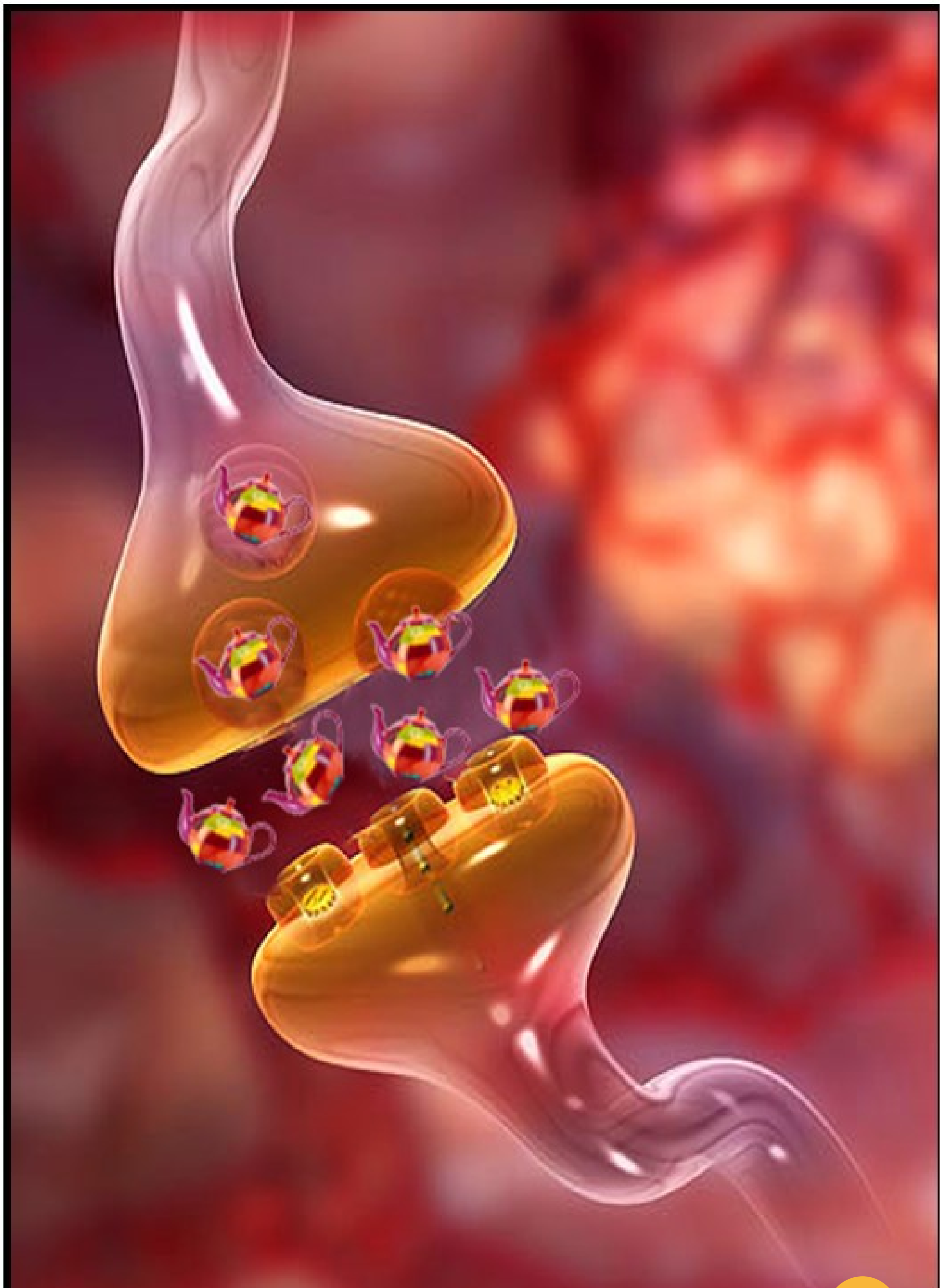
Feel And Sense The Product: Experimental based optimization methodology



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INTRODUCTION |ONE:

The today market is strongly user oriented. Starting from the Donald Norman seminal works (Norman, and Draper, 1986), in the design field, several studies and theories have been formulated, in order to put the user at the center of the design process. Today, designers do not design anymore basing on their own guts, but pay heed to the costumers' voices, carefully trying to understand the consumers' desires and limitations, basing their own work on the final user. As a matter of fact, however, to design for people is often more difficult than one might think. In order to catch the users' preferences and implement them in the final products a huge number of methods have been applied at several stages of the design process (McGraw, and Harbison, 1997; Nieminen, Mannonen, and Turkki, 2004; De Troyer, and Leune, 1998). All these methods come from a wide variety of fields, such as psychology, engineering, neuroscience, and marketing (Mao, Vredenburg, Smith, and Carey, 2001).

The objective of this thesis was to develop a design methodology based on three main phases (question definition, interaction study, and finally sensory boost), rooted in the experience design theorywhich is one of the more accepted design theories aiming to put the user in the center of the design process (Shedroff, 2001). The methodology proposed in this thesis is composed by different stages:

- The *question definition phase;*
- the *product-user information gathering phase*;
- the *sensory-user information gathering phase*.

In particular, the last two phases constitute the core of the methodology. These two phases are strongly experiment-oriented. In particular, in the product-user information gathering phase (also simply addressed in the text as "interaction study phase", or PUIG), the designer using the methodology will be able to carry out a series of experiments aimed at collecting important insights about the relationship between the product and the user, for example: What are the important features of the product, what the user considers important during the interaction with the product, and which are the sensory modalities and the emotions mainly involved in the product design. Afterwards, in the sensory information gathering phase (also simply addressed in the text as "sensory boost", or SIG phase), the designer will focus on the user, trying to understand how to maximize the salient features of the product (spotted by mean of the interaction study phase), investigating the user perception and cognitive abilities related to the perception of the product features.

At the end of the process, finally, the designer will put all the obtained information in a coherent model, in order to achieve a comprehensive understanding of the users' needs and, eventually acting on the design of de product, re-designing it to better match the user's needs. It is worth noting, however, that the whole methodology has to start from a specific design question. The designer must have clear in mind which aspect of the design of the product to optimize, at least in terms of pragmatic/hedonic, and work considering this for all the time he/she will need to make a decision on which method to adopt, which experiment to carry out, how many participants to involve, what population to select for the experiment etc. However, a set of guidelines will be offered in the course of this doctoral thesis, aiming at supporting the designers in making the right choices, and achieving an experimentally optimized product design.

Figure 1 shows the simplified structure of the methodology exposed in this document. Everything starts with a design question. Knowing what to investigate, the designer start to study how users interact with the product he (she) want to optimize. At a fist stage, the characteristics of the products found important during the interaction are highlighted by the interaction study phase. Subsequently, a study of the user perception is carried out . As a matter of fact, the results of the sensory boost can be represented by an optimization procedure that can be formalized through Pareto diagrams (Zitzler, Laumanns, and Bleuler, 2004) (as it will be shown the last chapter of this thesis). The result of the process is a new product design. The product has then to be tested by the user, and, if necessary, it has to go through a further optimization loop.

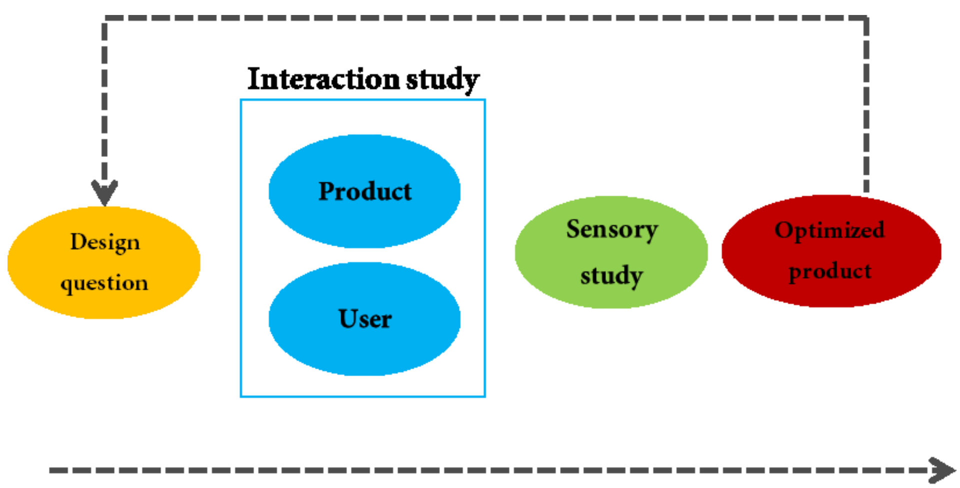

Figure 1.1: The methodology for the product's design optimization in a simplified version. Once spotted the design question, interaction between product and user is studied by mean of an interaction study. Subsequently, the sensory boost study is performed.

THEORETICAL FRAMEWORK:

ABOUT THE DESIGN PROCESS

This doctoral thesis collects a variety of arguments and methods coming from the different fields of psychology, cognitive science, engineering, and design, in order to develop a methodology for the product's design optimization. Nonetheless, the design theory represents a crucial matter that is worth of an in-depth treatment, given the aim of the methodology which has been created in order to help them in developing their products. To this purpose, the present chapter will linger on the design processes. In the first part it will try to give a definition of design as traditionally intended, leaving apart any distinction concerning the different design theories and conception (i.e. leaving apart all the distinctions between experience design, user-centered design, emotional design etc., and focusing on the design processes and on the design thinking). Subsequently, the chapter will focus on the relationship between design and the other disciplines, particularly lingering on its relationship with psychology. In particular two concepts will be analyzed: creativity, which is important to better understand the design process, and product perception. Finally, the chapter will report some of the methodologies currently used in the design field to optimize the product.

