pieces.
The technique was the same as for the Mk1 prototype, but additional difficulty arose from the fact that the center medial area between the legs had to have a convex curve when seen from the top, going in the opposite direction from the rest of the wood. Drilling holes in the plywood at the separation point of the convex and concave curve for zip-ties to go through and the use of wedges proved successful.

5.6 Evolution of Plywood Pieces

The design of the plywood pieces that touch the thighs and the buttocks of the occupant was a result of the experiences from the humanseat Mk1 and from the original snakeseat. The lateral support of the hips was designed similarly to that of the snakeseat, while the medial and lateral support of the thighs near the knees was adopted from the humanseat Mk1. The areas below the thigh were extended backwards beyond the reach of the buttocks. The medial areas between the buttocks were too intrusive in earlier designs and were corrected in later designs. The exact angle and curvature of the medial support above the knees proved to be very sensitive in so far that small changes would have large effects on comfort and function. Angled support areas in the back of the buttocks were tested but proved to lead occupants to slouch, that is, to rotate their pelvis backwards against the support. Another effect was that those pieces would limit movement by pressing against the rear pelvic bones. Plywood treated with protective stain resulted in too much of a loss of friction, limiting user confidence and the range of movements. Lining the inside of the plywood pieces with faux suede provide the right amount of friction (Figure II-30).

Figure II-30: Evolution of thigh pieces.
Original piece for Mk1 seat has lateral support area for hip, but has no support area for buttocks (left). The first pieces for the Mk2 seat have a lower lateral support area for the hips, and the horizontal concave support area is extended back beyond the buttocks (middle left). The second pieces for the Mk2 seat had additional support for the back of the buttocks and were more convex in the medial buttock area (middle right). The final pieces were mildly curved upwards in the back and were lined with suede-like fabric to increase friction. This resulted in an increased range of motion (right panel).

5.7 Simulators

The basic point of using video games to test the humanseat as a controller for vehicles lies in the fact that this provided an easy to use, cheap, and safe platform with good possibilities of comparison the humanseat control principle to traditional joysticks, thumb controllers, and steering wheels. The variety of games available also allowed us to test several aspects of driving and control, such as, input output mapping, intuitiveness, precision, level of physical and mental involvements, and fun. To test whether movements of the core are precise and intuitive enough to drive a terrestrial vehicle, a SONY Playstation2 (PS2)[18] was chosen, due to its realistic graphics and the ease of creating inputs using our own sensors, and because of the selection of games available. The games used were Burnout Revenge[19], which very successfully conveys the sensation of speed and movement in space, and Gran Turismo 4[20], for evaluating of precise driving. The latter poses a great challenge for novices even with the thumb controllers provided by the manufacturer. We also tested use of a steering wheel setup, with similar difficulties.

5.8 Generation and Mapping of Electronic Output

There are numerous ways to generate analogue or digital electronic output from the prototype, and various ways of mapping movement to the output(s). The determinant drivers of the mapping vary depending on the necessity to fulfill construction, movement, playability, or safety concerns, as will be discussed later. Our primary driver was finding a fun, healthy, and intuitive movement to steer a vehicle in a simulator. From experiences with the humanseat Mk I prototype, and from general experiences with sports, we first evaluated movements for suitability and then designed the output generator around the requirements generated by these movements. Rotation or sideways tilting of the pelvis, as found in skiing, dancing, and other activities, was found to be fun and intuitive. This also corresponds with the natural tendency to lean into a corner to counteract lateral g forces, contrary to the outward leaning of a car that does not have an active suspension.

Mapping the difference of the elevation angles between the left and the right thigh was found to be useful because the occupant can use a variety of smaller or larger movements to reliably generate output. A very simple mechanical mechanism was constructed consisting of an elastic band, either end of which was fixed to the inside of one of the seat pieces. The middle of the elastic was wrapped around a pulley located on the base plate or on the frame in between the seat pieces. This pulley drives a potentiometer identical to those found in the thumb controllers of the PS2. If the left and right thighs moved up and down together, the readout at the potentiometer would be zero, since the elastic would stretch or contract equally on both sides. If one leg went up and the other one remained still or went down, one side of the elastic would stretch while the other would contract, thereby turning the pulley. Several variants were made before a reliable solution was found.

The setup was such that either rolling the hips sideways using a small movement, or elevating one leg while lowering the other, using large movements, would generate equal amounts of output therefore giving the user a wide variety of choices in type and amount of movements to drive the simulator (Figure II-31).