A QUICK OVERVIEW TO MULTIDISCIPLINARITY IN DESIGN

It is not easy to give a definition of what is considered design nowadays. The word, as Brian Lawson pointed out in his book, is really complex to define, given the high number of implication that "to design" and "to be a designer" carry with them (Lawson, 2006). Let's take for example an engineer designing a bridge. Even though the bridge can be very simple in shape and appearance, there is no doubt of the scientific complexity and of all the calculation on weight distribution and even materials underneath the process of designing it. Even though this process can seem somewhat automatic and a little bit too "exact", then it is doubtless the necessity of properly design the bridge, and as consequence, is not wrong to consider the engineer as a designer. Let's think then to a product designer who is asked to re-design a common object in order to increase its purchasing effect. The result of this design process will likely be an innovative object, communicating its novelty mainly through estrous shapes. In fact, visual channel has been proved to be the most used by designers, and the most communicative for the users (Schifferstein, 2006; Schifferstein, and Desmet, 2007). As a matter of fact, this second example involves a different amount of fantasy and creativity, and one might wonder whether the process is even comparable with the one of the first example.

Indeed, the two examples represent an oversimplification of the design process. Both designing a bridge and designing an object include a high amount of creativity as well as precision. If examined with more attention, both the activities of designing a bridge and re-designing a product will be found to be multi-dimensional problems, requiring (as any design problem) both technical skills and inspiration. What the two cases have in common is the fact that the design process arises from a demand, or a problem, to which the designer has to give a solution through a process of creation. In this view we can give the definition of design as: the process of solution through creation, standing in between the exact application of the laws of the physical world and the limitless imagination of the human mind.

As illustrated in Figure 2, the today's design is a highly multidisciplinary field. In the space of "creation", design can be represented as in between art and engineering, , whereas art is more connected with the creative process mainly based on pure imagination, and engineering reflects more the application of the world's physical laws. Moreover, Figure 2 shows in the Y axis the relationship with the process of creation and in some extent, with the product of the creation process. In particular, on the Y axis there is a division between the disciplines that actively produce tangible creations, and the disciplines that study the process of creation. Indeed, while engineering is orientated on practically producing objects, structures, and goods, psychology is more interested in understanding the process of creating things, and in how the created things are perceived by people. In this view, art and design are in between the two poles, being interested both on the theoretical matters concerning the process of creation and in the practical aspects of it.

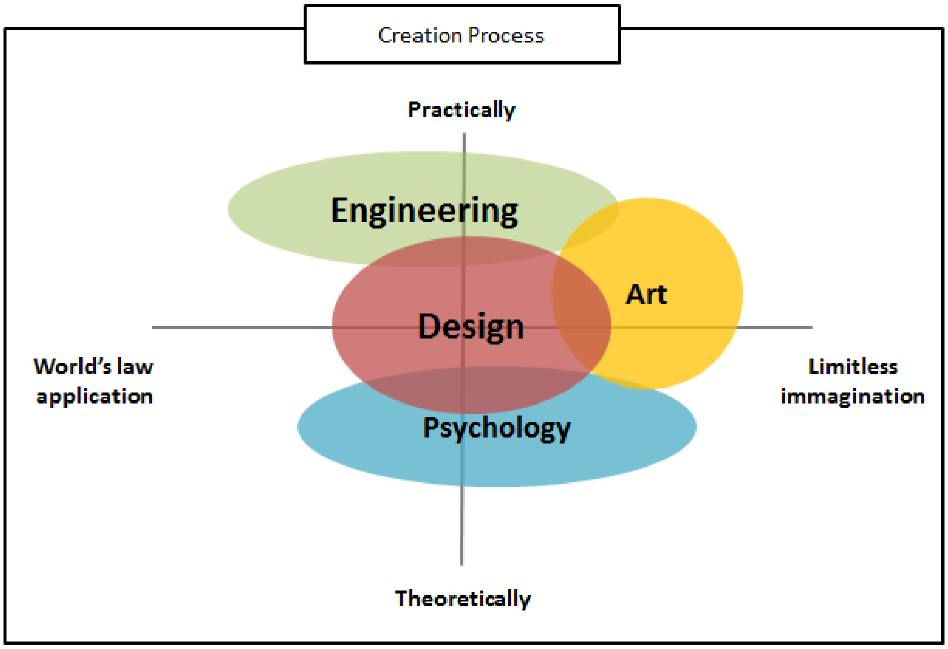

Figure 1.2: The position of the four disciplines of art, design, engineering, and psychology in process of creation. The X axis represents the continuum between the mere application of the world's laws of physic and the limitless imagination of the human mind. The Y axis represents the position of the four disciplines for what concerns the interest in the creation process, being it either practical or only theoretical.

Concluding, at the light of what stated so far, the design process can be also defined as a process anchoring the human imagination typical of the works of art to the real world, and it is interested both to the practice and the theory of the creation process itself, studying it and actively applying the insight of theoretical studies. In the next sections we will go deeper in the relationship between design and art, engineering, and psychology, expounding the definition in order to make it more clear. In particular, the connections between design and psychology will be deeply investigated, because it is a central matter in this doctoral dissertation.

DESIGN AND ENGINEERING

Among the disciplines examined in the present section engineering is likely to be the most associated with the idea of practical creation, and the closest to the conception of creation as the application of the physical laws. The term "engineering" itself recalls the pragmatism of the discipline, deriving from the word engineer (first reported in 1325, according to the Oxford dictionary), whereas an engineer (literally, one who operates an engine) referred to *"A constructor of military engines"* (Oxford Dictionaries).

The design process shares, in some extent, this pragmatical thinking. When facing a problem, as the design of an object or even a building (architects have been considered designers by several authors (Lawson, 1978; Potter, 1980; Hamel, 1994), designers have to keep in mind that the goods they are designing will need to work properly, and this is impossible without a pragmatical approach and an understanding of the laws that will allow the goods to do the jobs they were intended for.

In fact, in the last decade, design and engineering have been seen so coupled (especially in the field of industrial design) that the profession of "design engineer" is nowadays a consolidated fact (Liebman, 1989). In particular, a design engineer is a connection between the engineers and the designers working on a project, in order to develop a conceptual and detailed design, starting from the product concept to the last specifications, going through the design effort (Lawson, 2006). The role of the design engineer represents the relationship between engineering and design, and the necessity, for the designers, and of an understanding the physical principles underneath the goods they will create. Getting closer to engineering, product designers have been able to achieve a better understanding of the new technologies that in turn allowed them to carry out a series of innovations on existing objects and even to develop new outstanding tools (Chapman, and Pinfold, 1999).

An example of the connection between design and engineering is the virtual prototyping. Virtual prototyping allows the creation of virtual prototypes, which in turns allow to collect information on the user preferences concerning a real product. For example, merging the potentialities of Virtual Prototypes (VPs) and Digital Mock-Ups (DMU), Ferrise and co-authors (Ferrise, Bordegoni, and Graziosi, 2012) developed a flexible design scenario to interpret users' desires. Visual, acoustic, and haptic stimuli were reproduced in order to let users live a realistic multisensory experience interacting with the virtual replica of a product. Parametric models were defined to acquire users' preferences while optimization algorithms were used to transform them into technical specifications, improving the design and enriching the design procedures with a direct shortcut to technical specifications.

A further connection that design shares with engineering is represented by the push that the design gave, in the last decade, to the development of new technologies. In the recent literature a number of new tools for creativity and creation have been reported, created with the aim of helping the designer through their creation process. For example, Bordegoni and colleagues (Bordegoni, Ferrise, Covarrubias, and Antolini, 2010) developed the prototype of a system that allows designers to evaluate the quality of a shape with the aid of touch, vision and sound. The device consisted of a stripe mechanically able to deform and bend according to the geometries corresponding to a virtual prototype. Sound was used to communicate geometrical data, relating to the virtual object, which were practically undetectable through touch and vision. Another example is the PUODARSI framework that allows product designers to intuitively modify the shape of a product through haptic interaction and to test in real-time the structural and fluid-dynamics impact of these changes (Bordegoni, Ferrise, Ambrogio, Caruso, and Bruno, 2010).

It is not surprising then, that many universities traditionally associated with the field of engineering offer now courses in design and product design, proving the fact that the thinking and the competences necessary for the two consistently often overlap.

DESIGN AND ART

Although design is often associated (at least from an educational point of view) with engineering, it is also not unusual to find design courses thought in art schools and academies. Whereas, with engineering, design shares the necessity of a rigorous and efficient understanding of the physical world, with the realm of art the design shares the necessity of estrous solution and innovation, together with the ability of communicating the meanings and feeling of the creator through the creation itself (Frascara, 1988). In some extent, design itself can be considered a form of art. Despite dwell on what is considered art is not the aim of the present section, it is noteworthy that design is nowadays considered as a proper visual art, and that the fields of industrial design, graphic design, fashion design, and interior design are altogether considered applied arts (Steadman 2008). As a matter of fact, it is sometimes difficult to distinguish between a fine design and a work of art. Even more important, the processes underneath the development of a work of art have been considered similar to the ones involved in the design of a good, and often designers and artists have to share same skills. As the American graphic designer Paul Rand said once:

> *"…Design is the method of putting form and content together. Design, just as art, has multiple definitions; there is no single definition. Design can be art. Design can be aesthetics…" (Paul Rand, 1914-1996).*

When a designer is involved in a project, then, he/she is even expected to bring a certain kind of interpretation to the work, a sort of signature, which often constitutes the "artistic" part of the work. However, the design process is more constrained with respect to the work of art. The designer has to offer a solution that is both "artistic", and doable and functional. The designer has, then, to find the compromise able to satisfy the needing of hypothetical clients and his/her own self-expression. As Steve Jobs used to say, indeed:

> "…Design is not just what it looks like and feels like. Design is how it works…" (Steve Jobs, 1955-2011).

DESIGN AND PSYCHOLOGY

Among all the intersections that design can have with different disciplines, the one it shares with psychology it is extremely the most complex and interesting. Many important designers in the last 20 years came from a psychological background. Donald Norman, Marc

Hassenzahal, and many others have their roots in the psychological education and cognitive science. As a matter of fact, design shares with psychology the interest in creation and creativity. Moreover, while psychology is, by definition, the study of the human mind, design is often expression of it, and, in fact, it can benefit from a better understanding on the processes taking place in our brain (Carroll, 1997). In principle, we can find at least two main connections between psychology and design. The first connection stands before the process of creation, and regards all the psychological studies concerning creativity and design thinking. The second connection regards what happens after the creation of an object. Indeed, psychology can offer tools and insight on how the creations of the designer are perceived by clients and customers. In the next paragraphs it will be briefly expose the effort of psychology in understanding the creativity and the creation processes, to switch lately in exposing what is thought to happen during the design process. Finally, studies regarding the perception of products and goods will be exposed. This particular aspect of the connection between design and psychology actually fulfills a crucial role on this thesis.

BEFORE AND DURING THE DESIGN PROCESS: CREATIVITY

The study of creativity has been approached by experimental psychologists and neuroscientists with different methods and tools. A first classification of the studies regarding creativity is due to Simonton (2003) that broadly divided them into three categories. The first category included a number of correlational studies, investigating the creative person itself (i.e., Cattell, 1963; Eysenck, 1995). These studies collected personality traits and psychometric measures of cognitive style, supplemented by biographical inventories that collected familial and educational experiences. The goal of these studies was to identify the distinctive psychological characteristics distinguishing creative people (in these cases from others).

Another category spotted by Simonton concerned the studies on creativity concentrated on problem solving in laboratory settings (Hayes, 1989; Klahr, 2000; Newel and Simon, 1972). This approach could be seen as facing the creativity matters in a more rational view, implicitly defining it as the ability to solve problems in an uncommon way. Following this stream of thought, a series of tools to study the creativity processes were developed. Examples of these tools were computer simulations— especially the so-called discovery programs— able to implement, with a good approximation, the cognitive processes identified in the laboratory experiments (Langley, Simon, Bradshaw, and Zythow, 1987). Finally, a third approach, Suggested by Simonton himself (Simonton, 2003), aimed instead to study the products of the creative processes, in order to achieve information on the process itself.

However, whatever is the method of investigation, it is difficult to trace what is meant when we speak of creativity. Research in neuroscience and psychology has often obtained different and rather contradictory results on such matter, even when adopting the same methodology of investigation. In 2010, Dietrich and Kanso (2010), offered a review of most of the neuroscientific studies that tried to locate the creativity processes in the human brain, showing how the current theories in circulation (i.e., alpha synchrony, prefrontal activation, low arousal) were unable to catch the creativity process in its complexity, giving contradictory prediction and results.

Dietrich and Kanso grouped the studies on creativity in three different categories. However, while the categories founded by Simonton were based more on the methods of study, their categories were mainly distinguished by the definition that scientist gave to the term "creativity". The three categories were defined as: divergent thinking, artistic creation, and insights. Interestingly, from a neuroanatomical point of view, the studies falling into the three categories found different neural correlates. Indeed, while divergent thinking activates diffusely the prefrontal cortex, artistic performance, often include motor and temporoparietal regions. Neuroelectric and imaging studies of insight instead, showed a less spread activation pattern, reflecting changes in anterior cingulate cortex and prefrontal areas.

The idea of divergent thinking is probably the most adopted in science when it comes to creativity. First defined by Guilford (Guilford, 1967) as the ability to generate multiple solutions to an open-ended problem, it had lot of success, probably due to the fact that this conception of creativity allowed scientists to face the problems in the rigorous setting of a laboratory. In other words, divergent thinking reflects the human ability of processing divergent information. Several psychometric tools able to measure the divergent thinking skills were developed after the Guilford seminal work (i.e., Torrance Test of Creative Thinking (Torrance, 1974)). On these kinds of tools, divergent thinking tasks outcomes were usually evaluated on three scales: ideational fluency (i.e., the number of ideas), flexibility (i.e., the number of different types or categories of ideas), and novelty (or uniqueness/ originality) of the ideas (Basadur and Hausdorf, 1996). However, despite to study the creativity based on divergent thinking constituted a first important attempt to investigate creativity, it does not encompass the whole creativity process. It is possible to see, in fact, that creativity can also rise from a convergent processing of information, as what we know about the Bach composition method proves (Collins, 2005). Moreover, a divergent thinking does not grant a creative result. Another critique moved to the study of the divergent thinking is that it is itself a compound construct (Costello and Keane, 2000), that in turn requires in depth further testing to be better understood (Dietrich and Kanso, 2010).

However, not all the studies on creativity rely on the divergent/convergent thinking concept. The second category drawn by Dietrich and Kanso in fact included a whole branch of studies investigating the creativity processes that focused, expecially in the recent years, on the art and musical production. This kind of studies (i.e., investigations of musical and artistic processes, such as free jazz composition (Alterhaug, 2004), imagining a, or drawing an abstract concept painting (Yokochi, and Okada, 2005) had the advantage of allowing scientists in considering the creativity process in its integrity, bringing it to the conclusion that many of the theoretical distinctions that have dominated the field of this kind of studies—for example, divergent versus convergent thinking, right versus left brain processing, and focused versus defocused attention—were too simplistic (Dietrich and Kanso, 2010). Indeed, the results of these works lead to consider creativity at work as a consequence of simultaneous processes, skills, and ways of thinking.

Finally, studies on insights and intuitions have been taken into account as a third domain of studies investigating creativity. In fact, insight events have been considered as a subfield of creativity. The reason of this view is that the starting point to produce a finished creative product, more often than not, is represented by a creative insight (Runco, 1995). The tasks traditionally adopted to study insights are more narrowly defined than those of the other two domains, and they help reveal the full measure of how complex, varied, and multistep the neural mechanisms of creativity must be.

CREATIVITY IN DESIGN

While, from a psychological perspective, creativity has been studied in terms of its constitutive parts, and in terms of neural processes (obtaining a rather fuzzy set of results), theorists of the design focused their discussion on the stages needed to achieve a creative results, in how to augment the creativity in the design process, and most of all in how the creativity kicks into the design of a good improving its value. It is noteworthy, however, that sometimes studies in the design context assume a rather fuzzy definition of what is creativity. In their book, Hevner and Chatterjee (2010) defined the creativity in design as "doing something that is novel and judged by the expert of the field as being creative". Such a definition is supported by experimental data. In his study, Christiaans found that when specialists are asked to rate design products on 'creativity', they are quite consistent (as reported in Dorst and Cross, 2001):

> *"Apparently, they are much more in agreement (in an admittedly intuitive way) about recognizing the creativity of a design than the inconclusive discussions about the definition of creativity would suggest".*

Despite what this can be seen as a lack of precision in defining the center of the study, it is incredible how accurate design theorist can be in putting creativity in the stages of the design process.

One of the most used approaches which aim is to formalize the creativity in the design process models the latest is based on the information processing theory (Newell and Simon, 1972). According to this theory, problems are solved by searching in problem spaces, where a problem space is abstractly defined by the reasoning goal and by the domain knowledge, in the form of operators that enable a space search. In the design context, the reasoning goals are specified as part of the design requirements that express design variables and specific ranges of values they can take, and the operators are specific to the particular design domain (Goel and Pirolli, 1989). According to Gero and Maher (2013), design is creative when the designer is able to capture a change in the design variables and design values in the problem space. On this branch of studies it is worth to mention the work from Dorst and Cross (2001). In fact, they modeled the 'problem-solving' aspect of design in terms of Maher's model of the co-evolution of problem and solution spaces, underlying the fact that in creative design solution and problem co-evolve together. They also state that *the 'creative' aspect of design can be described by introducing the notions of 'default' and 'surprise' problem/solution spaces",* where the Surprise is defined as: *"what keeps a designer from routine behaviour", leading the design solution to become a creative solution.*

Another way to formalize the creativity expressed in the design process relies in the kind of prior information that designers have at disposal when developing their creations (Brown, 1997). In this view, if the designer knows both the structure of the design space (e.g., the structure-substructure hierarchy of the object) and procedures for systematically searching the space (e.g., the skeletal design plans), then the design process can be defined as *routine design*; if instead the designer knows the structure of the design space, but have no clue about the procedures, then it can be classified as *innovative design*; finally, if the designer knows neither, then it can be considered *creative design*. This view brings some interesting implications. As first, this suggests that problems formulation and reformulation are integral and continuous reiterative parts of creative design, leading to continuous changes in the design solution. Second, in creative design, knowledge needed to address a problem typically is not available in a form directly applicable to the problem. Some of the needed knowledge indeed, has to be acquired from other sources, by transferring it from a different problem to the design solution.