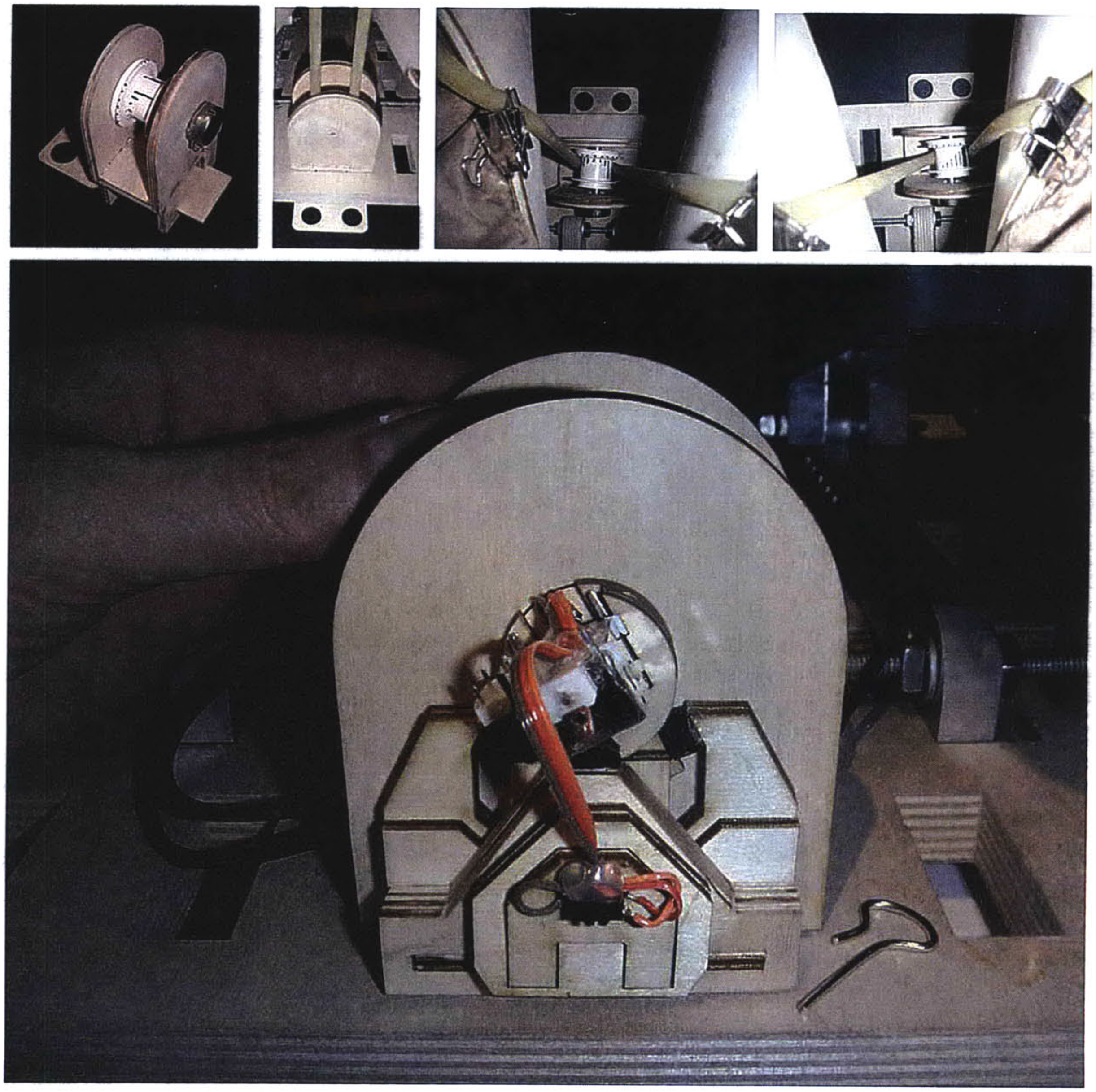


Figure II-31: Generating analogue electronic output to control the Playstation PS2 simulator. In the regular game controller, a potentiometer acts as a voltage divider to generate an analogue output signal for the PS2. We built a pulley whose axis was a potentiometer (Radioshack®, 50kohm) into an assembly that could easily be connected to the Mk2 seat platform. The axis of the potentiometer was parallel to the longitudinal axis of the seat. An elastic rubber band was connected at either end to the medial part of the plywood pieces and threaded through the pulley. Thus, relative motion of the left and right plywood seat piece would cause the pulley, and thereby the potentiometer, to rotate, while consensual movement of the seat pieces (both legs up or down) would cause the rubber band to stretch and contract, but no rotation at the pulley (top row of images). Later, a smaller ALPS RJXK potentiometer was used, and a different type of elastic, in combination with an oval pulleywhere the axis of rotation was moved ¾ down from the center of the pulley in order to create a mechanically progressive actuation of the pulley with the least amount of sensitivity around the center position. With this setup, the base of the potentiometer turned on the axis of the pulley, while the joystick-like lever of the potentiometer was fixed vertically facing downwards with a hard rubber bushing. The single sheet plywood parts were cut out on the laser cutter (bottom panel).

5.9 Connecting to Simulators

Connecting the humanseat to driving simulators was rather straightforward. Playstation 2 (PS2) controllers were modified so that the signal generated as described above bypassed the thumb controllers operating the steering function in the games that were used. (Figure II-32).

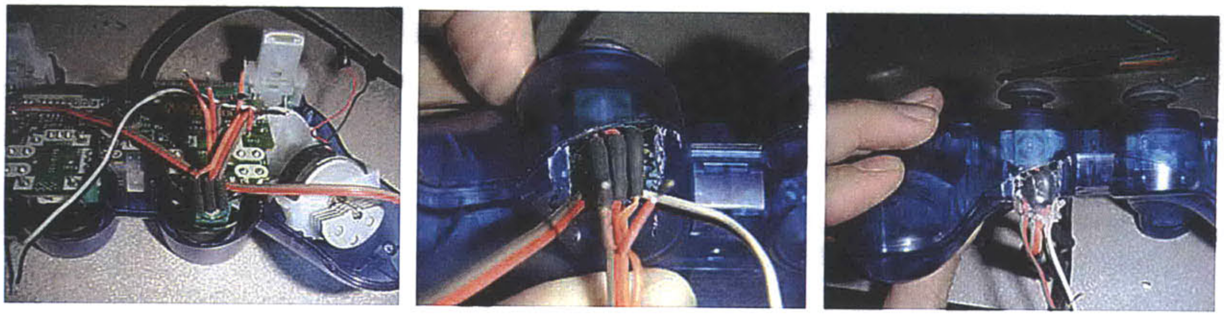


Figure II-32: Connecting the humanseat Mk2 output to simuators.
Output from the potentiometers on the humanseat Mk2 was connected to the output of the equivalent potentiometer of the commercially available game controller with a plug connection that allowed switching between the potentiometer in the game controller and the one in the humanseat.

6. Evaluation of the humanseat Mk2

Evaluation of the humanseat Mk2 by members of the team and by non-members was done regularly during development. These mostly consisted of brief seating trials, lasting a few minutes. More in-depth trials were conducted at times but were mostly the focus of analyzing the final prototypes.