Concluding, it is rather complex to speak about creativity, both in the fields of design and psychology. What is clear, though, is that creativity in design arises from a co-evolution of the problem understanding and of the solution. Even ignoring when insight and inspiration kick in during the process, and the neural and psychological processes underpinning this mechanism, it is important to keep in mind that these events can distinguish between routine and creativity. Nonetheless, these events cannot arise without an in-depth understanding and definition of the problem and without the right amount of information needed to solve it.

AFTER THE PROCESS: PSYCHOLOGY AND DESIGN ON THE PERCEPTION OF THE PRODUCT

A further interest shared by designers and psychologists concerns the perception of the design product. As previously mentioned, the creation of a designer is often something that goes beyond the simple purpose the good was intended for. Designers put in their product their signature, and a lot of further implicit information about the messages they want to communicate to the consumer. In the packaging design, for example, the container of a good is designed not only to store it, but it also has the specific purpose of suggesting to the users of a given product a series of information intended to encourage the product consumption (Ampurero and Vila, 2006). In interior design, a given chair or even a space can be designed not only in order to make the user feel comfortable, but also to communicate the idea of comfort and luxury to him/her. Unfortunately, it is not easy for the designer to understand how to suggest a concept or an idea through his/her work. As it will be presented in the next section, there is a gap between who creates a solution to a design problem and people that are going to use the solution. In order to close (or at least reduce) this gap, designers grown interest in the field of psychology and marketing that studied human perception (Schifferstein and Desmet, 2008).

Psychology has always harboured lot of interest in the study of perception, sharing this interest with art, architectures and eventually design. At the beginning of the past centuries, studies on human perception were well represented by the Gestalt psychologists, whom looked for the rules that allow us to perceive the shapes and figures in the world around us (Koffka, 1935). After the First World War, the work of the Gestalt psychologists began to be considered by artists and architects, as demonstrated by some documented story. For example in 1929, the student of Wolfang Kohler (one of the founders of the Gestalt psychology), Karl Duncker, offered a lecture in Bauhaus on the human perception. In the audience was the painter Paul Klee, who had known about Wertheimer's research as early as 1925. Other artists also interested were Wassily Kandinsky and Josef Albers, whom attended a series of lectures about gestalt theory by Count Karlfried von Diirckheim (a gestalt psychologist from the University of Leipzig), in 1930-1931 (Behrens, 1998). As the gestalt theory has been used by artists, so it has been used with similar mechanism by designers too. Important books in design education, including Kepes's "Language of Vision" (1995) and Arnheim's "Art and Visual Perception" (1954) formalized the use of several gestalt visual principles for design. As a matter of fact, knowing and applying some of the gestalt principles (i.e., grouping and completion) can often represent a shortcut for designers. Among others, Gestalt psychology has been used to design multimedia and multisensory display and interfaces (Chang and Nesbitt, 2006). The approach that gestalt had in studying basic components of our perception is still used by designers, which look for principles regulating perception in their products. For example, in their paper, Lim, Stolterman, Jung, and Donaldson, (2007) proposed the concept of interaction gestalt, as a way to enhance the results of design thinking. They proposed a set of interaction gestalt attributes that can be used in designing aesthetic interactions, pointing out implications and benefits of this approach.

The psychological study of perception is often associated with psychophysics. Psychophysics quantitatively investigates the relationship between physical stimuli and the sensations they elicit. Psychophysics has been described as "*the scientific study of the relation between stimulus and sensation*" (Gessheider, 1997) or, more completely, as "*the analysis of perceptual processes by studying the effect on a subject's experience or behaviour of systematically* *varying the properties of a stimulus along one or more physical dimensions*" (Bruce, Green, and Georgenson, 1997). Despite psychophysics can be rather technical, the application of its methods provided useful results in many design applications, especially the ones related with new technologies and engineering. The measures of thresholds and the understanding on how the information coming from different senses is merged to create a given percept are doubtlessly important when it comes to create a new product. For example, Gatti, Ferrise, Re, and Bordegoni (2011) measured by mean of psychophysical methods the minimum discontinuity perceivable during the haptic exploration of a surface. Results allowed setting up the design of a new technology able to replicate curved surface by mechanical deformation. In this way, psychophysics can help design in providing technical specifications for the product the designer intends to create.

Finally, the probably more interesting intersection between design and psychology of perception regards the whole branch of studies on crossmodal correspondences and synesthesia. In a recent work, Gatti, Bordegoni, and Spence (2013) defined the crossmodal correspondences as a series of dimensions of experience that are shared across sensory modalities (see Spence, 2011, for a review on this topic). In other words, this means that even complex ideas or concepts can be communicated through relatively simple stimuli acting on the human senses. Moreover, crossmodal correspondences make possible that a given sensory characteristic of a stimulus belonging to a given sensory modality is enhanced by a congruent stimulus in one of the other sensory modalities. The application of crossmodal correspondences to the design world is straightforward and constitutes one of the main fields of the research in the modern design.

For example, Gatti and colleagues (2013) recently investigated the effect that weight, colour, and fragrance had on the expected efficacy of a product (a liquid soap) through a crossmodal correspondence mechanism based on the idea of intensity. To this end, they conducted an experiment were a series of soap bottles identical in shape but with different intensities of colouring (white, pink, or red) were produced. The weight of the bottles also varied (either light - 350g, or heavy - 450g). Two different concentrations of perfume were added to the liquid soap contained in the bottles (either low or high). In the experiment, participants evaluated the perceived intensity of the fragrance contained in each bottle, the perceived weight of each bottle, and the expected efficacy of the soap itself (that is, the soap's expected "cleaning ability"). A significant effect of the attribute intensity, suggested by a more intense colour and a heavier bottle was finding to enhance the perceived intensity of the smell contained in the bottles. Moreover, the same mechanism seemed to affect the expected efficacy of the soap. Indeed, "more intense" bottles (that is: With a stronger smell and heavier) were perceived as significantly more efficacious. As further example, a study involving crossmodal correspondence has recently provided insights concerning the design of cutlery. In fact, Piqueras-Fiszman and Spence (2011) recently demonstrated that food is rated as significantly more pleasant, and perceived to be of higher quality, when tasted with a heavier metallic spoon as compared to a metallic-looking plastic spoon. Crossmodal correspondences between colour and flavour of the food were also fond, providing insight concerning the packaging design of aliments (i.e., Piqueras-Fiszman, Spence, 2011). For Example, Piqueras-Fiszman, Velasco, and Spence (2012) recently demonstrated that the taste of the food (crisps or potato chips) seems to depend, at least to a certain extent, on the colour of the packaging.

Crossmodal correspondences have been theorized to be relevant also in eliciting not only on the sensory-related features of the design products, but also the emotions and the arousal level that users have interacting with products. Spence and Gallace (2011) reviewed several works and case studies, coming to the conclusion that hedonic attributes of a products perceived via one sensory modality can "push" (or bias) a person's estimates of the quality and pleasantness of the product derived from other sensory modalities into alignment, and by so doing, modulate a person's overall (multisensory) product experience.

Concluding, design and psychology can mutually help each other in understanding some traits of human behaviour. While psychology is more devoted to the theoretical study (Figure 1), design seems to be a good way to put into practice the insights achieved from psychology, also giving important insight on human creativity, perception, and even emotions.

THE DESIGN PROCESS ITSELF

So far have been mentioned, in the previous sections, some characteristics of the design process. The present section will linger more on the design process, as described by Bryan Lawson in his book "How designers think". According to the RIBA "architectural practice and management book" (Emmitt, 1999), design can be divided in four principal stages: Assimilation, general study, development, and communication. Assimilation refers to the first part of the design process. It consists in the collection of all the information related to the problem the designer wants to solve with his creation. In the general study, the designer deeply investigates the nature of the problem, together with a range of possible solutions to it. Subsequently, during the development phase, the designer refines one or more solutions isolated in the previous phase. Finally, in communication, the solution is communicated inside and outside the design realm.

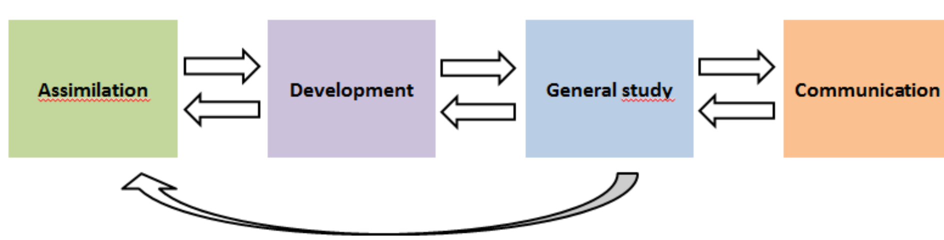

Figure 1.3: the design process as illustrated by the RIBA "architectural practice and management book"

Despite these phases are often illustrated in this order, it is not compulsory for the designer to follow them strictly. Indeed, it is more likely that, during the design process, the designer jumps from the definition of the problem to the gathering of the information several times before coming to communicate the ultimate solution. In fact, in a more realistic view, the design of a solution can provide further information by itself, and often this further information allows the designer to re-define the problem space, starting the whole cycle once again. In this view, the prototyping of products assume a huge importance. Gathering information through prototypes is one of the core concepts of virtual prototyping. Virtual prototyping offers indeed the opportunity of designing different solution without concretely building them, allowing the designer to test them, gathering both subjective statements from users and technical specification. For example, Ferrise, Ambrogio, Gatti, Lizaranzu, and Bordegoni (2011), presented at the ASME/CIE conference the virtual prototype of a refrigerator, with which users were able to interact, and from which was possible to gather information about user preferences and interaction.