6.1 Experimental Setups

The first experimental setup consisted of two plywood pieces connected to a board via hinges that could be positioned in 20 different longitudinal positions along the plywood pieces (see also 5.3). This setup was easily placed at different heights, such as, on the floor, at typical seat height, and at table height. This assembly was tested in settings with different angles in the knee joint, allowing for the legs to balance freely in the air on one extreme, or being put on the floor, so that the heals of the occupant were 10cm below the line of the upper rail, or above, if a box or similar object was given to the occupant to support the heals.

The second setup used the same easily portable base plate, but the plywood pieces were connected using single piece flextures instead of hinges (see also 5.4).

The third setup was identical to the second one, except that the hinges were split in the middle to facilitate rolling movements of the hip. Driving simulator tests were conducted with this setup.

The fourth setup had three significant relative to the third setup: the frame, one more degree of freedom, and more friction inside the pieces.

Frame: A frame was made from 80/20 beams and connector pieces so that the height and longitudinal position of the seat could be adjusted easily. The rails that hold the bottom fixtures of the flextures were fixed to the frame in a manner that allowed changing their relative distance, like before.

Opening/closing legs: An additional degree of freedom was introduced by allowing the fixtures to rotate at their attachment point, permitting the user to determine the relative angle of the thighs. The resistance of this degree of freedom was high enough to provide a sense of stability. The fourth setup was also connected to the driving simulator.

Friction: The insides of the plywood pieces were lined with faux suede in order to increase friction, for better maneuverability and user confidence. Natural, untreated plywood provided barely enough friction, while plywood treated with protective wood stain finish was too slippery for users to take full advantage of the range of movement provided by the humanseat.

These evolutions were direct results of the designer's striving for improvements and inputs from user trials, as discussed below.

6.2 Experimental Procedures

Due to the novelty of the concept and the power of pre-conceived notions when assessing comfort in chairs, ref, a mixture of getting spontaneous reactions from a variety of people, and more in depth tests and interviews were conducted.

Evaluation was done in two stages. In stage 1, feasibility of different designs and mechanical layouts were tested. The most successful designs and the most significant and parametric settings were be further evaluated in stage 2.

Due to the different ways males and females relate to their bodies, cars, and movement, and due to anatomical differences tests were conducted with persons of both genders. It was also our goal to break away from gender stereotypes relating to cars and driving.

Subjective evaluations played a central role in this project. One group of subjects well suited for the evaluations were people who easily feel uncomfortable in seats. Also subjects with a background in sports, and other movement related activities, such as Yoga and, the Alexander Method, have a heightened body perception and control compared to the average person and therefore were ideal for subjective evaluation during the design process. Commentaries and spontaneous movements and movement explorations were very interesting to watch.

6.3 Brief Trials

The purpose of brief trials, typically a few minutes in duration with subjects of different ages, gender, body types, and body experiences, was to test time and process of familiarization with and general acceptance of the concept. During development, this was important to get feedback for small improvements and to do quick, cursory evaluations at a large scale.

Members of the Media Lab or passers by during the school year and during sponsor week were invited to seating trials. Getting into the humanseat typically takes three steps:

- Stand in front of the seat, your back to the seat.
- Slip the pieces around your legs right above your knee, one by one.
- Sit down backwards.

These short, spontaneous tests were conducted as follows:

- Invite the subject to try out the seat. Note if subject has observed other people using the seat. Observe approach behavior, potential hesitance, ease of getting in. If subject is hesitant, demonstrate how to get in and demonstrate some simple movements.
- Observe facial expression and posture of subject when sitting down.
- Observe facial expression, posture, and initial movements. Position of arms, hands? What is the dominant state of mind, what does the facial expression, and posture convey, fearfulness, surprise, exploration, playfulness, amazement, amusement?
- Observe behavior over the next few minutes. Are there shifts in attitude, is there explorative behavior, are states of comfort and balance reached, do the benefits of the system as a whole help overcome small imperfections?
- Spontaneous comments. Answers to directed questions.

In general, the reactions were very positive, although there were large differences in initial comfort depending on the sense of balance and anatomical fit of the test person. It was interesting to observe that confidence of gait and general appearance did not translate directly into confidence during the seat trial. Rather, experience with activities that require balancing and good coordination of the body, such as, yoga, skiing, figure skating, ballet, and, being female, helped. The latter is an observation for which there is no explanation as of yet, whereas it seems natural that individuals who are more proficient at balancing their bodies would be at ease more quickly in the humanseat.

Observing the posture, spontaneous movements, facial expressions, and general feel of ease or unease the test subjects exhibited while sitting down and during the first few seconds in the seat, and after roughly minute for getting acquainted with it, usually lead to good predictions about the types of athletic activities they are proficient in (Figure II-33, II-34).

6.4 In-Depth Trials

In-depth trials were conducted with a few subjects. These trials typically lasted for an hour during which different parametric settings and their subjective effect on the subjects were documented (Figure II-33, II-34).

6.5 Movements

A wide range of movements was done by test subjects, from gentle rocking back and forth and almost imperceptible balancing movements to rolling and circling of the pelvis, and rather extreme leaning and skiing motions. Subjects would spontaneously do movements they were familiar with: yoga poses and -stretches, skiing, bicycling, riding, and other movements.

The type and degree of spontaneous movements depended on the initial amount of confidence and on the type and degree of balance and athletic training of the subjects. Gymnasts, figure skaters, and other athletes, were usually quick to explore the whole range of movement the humanseat Mk2 allows.

Other subjects typically took a bit longer to feel confident or started exploring more extreme movements after watching other people move in the seat or being told that it was safe. Notably, there was no subject who did not get to a point where they felt comfortable and balanced (Figure II-33, II-34)

Figure II-33: Seat Trials

Top row: In-depth trial with a former figure skater, ballerina and gymnast.
Second row: Hobby trapeze artist; Media Lab professor; Media Lab grad student.(Brief trials).
Third row: Sponsor day visitors (Brief trials).
Fourth row: Media Lab grad student, sponsor day visitor (pregnant, 2^{nd} trimester; brief trials). .

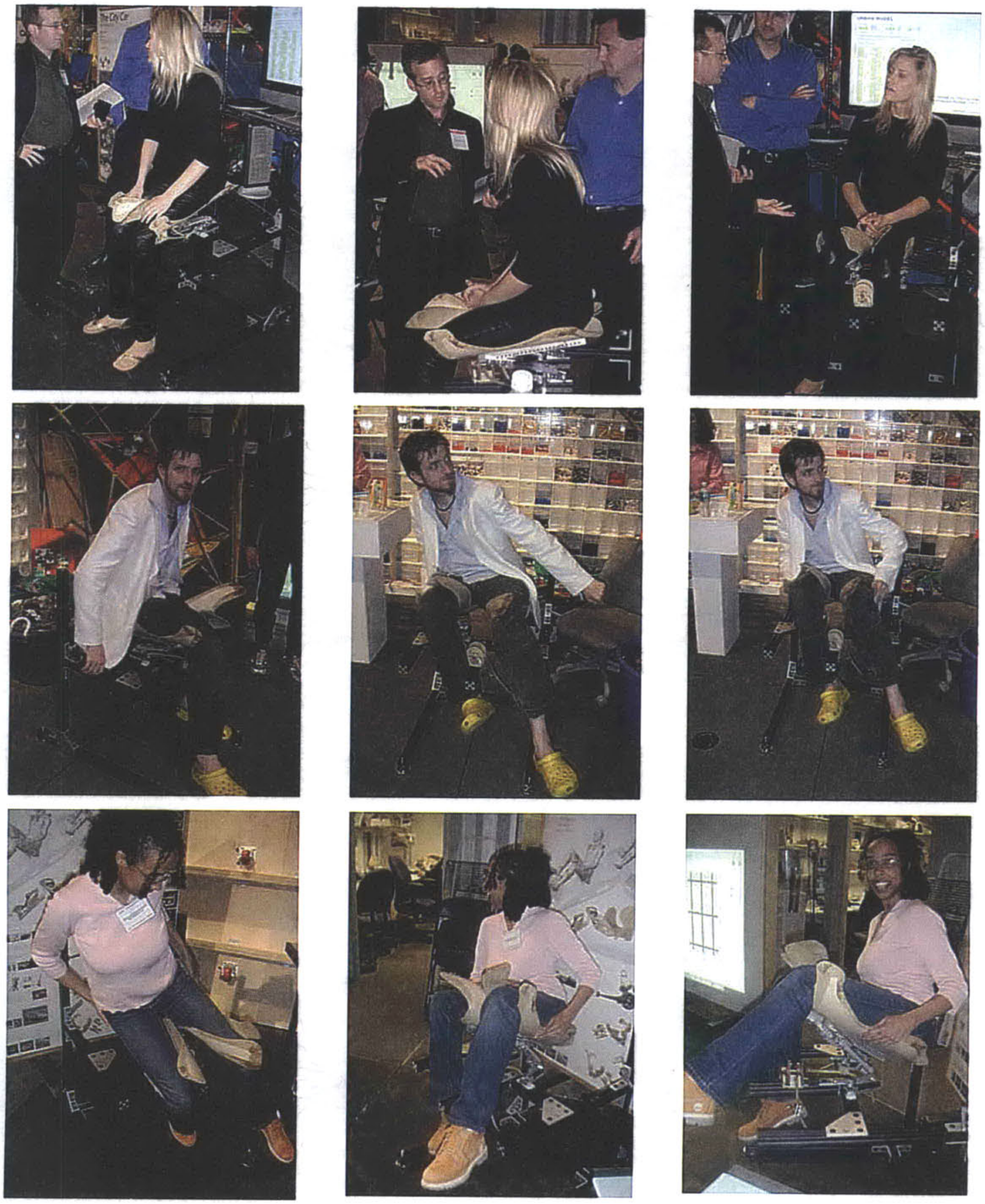


Figure II-34: Seat trials.
Brief trials:
Top row: Alexander trainee, actress and model, sprint world record holder, double below the knee amputee.
Middle row: Media Lab grad student
Bottom row: Media Lab grad student, former gymnast.

6.6 General Emotional Effects and Comments

In general, sitting in the seat would put a smile on the subject's faces. The experience was typically called, fun, nice, and amazing. Several subjects related some of the movements to dancing, sex, or rocking movements they used to do as children (Figure I-33, II-34).

6.7 Separation of Upper and Lower Body

When asked where they would put a keyboard for typing on, subjects typically held out their hands at two height levels, having no difficulty keeping their hands still or doing complex tasks with their hands while rocking or moving their lower bodies. Another subject changed a tape in a video camera with the same level of ease as if she would have been sitting on a regular chair.

Being able to easily and intuitively separate movements of the lower body - lower spine, hips, legs - from those of the upper body, is important for a number of reasons.

Seating is typically not an activity that should take up a lot of our attention. Most tasks that we do while seated are fine motor tasks. Being able to separate the movement of the upper and the lower body while seated and being able to do the balancing that is part of sitting in the humanseat, without having to pay any attention to it, is therefore vital for potential applications in homes and offices.

For potential vehicle control applications, one of the great benefits of the human seat is that the hands can be used for other things than driving. This separation is normal during walking: we can talk on cell phones, type in text messages, hold people, purses, bags, and dogs, gesticulate, and point in directions without interfering with the activity of walking unless unexpected obstacles appear all of a sudden.