Another view, first introduced by Markus and Maver in the seventies, reflects an apparently more elaborated procedure. Markus and Maver theorized that the design process is composed by a decision sequence about the design problem. This sequence is composed, according to them, by four different stages, named analysis, synthesis, appraisal/evaluation, and decision. According to their view, that this decision sequence takes place at different levels of details in the design process, from the first proposal to the design details. In particular, the analysis stage involves the exploration of the problems (looking for each pattern of information available) and the setting of the objective. Synthesis is instead the phase in which the responses to the problem are generated. During the appraisal/evaluation stage, designers evaluate the solutions, and finally take a decision (Lawson, 2006). In some extent, these four phases can be compared to the four previously mentioned and extracted from the RIBA handbook. The novelty of this approach, though, is the idea that the design of a whole solution is composed by a reiterative loop of decisions on hierarchically organized sub-problems, on which these four stages take places several times.

However, whatever is the model assumed to take place during the design process, all the models share two main aspects that seem to be mandatory for the designer in order to come to a solution:

- Needs of information: Whatever is the approach used by the designer to come to a solution, it needs lot of information in order to define a problem, organize and finally test the solution. Information then works as a fuel for the designer that can use it to feed his creativity.

- Reiterative process: it is also clear that the process that stands between the design problem and its solution is not straightforward. Designers acquire an understanding of the problem gradually with developing their solutions, coming back to the problem definition and the discussion of the solution several times.

THE ACTORS IN THE DESIGN PROCESS

The design process serves to achieve solutions from a given problem. The previous section exposed some theories concerning the structure of the design process, suggesting how things are far from being a simple application of solutions to a problem. As a matter of fact, design process solution is often a compromise between the needing of a client, the user, the designer, and possibly (but not necessarily) a beneficiary (Lawson, 2006).

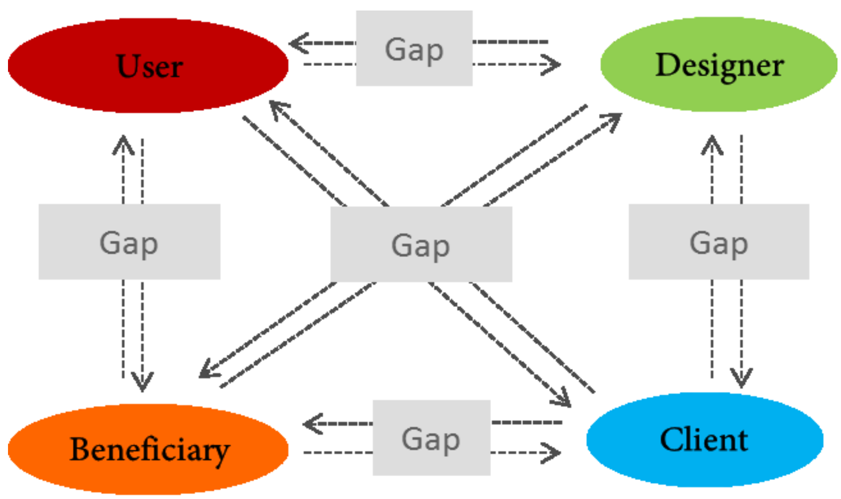

Figure 1.4: the protagonists of the design process. The figure evidences the gaps between designer and client, and client and user

In fact, the design of a solution usually starts with the demand of a client, which needs to find a solution for a problem. Far from being just a committer, a good client is an active partner in the creation process, so that

> *"...the worst client is the person who tells you just get on with it and give me the final product ... " (Bryan Lawson).*

The client is then a crucial character in the design process, and the relationship between him/her and the designer must be as good as possible, in order to allow the designer to have a complete grasp of the problem. Unfortunately, even though the synergy between user and client is theoretically possible (although pretty hard), the complete understanding of how users will understand the solution is more difficult, if not virtually impossible. The user is in the great majority of cases the reason why the client raises the problem, and the one that will benefit from the solution. The user is often not a single person but a population. As consequence, it is impossible for the designer satisfying all the users, but a good designers will be able to "solve" the problem for the majority of them. The designer has then to reach a compromise to satisfy the client and a whole population of user. However, whereas the communication between designer and client is direct, the communication between designer and user is often mediated by the client and obtained in rather unreliable ways. A further problem is indeed the mediation of the client, which often interprets the needs of the users to raise the problem. This interpretation can be sometimes wrong, or incomplete, making then the gap between the designer and the user even bigger (Lawson, 2006).

Finally, the eventual presence of a beneficiary, other from the user, could constitute a further problem the designer might be forced to consider. In several cases, the interaction between user and object can affect another class of users (beneficiary), who are, in some way, exploiting the interaction between the user and the product (for example, the passengers of a bus might benefit from the interaction between bus driver –the user- and a new particularly comfortable steering wheel).

In this doctoral thesis, a methodology helping designers to navigate through a series of experimental tools will be proposed, with the final aim of support the designer in reducung the gap between how the user perceives the design solution, and what the design solution actually is, according to the designer's intention.

RECOGNIZING THE GAP BETWEEN DESIGNER AND USER: FROM USER CENTERED DESIGN TO EXPERIENCE DESIGN

In the last few decades designers in the field of the product and interaction design began to consider the user as an important component of the design process. In order to reduce the gap between user and designer, and to design products closer to consumers, it has been developed a new and innovative method of design, based on guidelines aimed in augmenting the usability and the learnability of use of new products. As a matter of fact, user centered design (UCD) entangles a varieties of methods and tools, all of them connected by the idea of putting the user in the center of the design process (Maguire, 2001). However, UCD is traditionally associated with the three tools called persona, scenario, and use case (Aoyama, 2001; Vrenderburg, 2002).

In particular, the persona refers to a model of the user's need that may be created. Personas are then fictional characters created after the field research process. Personas are usually created after the information achieved by a population sample. In most of the cases, several personas are created to summarize the characteristics of the same group of individuals, since it is almost impossible to apply all the characteristics of the sample group on one character. The personas should represent not the average individual in the group, but instead the most typical. Creating personas in the design process basically force the designer to focus his/her attention on the user, furthermore providing to the designer with the impression they are actually designing for someone rather that basing their design on simple data or population. A scenario is instead the description of a series of standard situations that the persona has to face during his/her daily life. Finally, the use case refers to the persona's interaction in the scenario's world. It is represented as a series of simple steps for the character to achieve his or her goal, in the form of a cause-and-effect scheme. Use cases are normally written in the form of a chart with two columns: The first column is labeled actor, while the second column is labeled world, with the actions performed by each side written in order in the respective columns. Through the information achieved with this mental effort of simplification and representation designers should achieve a better knowledge of the user, designing objects, interfaces, and in general design solutions.

It is important to highlight, though, that all this information is used by UCD designer with the objective of creating more usable and performing solutions. In his book "The Design of Everyday Things" (originally called "The Psychology of Everyday Things") first published in 1986, the famous designer Donald Norman wrote the apology of the user centered design, inviting designer to pay attention more on the usability of the objects rather than to their aesthetical characteristics (Norman, 1986).

THE EXPERIENCE DESIGN FRAMEWORK: INTERPRETING THE WAY THE USER PERCEIVES THE PRODUCT

Interestingly, in the last two decades the same Norman updated his view, readdressing his reductive view on the design matter. On this new view, Norman exposed the importance of users' emotions and personal needs in the design process. This view is nowadays the core of the user experience design, a branch of design that pays on the emotional and personal needs of the user as much attention as it does to the usability and practical matters, trying to account for the entire experience involving the users (Shedroff, 2001). It is noteworthy that the definition of the "experience" itself has been the focus of a large number of theoretical studies, boasting contribution from design, business, philosophy, anthropology, cognitive science, social science, and other disciplines (Forlizzi and Battarbee, 2004). According to Forlizzi and Battarbee (2004), all these works allowed the designer to consider the experience from a number of perspectives, which have been grouped by the authors in three main categories: Product-centered, user-centered, and interaction-centered. Product-centered models provide straightforward application for the design practice, helping the creation of new products able to suggest given experience to the users (Alben 1996; Jääskö and Mattelmäki, 2003). User-centered model tries to understand the consumer behaviour and the needing of the consumers in terms of "desired experience" (Hassenzahl 2003; Cain, 1998). Finally, interaction-centered models are based on the John Dewey's philosophical theory of experience (Dewey, 1980), and are aimed to examine the totality of the relation between the product and the user in a given moment, in order to help designers in understanding the aspect composing the experience itself.

In the present thesis the experience design is addressed from a user-centered perspective. In particular, the idea of user experience as modeled by Hassenzahl in (Hassenzahl, 2005, 2008) is considered. According to this model, users perceive products according to two main dimensions: Pragmatic and hedonic. The pragmatic qualities of a product refer to its ability in accomplishing "do-goals", that are the purposes for which the object has been created for (for example, a do-goal for a pen is “write”). Hedonic qualities refers to the product's perceived ability to support the achievement of "be-goals", that means the accomplishment of the hedonic and symbolic needing of the costumer (referring to the example of the pen, a be-goal for an elegant-shaped pen could be “be professional, or “be elegant”) (Craver and Scheier, 2001). Moreover, a third category of goals, called motor goals, has been added to the framework. Motor goals are still related with the pragmatic qualities of the object, are mainly subconscious, and refer to the motor plan the user establishes in order to interact with the object (see figure 5).