Being able to do complex tasks that demand full attention, like changing the recording tape in a finicky video camera while sitting in the humanseat indicates that the cognitive load required for sitting and balancing in the humanseat is very low (Figure II-35).

Figure II-35: Separation of upper body from lower body.
Subjects are performing typical activities that one performs when seated with their upper bodies, without having to pay attention to the way they balance and move the humanseat with their lower bodies.

6.8 Trials with Hinged Setup

Before the prototypes with the flextures were built, trials were conducted with the hinged prototype. The feedback was very encouraging. These trials also revealed the importance of the angle of the knees for feel, balance, and effort of movement of the hips. (Figure II-36).

Figure II-36: Trials with hinged setup.
Triathlete (left panel); Yoga, martial arts and Alexander trainees (other panels).

6.9 Driving Simulator Trials

Setups 3 and 4 were connected to SONY® Playstation® PS2 driving simulator games. About 20 subjects, mostly undergraduate and graduate students, used setup 3 with the simulator, three more used setup 4. Speed was controlled using the regular game controller.

The parametric setup of the humanseat were chosen so that rolling the hips was easy, allowing the subjects to use two ways for generating steering input, either large, skiing like movements of the legs accompanied by leaning, or smaller, sideways rolling movements of the hips (Figure II-36).

Throughout the trials it proved challenging to reliably translate motion of the seat with the help of the potentiometer into analogue output for the Playstation. At times the data reading was excellent, at times not. This made it more difficult to compare lap times.

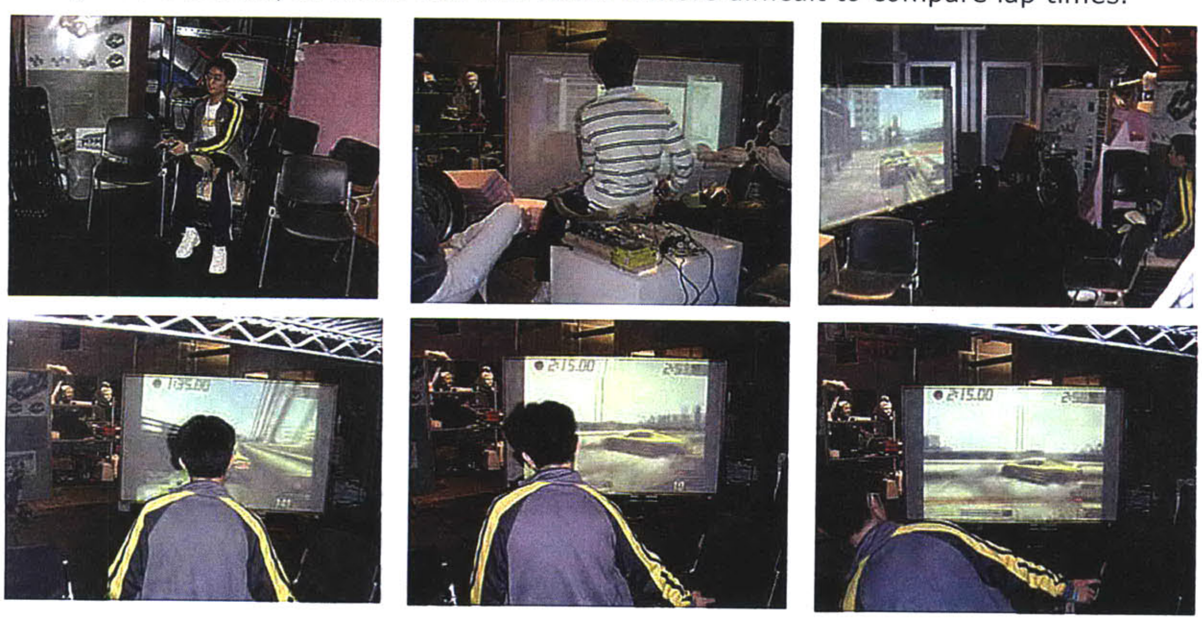


Figure II-36: Driving simulator trials.
Steering was controlled with hip- and leg movements while sitting in the humanseat Mk2. Speed was controlled using the game controller. Top: Setup in studio. Bottom: Turning car using body movements. This subject used whole body leaning motions, others used hip movements.

6.9.1 Performance

Using the humanseat controller, subjects with lots of experience using game controllers, and subjects who had spent extensive amounts of time playing "Burnout Revenge" before using game controllers, reached proficiency levels only slightly below their performance using the controller. Subjects with no or very little experience with game controllers reached equal and at times better levels of proficiency when using the humanseat controller.

For the game Gran Turismo 2, (GT2), controlling vehicles with either system proved difficult. The correlation of previous experience with game controllers and/ or experience with the game to relative performance using the game controller vs. the humanseat was similar.

6.9.2 Subjective Ratings of Enjoyment: "Fun"

The subjective impression of virtually all participants and even bystanders during trials was that of great fun and enthusiasm for this highly involving way of steering the car, by far exceeding the excitement generated when using the game controller.

7. Conclusions

The main achievement of the humanseat Mk2 is that it liberates the body in the 3D space, letting it assume postures and movements that are natural, fun, and beneficial, with effortless initiation and termination of movement and rest. This is novel in a seating device.

From gentle balancing, to extreme gyrating, leaning, and rocking movements, the humanseat Mk2 allows the user to freely move their body as desired.

The user can chose and continually vary the angle between the thighs and the back, thereby regulating the load on the posture apparatus of the body, from reclining far backwards to perching forward in a state that the brain maps neither as "sitting" nor as "standing," providing a sensation of weightlessness, gliding or flying, in an apparatus that is fixed to the ground.

The humanseat Mk2 thus fulfills the requests that Galen Cranz states in his book "The Chair,"[1] that "human beings are designed for movement, the important thing for posture is the coordination of movement," and that "you want the possibility of choosing either movement of the system at any time, ... the head initiating all actions."

The humanseat Mk2 also supports the body and strengthens its posture apparatus without requiring the effort of sitting straight on a stool or for balancing when sitting on an exercise ball.

Thus, the humanseat Mk2 solves the ancient problem of providing support and stability while allowing natural and beneficial movement.

Balancing and moving in the humanseat are intuitive, and the movements and coordination of the upper and the lower body can easily be separated, similar to sitting on regular chairs or walking, indicating that the cognitive load requirements of moving and balancing in the chair are low. This is important for home, office, and vehicle control applications.

The humanseat can also convey sensations of flying, gliding, or being weightless, which is novel for a stationary seating device.

Applications for the humanseat principles Mk1, Mk2, and combinations thereof, can be found in many environments, as will be discussed in part III.

Part III: Future Directions:

1. A Universal 3D Movement Apparatus.

The humanseat is basically a universal 3D movement interface. It allows the occupant to assume a wide variety of postures and to make a wide range of movements. These movements can be mapped to generate outputs for vehicle control, to control computer mice, and for other purposes.

The humanseat approach has many potential applications in cars, other vehicles, exercise, wellbeing, prosthetic, and medical devices. It provides a novel way for exploring the human body and its movements. It allows me to combine my medical and neuroscience training with my passion for cars and movement, but it is also an excellent vehicle to get people with different interests and backgrounds to work together and learn from each other. I have great passion for this project and the continuation of its development for specific applications.

1.1 Medical Uses

The humanseat can be used as a seating, core muscle exercise, or therapeutic device. For example, the knees are completely unstressed in the humanseat, making it an attractive application for patients with knee injuries or after knee surgeries. Wearable parts of the humanseat could also be used to replace knee- and other braces, in conjunction with flextures, for faster rehabilitation.

It also allows to control devices without having to use hands or arms, which is useful for people who don't have functioning arms or hands.

The humanseat is also an interesting application for wheelchairs, from a medical, and from a self-display point of view.

1.2 Airplanes

Airplane seats have to be light, compact, and comfortable over long periods of time. An ideal application for the humanseat.

1.3 Child Restraint Systems

Children don't like to be restrained. The humanseat would allow for children to be fixed in place, while still being able to move their bodies as violently as they may wish, providing stress relief for the children and their caretakers.

1.4 Music

It would be interesting to make new musical instruments Make new musical instruments that everyone can play. Todd Machover' s efforts, lets make musical instruments that you don't need tons of training, virtuosity comes from the inside, using capacities we already have. The ultimate expression of this would of course be if we

1.5 Mapping General Outputs

Generating outputs can be done as discussed, or in other ways, using accelerometers, optical sensors, and pressure sensors in combination with elastics, strain gauges, and other devices. As sensors are becoming smaller, cheaper, and more accurate, they can be placed almost anywhere, including the occupant, so that the humanseat would provide support and the basis for movement.

Depending on the application mapping can be done arbitrarily and can be varied according to user preferences. This is especially easy for applications where there is no risk of harm, like computer games, or for controlling computer mice, electronic musical instruments, and the like.

For vehicle control, several factors will have to be taken into account and researched in order to ensure safety. The control inputs not only have to be intuitive, they also have to be performed precisely under real-world conditions given in a vehicle. Natural reflexes and instinctual movements have to be taken into account. The fact that separation of movements of the upper and the lower body are easy to do, indicates that this might be possible, but simulator tests would have to be done.

1.6 Vehicle Control in the 3D Space

Since the humanseat principle employs our sense of balance, movement, and gross motor coordination, it lends itself naturally for intuitively controlling vehicles that move in the 3D space, such as, submarines, and helicopters, with a potentially great reduction in cognitive load, which would be desirable for rescue, military, and high-traffic applications. Control of planes might also be feasible, although the potential high g-forces would give pressure sensitive joysticks the advantage.

2. Opportunities in Road Cars

2.1 Resolving the Contradiction: Improvements in Driver Comfort and Vehicle Perception

The humanseat principle could be used to provide better long-term comfort in cars. The setup used would have to be more rigid than the one used for gaming applications. Both types of setups were explored using our parametric mockup.

The humanseat principle can also solve the problem of comfort and freedom of movement vs. support and safety in car seats.

2.2 Improving Safety

Having larger surfaces on the body would reduce local pressure peaks during accidents. Having more vehicle information available at lower cognitive load would be positive for active safety.

2.3 Reducing Cognitive Load

The demands on cognitive load while driving are increasing steadily. Communication and navigation devices, and the availability of more information about the car itself, are taking up attention that should be devoted to the act of driving itself.

The humanseat could be used to provide feedback from the car to the driver in a way that has low impact on cognitive load. Furthermore, feedback that is often seen as intrusive, could be presented in more pleasurable ways.

2.4 Driving Using the humanseat?

The movements done in the humanseat are intuitive and highly controllable. They relate to movements that we naturally do for moving in space when we are walking. It is therefore conceivable that these intuitive movements would be mapped to drive a vehicle.

There might be significant reduction in driving-related cognitive load. Cognitive load testing could be performed using the N-Back working memory paradigm[21] for comparison with a pedal-wheel setup. This would be most relevant in city car applications, as improved tactile vehicle feedback can reduce cognitive load[12].

The humanseat could be supplemented with a joystick or similar device, the driver could choose whether to use their hands or not. Driving without having to use one's hands would have several advantages.

3. Opportunities in Race Cars

The physical and mental stress on racecar drivers is very high. So is access to customization, high tech materials, and clothing commitment. Racecars therefore might be a promising application for the humanseat principle.

Obstacles that would have to be overcome might be cultural, insofar that drivers take pride in being experts at compensating for the weaknesses of the system rather than questioning the underlying principles, although this probably varies between drivers and teams.