In Hassenzahl (2005) has been proposed a product classification based on the pragmatic and hedonic dimensions. According to this classification a product can be considered as an ACT product if its pragmatic characteristics are able to fully accomplish its do-goal. Interaction with ACT products usually results in the user’s satisfaction. A SELF product is, instead, a product that well accomplishes the be-goals it was intended for. Interaction with SELF product usually results in pleasure for the users. It is worth to note that the hedonic and the pragmatic dimensions have been proved to be independent each other (Hassenzahl, 2001). This assumption results in the possibility to have purely ACT or SELF products, but do not exclude the possibility to have products that are both act and self (DESIRABLE product) or neither ACT nor SELF (UNWANTED product).

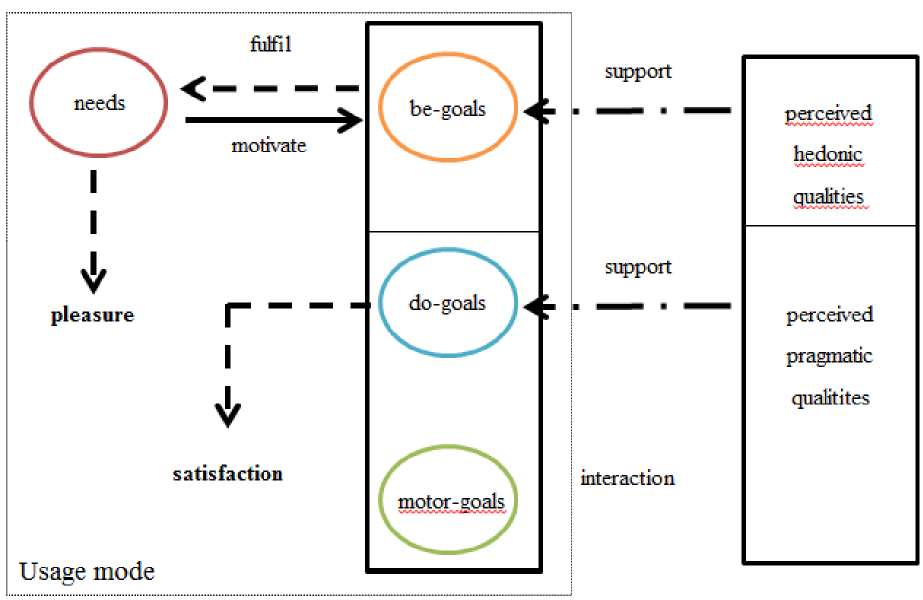

Figure 1.5: the experience design framework. Adapted from Pucillo and Cascini (2014)

In this view then, the interaction with the product is achieved through the product's pragmatic and hedonic qualities. Connecting what said in the present section to what stated in the previous one (i.e., the presence of a gap between the designer and the user) it comes straightforward that the misconception of the design solution on the user side must come from a misperception of the hedonic and pragmatic properties of the object intended by the designer.

The properties of an object, as also the properties of all the entities in the surrounding world, are perceived by the user through senses. The interaction itself is a motor act allowed by the perception of the features composing the design of object. In a psychological view, the hedonic features of the object are perceived by senses, and interpreted as able to satisfy the needs of the user. In the same way, the pragmatic features of the object, that allow the user to use the product for its material purpose, are straightly bonded to the user sensory perception. To be usable, a product must match all the sensorial needs of the costumer, providing all the sensory feedback in the fashion necessary to optimize the accomplishment of the task it has been created for. It would be crazy to create an alarm not perceivable by the user, or a knob that one cannot perceive when turned.

The research addressed by this thesis aims to offer to a designer a procedure, based on experimental methods, able to optimize the product augmenting the efficacy of the sensorial feedback underpinning the hedonic and pragmatic features of the product. Indeed, providing the designer with all the information concerning how the prosuct is perceived and how the sensory characteristic of the product are elaborated by our brain will allow the designer to create design solutions closer to the user, narrowing that gap indicated in the previous paragraph.

EXPERIMENTAL BASED METHODOLOGIES

EXPERIMENTAL APPROACHES FOR THE DESIGN SOLUTION

Over the years, a series of studies have been conducted in the design and marketing field in order to understand how to guide the designers in understanding the users' perception of the product, and therefore spot the user preferences implementing them in the design solution. For example, Raz, Piper, Haller, Nicod, Dusart, and Giboreau (2008) set up a protocol aiming to act on the sensorial characteristic of the product, based on experimental data collected by users. In particular, they articulated their protocol in three phases. The first phase consisted in a qualitative study of the product, aiming to understand the sensory channels that played a major role in the product perception. In the second phase, a series of prototypes, varying for different levels of the same attribute were created in all the meaningful sensory modalities (i.e., meaningful sensory modalities: vision and haptic; attributes: color and weight; levels: dark/light, heavy/light). Finally, a quantitative phase allowed for evaluating the liking and concept fitting the obtained prototypes from the experimental design and data was analyzed with a conjoint approach.

Similar methodologies have been proposed for years in the realm of design of food products and aliments. In 1996, Ellekjaer, Ilsengb, and Naes (Ellekjaer, Ilsengb, and Naes, 1996) studied a strategy aimed to improve the sensory qualities of a food product. The methodology suggested by them started with a screening experiment, in order to identify the variables of the product having the greatest effect on the sensory quality. In particular they suggested adopting a fractional factorial design in the screening experiment, in order to keep the number of experimental runs to a minimum. The impact of each variable was then assessed with statistical tests. Finally, (Principal Component Analysis) PCA was used to group the significant variables into meaningful dimensions, in order to categorize different prototypes of the same product. Finally, the variables for each PCA spotted dimensions were maximized, and an analysis of effects were performed in order to select the best prototype among the one produced.

Another strategy used to link the user perception of the product with the design solution is reported by Buchenau and Suri (2000). Their method is rooted in the co-design realm, therefore involving an active collaboration between users and designer at the prototyping phase. In particular, through a procedure defined "experience prototyping", they studied the interaction between users and product prototype, collecting descriptors of the user's experience and perception of the product, in order to maximize the characteristic of the products underpinning the emotional reaction intended by the designer when designing his/her solution.

Desmet also focused his work on maximizing catching the emotional perception of a product (Desmet, 2005). In particular he developed the Product Emotion Measurement instrument (PrEmo), an instrument to assess emotional responses to consumer products. In fact, the PrEmo was described as a non-verbal self-report instrument able to measure a set of 14 emotions. Each emotion in this set was portrayed with an animated cartoon expressing the emotion by means of dynamic facial, bodily, and vocal expression, and presented on a computer interface. With this method, users reported their responses by selecting those animations that correspond with their felt emotion(s). The emotions were elicited by the presentation of a product. The author discussed the method as useful to relate the user's emotional reaction to the product characteristics, enhancing the positive emotions and minimizing the negative ones.

In fact, the examples introduced so far employ an experimental approach across different stages of the design process. In particular, the greatest majority of the design methodologies to achieve feedback from the user, and to tune the design product on the perception are located in the initial phase of the design process (assimilation, that is: gathering of information about the design problem), and on the third phase (general study, that is: selection of the possible solutions for the project, see previous section).

In 2009 Kaczorowska made the effort of listing different methods used nowadays to relate the consumer perception to the product development, organizing the different methods according to their appearance in the different phases of the design process (Kaczorowska, 2011). In particular, Kaczorowska listed the methods on five different stages: Idea generation (called in our reference model assimilation), concept generation (addressed by our model as development), prototype development and verifying test (composing in the model introduced in the previous section the general study stage), and product introduction to marketing (communication). Methods to link the product to the consumer sensory perception and preferences in the Idea generation phase are, according to the author: Ethnographic research, laddering, lead user technique and interview. In the concept development instead, the group collaboration is highlighted as the principal tool. In the prototype development, conjoint analysis is suggested in order to find the best combination among the sensory features of the product. Preference mapping is advised to understand the preference of the user concerning the prototype. Still in the prototype development stage, quality function deployment (QFD) is reported as the most indicate tool to spot the characteristic of an ideal product (Akao, 1994). Finally, in order to verify the final solution, Kaczorowska suggested the use of boredom test, preference test, and finally purchase intent test. In the fifth phase, that is the introduction of the product in the market, no method is described.

However, regardless to the stage of intervention in connecting the user's perception of the product with the final design solution, the design methods exposed in literature so far seems to share, an important drawback. As a matter of fact, none of the methods highlighted are grounded in any design theory, and in particular none of them pays attention to the user's experience as described by the design researchers. The understanding of the user stops indeed at his/her behavioural reactions, focusing on preferences and raw perception, without any consideration on how the preferences of the user can be modeled and properly communicated to the designers. Integrating all these methods in a bigger frame, relating them to what is known about the user perception and experience, may help the designers in better understanding the implementations needed to achieve a successful and well spendable product.

In this doctoral dissertation, a methodology which aim is to help the designers in optimizing their products exploiting the users' perception of the product itself is presented. The methodology encompasses a bench of experimental methods that will help in gathering data from customers. All the methods exposed in the methodology are related to the experience design theory, according on whether the improvement the method gives to the product is mainly pragmatic or hedonic. In this way the designer will know exactly how the changes in the product will influence the experience elicited by the product itself, and will be able to spot occasional weakness (if present) in his (her) design style. It is worth to note however, that the relation between a given method and the hedonic/pragmatic dimension of the product greatly depends on the variable that the designer intends to investigate. As we will point out in the following chapter, many of the methods presented (i.e., PCA, Multi-Dimensional Scaling, surveys and the like) are suitable for investigate both the pragmatical and hedonic dimension of the product. It is therefore more correct to state, in fact, that the methodology and the map within it, together with the designer purposes and choices, will connect the results from the experiments to the experience design theory, and in particular with the dimension of the experience elicited by the product, that is: pragmatic or hedonic.