The humanseat approach might also add the numbers of feedback channels that could be given to a driver in a way that he or she can handle the information.

3.1 Race Cars Step 1: Conventional Controls

Even with today's controls, the design and shape of the humanseat pieces could provide better support and comfort for racecar drivers. We know from our daily lives that pressure and touch to the body can be positive. Using highly customized, wearable pieces, it must therefore be possible, to channel, modulate, filter, and direct the forces and vibrations in a racecar towards positive outcomes. Lateral forces and vibrations could be transformed from uncomfortable or even hindering to positive and supportive, improving the driver's wellbeing and performance. The humanseat approach could also improve performance and shorten reaction times by increasing the amount and accuracy of vehicle feedback while filtering out noise. The weight penalty, if any, should not be too great, since the area of the custom fit pieces is relatively small and the pieces can be made thin.

3.1.1 Improvements in Safety

Worn as an exoskeleton, humanseat pieces could provide protection to the driver to prevent injuries from accidents. Parts that are unprotected now, like the legs and chest, could wear armor. Studies would have to be analyzed on the types, severity, and frequency of injuries so that the pieces could be designed accordingly. A slight psychological advantage might also be gained, since it is likely that drivers who feel safer wearing humanseat parts and would be less inhibited to explore the limits of their cars.

Having exoskeleton pieces on the driver might also help weight reduction, effectiveness, and wearability of the neck-stabilizing HANS device, and improve head support, stability, and movement. This might be especially relevant for racetracks with violent vertical vibrations, which can cause difficulties in focusing on the apexes in corners and affect readability of instruments.

For extraction of the driver in an accident, having a more comprehensive support system of the driver than the seat bucket might also be an advantage. Joints between different parts of the humanseat could be lockable, or there could be attachment points for external fixations that would be applied in case of a suspected fracture or spinal injury.

The humanseat or parts of it could be worn, and the connection to the car could be snap-in, snap-out, like with skiing boots and skis.

3.1.2 Improvements in Vehicle Perception

Anatomically, neurologically, and emotionally, all our bodies are different. These differences become more pronounced as the stakes become higher, such as, in intimate, medical, or high stress situations. It might therefore make sense to support each driver exactly in the places where they need it, for support, wellbeing, and vehicle perception.

Having wearable pieces allows new areas that are sensitive to tactile inputs, and where tactile input is read as positive, to be touched and therefore to be used for vehicle perception. This might improve the driver's performance. For specific tracks, specific modules of padding or suspension or attachment elements of the seat to the car could be used, to optimize the signal to noise ration in tactile feedback.

3.1.3 Improvements in Physical Comfort and Performance

The anatomically correct shape of the seat would also allow for the use of intelligent padding for each specific part of the body for better comfort and better tactile signal to noise ratio.

Having more surfaces covering the body would reduce local pressure peaks. The thighs, buttocks, lower back, and shoulders, could all be fixed to the car with their own specific degrees of freedom and support, tailored to the needs of each driver and of each track. Each part of the body could be given exactly the degree of freedom and support that it needs for optimal performance, and for optimal comfort.

The hips and thighs, for example, could be stabilized laterally and from underneath, but allowed minute movements with a humanseat Mk2 suspension for the lower spine to be relaxed, while the shoulders are fixed again for precise operation of the steering wheel.

3.1.4 Improvements in Mental Performance

The mental demands on racecar drivers are very high. There are three types of situations that are mentally especially demanding: The start and the distance right after the start until a running order is settled, where concentration has to be very high; being followed by a faster car, where mistakes have to be avoided; and periods where the driver is under no pressure and therefore prone to mistakes due to a lack of concentration.

Mental and physical states can be coupled, as is done in many practices, like yoga. It is therefore conceivable that either a driver wears humanseat pieces during mental exercise, or that active or reactive humanseat pieces change the grip on the driver, making him feel on edge, present, and strong during the start, relaxed when pursued, and gripping him more tightly when he's loosing concentration.

Parts of the seat could be worn in environments where the driver is relaxed, forming a positive association. Simulator training of difficult race situations could also be done to train the seat reacting to the driver's biophysical signs, so that the seat could assume mentally guiding functions. The way the seat touches the driver in these situations would then aid concentration.

3.1.5 Platform for Biofactor Measurements

A reactive humanseat could be done in conjunction with biofactor measurements. Due to the fact that the pieces are close to the body, they can serve as an ideal platform for measuring heart rate and other indicators of the driver's state. This could provide important information for the pit crew, but it could also be used for direct feedback from the seat to the driver, as discussed above.

3.1.6 Active Seat

The seat itself, parts of it, or the connections to the car could be active, using actuators to move the seat or parts of it, or MR fluids to change the damping characteristics of the seat suspension.

The idea is that the sensation of oversteer, or other driving relevant sensations, could be attenuated or enhanced according to the needs of the driver or the track.

This might be relevant when the setup that is theoretically ideal for vehicle performance has to be compromised according to a driver's preferences, or in cases where, for example, more sensitivity to oversteer, would give the driver an advantage in balancing the car.

3.1.7 Increase Driver Output Channels

It is of course thinkable, that the driver can be assigned new output channels. Movements that so far cannot be used to generate output, like opening or closing the legs, could be used to give input to the car. Of course, the assignment of input to output would have to be developed and tested carefully. This will be discussed in more detail below.

3.1.8 Tactile Presentation of New Information Channels

Some types of information would be very valuable to a driver during a race, but are hard to present in a way that is useful. The additional surfaces of the humanseat could be used to convey such information in a useful and intuitive manner at low cognitive load.

For example, drivers cannot tell tire temperature accurately. This leads to loss of time, as when on rain tires on a drying track, drivers seek out wet spots to cool their tires, slowing down the car, without really knowing if it is necessary.