THE METHODOLOGY IN DETAIL

As previously mentioned, the methodology for the product optimization proposed in this thesis is composed by different phases, aimed to guide the designer on the optimization of the product. The first phase is preliminary, and is related to the design question that the designer wishes to answer, that is, in other words, the focus on what the designer wants to optimize in the product. Does the client want a more efficacious product? A more usable one? does the designer wish to communicate feelings with the object he (she) is going to re-create?

Although it could seem easy, and at some extent not a proper design problem, there are many reasons that should particularly draw the attention of the designer for understanding the kind of optimization requested by the client. A better understanding of the design question could may reduce the number of experiments needed to reach a good optimization, allow an experimental procedure more focused on the problem, and make clear from the beginning of the experiments for the optimization (phases 2 and 3) the variables to inspect in the products. However it is not always easy to understand what the client wants, and often the client itself cannot be aware of the direction the optimized product have to take.

As a matter of fact, a first step is to understand, in the experience design framework, whether the changes of the products belong to its pragmatic or hedonic characteristic (or even both).

Concerning the hedonic characteristic of the product, we previously mentioned how this characteristic relate to an intrinsic need of the user, which the interaction with the product is, at least in some extent, supposed to accomplish. Sheldon and colleagues investigate these needs, and the results of their study can be useful in case of a hedonic optimization of the product is needed (Sheldon, Elliot, Kim, and Kasser, 2001). In particular, they performed three studies comparing 10 candidate psychological needs in an attempt to determine which were truly fundamental for customers. In these studies, participants were asked to describe the "most satisfying events" within in their lives. Subsequently they rated the salience of each of the 10 candidate needs within these events. The results of the study supported self-determination theory postulates introduced by Ryan and Deci (2000). Autonomy, competence, and relatedness, were consistently among the top 4 needs, in terms of both their salience and their association with event-related affect. Self-esteem was also important, whereas self-actualization or meaning, physical thriving, popularity or influence, and money-luxury were less important, but still present. It is advisable then, in the optimization, to look at how a given product is able to satisfy these needs, in order to re-define the design question.

At the same time in the pragmatic optimization it could be crucial to understand whether the client is interested in augmenting the performance of the product, augmenting the client perception of the performance of the product, or maybe keeping the performance of the product constant while diminishing the costs. As a matter of fact, in some cases the designer cannot improve the performance of the product because this would exceed his (her) competences. In other cases though, a design aid is useful and even necessary. In these cases a pragmatic optimization as described in this thesis would be of great use.

Once defined the design question, the methodology here exposed aims to gather information on the relationship between user and product, in order to better answer the design question, finding which features in the product are considered important and how to work on them in order to subsequently (during the third phase) boost these features by means of a sensorial experiment. It is important to note that the methodology is not restrictive on what methods to use for relating user and product, as far as this relationship is investigated.

Hereafter it is reported a list of the tools reviewed by the methodology in this phase. The concept and the procedure that underneath each tool will be developed in the next chapter.

- Paper and pencil tests
- Conjoint analysis
- Multi-Dimensional Scaling (MDS) for the perceptual space
- Semantic Differentials Method (SDM)
- Kansei engineering

- Attrakdiff
- Sensory snapshot
- Quality function deployment
- Product Emotion Measurement instrument (PrEmo)
- SAM
- Emotion wheel
- Performance/ usability measures
- Tracking experiment (eye tracking, mouse tracking, body tracking)
- Implicit association test (IAT)
- Evaluation of the physiological activation
- Neural activations

A side-aim of this PhD was to spot and catalogue a series of methods to investigate the user-product interaction, and describe them allowing the designer to use them if selected in the methodology.

In the third Chapter we will linger on the concept of crossmodal correspondences and psychophysics, explaining the third part of the methodology. In this phase, sensory experiments will be performed in order to boost the characteristics of the product considered meaningful for a pragmatic or a hedonic optimization (that is, to answer to the design question), spotted by the second phase of the methodology. In this chapter, we will explain the basic functioning of the five senses, and introduce the concept of crossmodal correspondences as a tool for the product optimization. We will provide insight about psychophysical experiment as well, crucial on the matter of pragmatic optimization.

In the fourth Chapter then, we will introduce different case studies developed during the current PhD. Finally, in the final Chapter it we will be mentioned the formalization of the methodology using Pareto diagrams, a typical tool for the product optimization and well-known in the field of engineering.

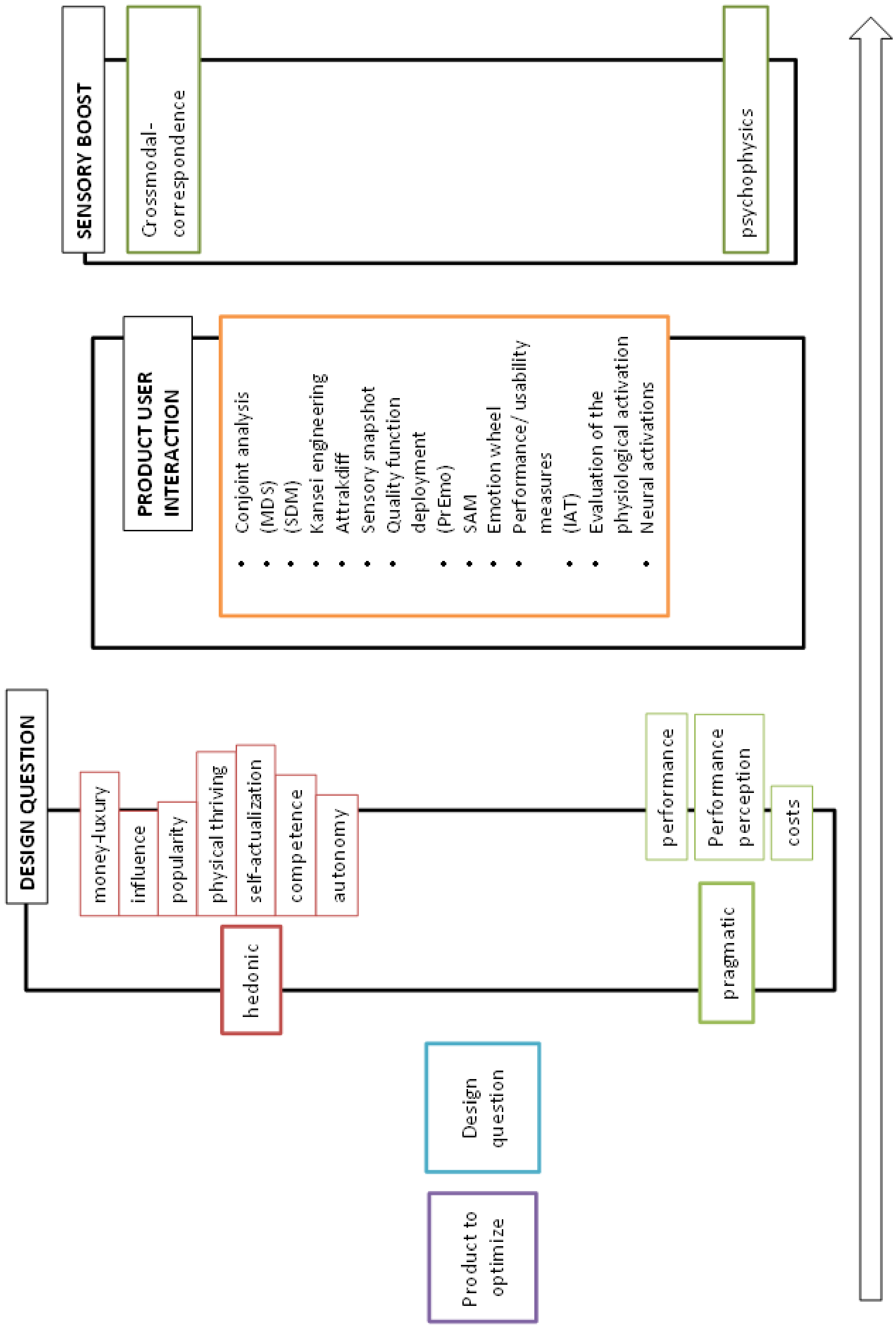

Figure 1.6: Representation of the methodology

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As highlighted in the previous chapter, the methodology proposed in this doctoral dissertation first focuses on the way people perceive and interact with the product, in order to spot what the users consider important, and which are the features of the product underpinning its hedonic and pragmatic characteristics. Noteworthy, the methodology proposed is not restrictive on how to investigate the relationship between user and design object, but instead offers a number of tools to investigate this relationship. Indeed, this methodology must be intended as a series of steps to perform in order to optimize the product. Therefore, it is not important how to perform these steps, as far as the steps are performed, and a better understanding of user and product is gained. In fact, the strength of the methodology is the high number of experimental methods and procedures collected and explained, that allows the designer to select what (s)he considers to suite him (her) (and his/her case) more, in order advance in the methodology, and eventually reach an optimized product.

In this chapter we will focus on the different ways reported in literature to connect the user's preferences and perceptions to the design product. We will report the different methods explaining the procedure to apply them in detail, supporting the explanation with examples and practical advices. Advantages and drawbacks will be highlighted, and indications on the experimental procedure as well. In this way the designer will be able to select the method closer to his (her) competences and demands, basing the optimization of the product on solid and reliable experimental data.