In open wheel cars, drivers can observe tire wear visually in the rear view mirrors or by directly looking at the front wheels. In other cars, this is not possible. Even visual input does not indicate tire wear accurately and in a timely fashion.

These factors, if they can be measured, can be transmitted to the driver using touch or heat in the humanseat, or by moving parts of it. Hot buttocks could mean hot rear tires, etc.

3.1.9 Platform for Exercise and Training

Physical exercise has become a critical component of driver training, for strength, and for general fitness and endurance, to better endure the thermal, vibration, noise, and other demands of the racecar environment.

Using the humanseat approach, the driver could train in the same tactile environment as the car. This could lead to improvements in driver performance due to the better familiarity of the driver's body with the car interface.

Vibrations, and reflex exercises could be added during exercise, so that the body learns to perform optimally in this environment. It is even thinkable that a driver would sit in some humanseat parts while watching TV, and would receive random sequences of inputs, for example, simulating oversteer, a slippery track, or curbs, and would improve his reflexes.

3.2 Racecars Step 2: Take Advantage of Sensibilities of the Body to Drive Car

As discussed above, humans can precisely coordinate and balance a vast number of gross motor activities, especially if they have to do with motion-related activation of the inner ear. These mechanisms are evolutionarily much older than fine motor coordination and should therefore be faster, more accurate, and provide better coordination for more output channels if used correctly.

The fact that reaction times are shorter with a hand operated clutch than with a foot operated clutch, might have to do with the fact that the balance and motion sensing system of the inner ear is not activated in that process.

Exploring these possibilities is not trivial, and has to follow a systematic evaluation of the instinctual and compensatory movements of drivers on a track, and of the ability of these movements to generate precise output. There might be pros and cons to both systems, which would have to be balanced, or the systems would have to be combined.

3.2.1 Study Weight, Muscle Tension, and Natural Compensatory Movements

A first step would be to study weight distribution, muscle actions, instinctual, and compensatory movements in simulators taking advantage of the anatomically precise fit of the humanseat. Some of this was done for this thesis at the Media Lab, but more data would have to be generated.

3.2.2 Studies of Context- and Reflex-Induced Motions in Cars

A non-driver would start doing compensatory or faux- control movements while being driven on the track, in order to find the most natural and beneficial movements for the body to do in this environment. The driver of the car would induce different types of maneuvers, oversteer, understeer, etc, and the passenger's compensatory movements and reflexes would be monitored. Reaction times could then be compared to those of a passenger with a regular mock setup.

3.2.3 Apply those Movements to Drive Car

In the final step, these movements would then be mapped to a drive by wire system or connected electronically to an actuator system that actuates the regular controls to drive a car.

3.3 From Wearable Seat To Wearable Car: Radical Car Concepts

The Athlete Car investigated the idea of building an articulated car around movements of the human body as they occur during high-speed athletic activities, such as, skiing and ice-skating.

The Mini Athlete was a more radical form of this concept by reducing the car to the driver, an exoskeleton, and the wheel.

The most radical concept coming out of the humanseat would of course be a wearable car.

The engine and back wheels would be strapped to the back of the driver, who would control one front Wheelrobot with each foot, wearing an exoskeleton that measures his state and makes the car react accordingly.

4. Conclusions

Separately or in combination, humanseat Mk1 and Mk2 might find many applications related to being stationary or to moving in space.

The exoskeleton principle shown in the humanseat Mk1 may be a good platform for a novel approach to safety, comfort, and vehicle perception in road and racecars, while the benefits of the pelvic movements in the coronal plane of the humanseat Mk2 prototype as far as emotional satisfaction and comfort make it an ideal application for situations where people have to sit for a long time with little space available to them.

Due to the way it allows intuitive movements in the 3D space from which multiple output channels can be generated, the humanseat Mk2 might be especially suitable for controlling vehicles in 3d space, such as, helicopters and submarines.

Health- and gaming applications are also feasible.

Part IV: Conclusions

In this thesis, we discuss an approach to seating that takes the moving body as the origin of its design process rather than the sitting body.

Basic paradigms of movement, sitting and standing were analyzed and the hypothesis was made that rocking of the pelvis in the frontal plane was missing in sitting and standing, both postures that can be troublesome from a health perspective.

The shapes, textures, and movements of the body and their medical and emotional significance were analyzed in order to develop our design strategy to develop a seat that would translate motions from sports, like skiing, into output to drive a vehicle.

The result of this approach fulfills the requests that "human beings are designed for movement, the important thing for posture is the coordination of movement,"[1] and that "you want the possibility of choosing either movement of the system at any time, ... the head initiating all actions."[1]

The main achievement of the humanseat Mk2 is that it liberates the body in the 3D space, letting it assume postures and movements that are natural, fun, and beneficial, with effortless initiation and termination of movement and rest. This is novel in a seating device.

The humanseat can also convey sensations of flying, gliding, or being weightless, which is novel for a stationary terrestrial seating device. Due to the way it allows intuitive movements in the 3D space from which multiple output channels can be generated, the humanseat Mk2 might be especially suitable for controlling vehicles in 3d space, such as, helicopters and submarines.

The exoskeleton principle shown in the humanseat Mk1 may be a good platform for a novel approach to safety, comfort, vehicle perception and control in road and racecars, while the benefits of the pelvic movements in the coronal plane of the humanseat Mk2 prototype as far as emotional satisfaction and comfort make it an ideal application for situations where people have to sit for a long time with little space available to them.

Balancing and moving in the humanseat are intuitive. Just as in regular chairs, the movements and coordination of the upper and the lower body can easily be separated. This indicates that the cognitive load requirements of moving and balancing in the chair are low, possibly comparable to regular chairs. This would be important for home, office, and vehicle control applications.

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