In order to allow a better and faster understanding, the methods will be grouped in two main categories, according to the experimental procedure adopted and the results that can be achieved by their applications. The two categories have been called "explicit" and "implicit" experiments. The first "family" of methods is indeed composed by the "explicit" experiments. With explicit experiments we refer to the methods in which the user is directly asked to give an evaluation of the product, often without necessarily interacting with it. Usually, explicit experiments look for generic connection between product and user, such as a semantic characteristics and basic sensory assessments. The most representative explicit method is the factorial experiment. This kind of experiments involves the creation of different variants of the products, rated by user and panelist mainly through a class of pre-defined attributes on a Likert scale or through semantic differentials. These methods (Figure 2.1) are traditionally used by designers, marketing experts and engineers to optimize the product. The application of the information obtained by mean of these methods is usually represented by simplex optimization model (Lundstedt, Seifert, Abramo, Thelin, Nyström, Pettersen, and Bergman, 1998; Scheffe, 1983), often associated with a Response Surface Methodology (RSM) for product optimization (Green, Carroll, and Goldberg, 1981).

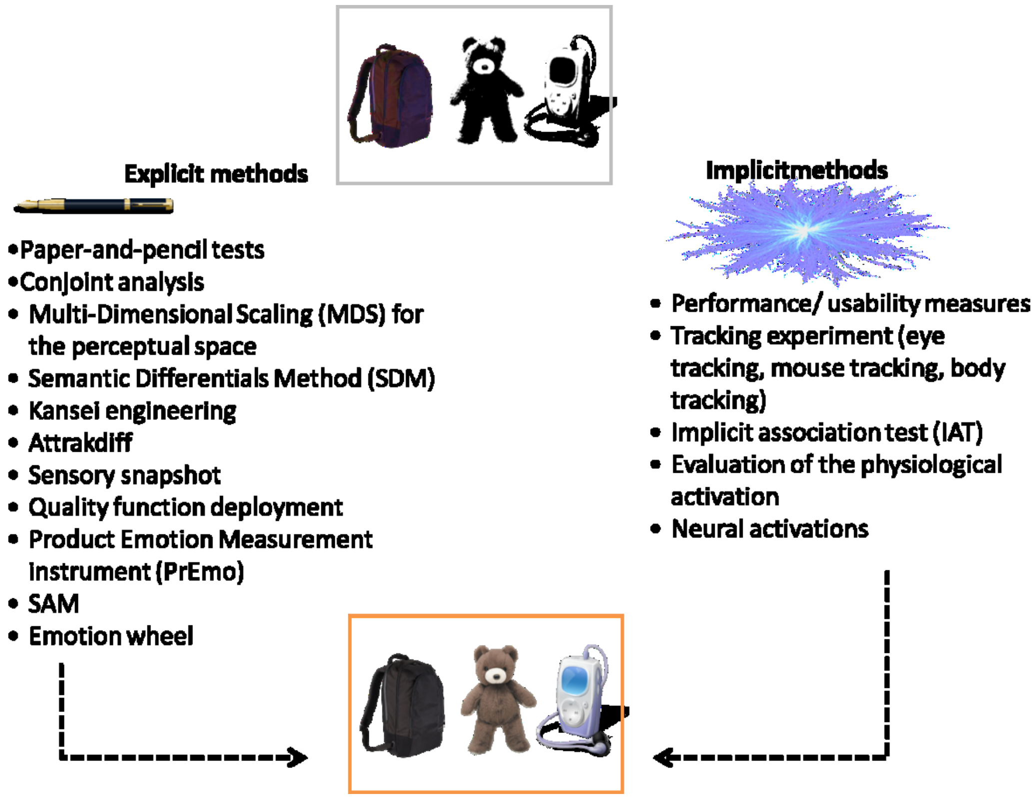

Figure 2: Methods for the product optimization treated by the present methodology

Skip directly to the final optimization phase is therefore possible by adopting these methods. However, the methodology here proposed allows (and basically advices) a further step, and a different interpretation of the results. In particular, this methodology allows the designer to discuss the optimization process in terms experience design (hence distinguishing between optimization of the pragmatic and hedonic characteristic of the product, not taken into account by a straightforward application of the factorial experimental results to the product optimization). Moreover, this methodology adds a further phase in which we investigate the user sensory perception of the product and relate the information obtained to the results of the first phase for a better, faster, and in some case cheaper optimization results.

The second "family" of methods useful to relate the product to the user is collected in the family of the "implicit" methods. This family of methods encompasses the most different procedures, however connected by the particular attention to the user interaction with the product. The application of the methods in this group is often carried out by psychologists, ergonomists, and knowledge engineers. These methods are usually focused on one aspect of the interaction with the product (i.e., learnability, comfort, usability), giving a narrower kind of information to the designer, if compared with the explicit experiments. However, this is not always the case, as we will see in the next section. These methods are particularly recommended when the design question is quite narrow, and focused on the interaction (i.e., how to make the product more learnable? How to make the product more usable?). However, it is possible to combine these methods with the explicit ones, in order to achieve a complete set of information.

EXPLICIT EXPERIMENTS

Under the name of "explicit" experiment, we collected all these experimental methods based on the assessment of the participants on a given product (or on some of the variants of it). The collected methods have in common the fact that this assessment is always explicit, although some of the results from some of these methods can lead to the understanding of some explicit information, such as in case of factor analysis and multidimensional methods.

PAPER-AND-PENCIL TESTS

One of the simplest methods to study the interaction with products is simply to ask users. This kind of information can be retrieved having the user answering to some questions. Answers can be given both as multiple choices (as in case of questionnaires) and as free written production.

Regarding questionnaires, this kind of assessment can be performed both on some semantic attribute (i.e., quality, luxury, etc.), preference, and on the product itself, asking an overall evaluation of the product. For example, Gentile, Spiller, and Noci (2007) asked a group of several hundred consumers which sense was most important to a number of popular brands. The results showed broad consensus amongst consumers. So, for example, the majority of those questioned argued that taste was the most important sense for brands such as Gatorade and Pringle's while vision was most important for Harley Davidson and iPod. In the era of internet and social network, the great advantage of this method is the possibility of collecting a huge amount of data in a short period of time (Stanton, 1998).

However, despite the big advantage of allowing a simple and fast data collection, this method strongly rely on the user introspective ability. As a matter of fact, users will base their feedbacks only on their conscious perception, without providing the designer with all the information related to the subliminal and unconscious stimulations that has instead been demonstrated to play an important role in the interpretation of the semantic of a given stimulus or, in this case, product.

An alternative approach is based on written analysis of product functionality (see Adank and Warell, 2008). In this kind of experiment, the participants are usually asked to report by writing their impressions about a given product, or about a series of product. The written description of the product can be either in the form of a totally free report, or can be guided by open questions, addressing at the aspects which the researcher is interested to investigate. Fenko, Schifferstein, and Hekkert (2010) and colleagues investigated by means of content analysis how varied the sensory dominance in the product usage among 243 users from the design University of Delft. The participants of this study were asked to answer to three open questions: In particular, they had to describe the most pleasant experience with the product they were testing, from a sensory point of view. They also assessed qualitatively and comparatively to what extent different sensory modalities contributed to this experience. Second, they described the biggest disappointment with their product, still from a perceptual point of view, indicating to what extent the different senses contributed to this experience. Third, they rated what the importance of the different sensory modalities in their consumer experience with their product in three moments of interaction with the product: a) choosing the product in the shop; b) during the first week of usage; c) after the first month of usage; d) after the first year of usage. Results of the questionnaires were subsequently used to find category of products that leaded to the same kind of answers.

In fact, despite the easiness in collecting the data (collection of data can be, in fact, web based), dealing with the massive amount of information deriving from the participants' report may constitute an issue. One option to analyse data from written texts consist in semantic categorization (Van Dijk, 1985). Modern approaches of semantic categorization are based on statistics of co-occurrence of names, adjective, and verbs in the text (Bullinaria, 1999). As alternative to semantic categorization, others approach (i.e., coding), are used to analyze consumers' written production (Burnard, 1991). However, all these methods share the drawback of being time demanding for the experimenter. Despite some program already exist to automatically perform an analysis of the content of the texts, the texts usually need to be edited, in order to account for grammar or lexical errors, with the consequent demand of time for the experimenter. In many cases, the aggregation of synonyms is carried out manually, and furthermore need to be checked by a second experimenter (Agapito, Valle, and Mendes, 2014).

CONJOINT FACTOR ANALYSIS

Conjoint factor analysis is probably the most used method when it comes to understand the impact of the product features on the consumer perception of some of the product characteristics, such as likeability, preference, and appeal, and it is probably the one that in the most straightforward way relates the consumer's behaviour with the product's single components. In the next section we will provide guidelines on how to perform a factorial experiment, in order to allow the designer to understand how to get information about the relationship between product and user by means of this experimental method.

A conjoint factorial experiment is, basically, an experiment in which the user is asked to evaluate a series of multi-attribute alternatives of an object (Oppewal and Vriens, 2000). The aim of this procedure is to determine what combination of attributes is most influential on the consumer choice or in his (her) decision making. In particular, a controlled set of potential products or services is usually shown to users and consumers, and by analyzing how they express preferences between these products, the implicit evaluation of the individual elements making up the product or service can be determined. These implicit valuations can be used to create market models that estimate market share, revenue and even profitability of new designs.

Then, the structure of a conjoint analysis experiment is very similar to the implementation of a factorial experiment (Giordano, Lauro, and Scepi, 2011). Each aspect of the object tested can be seen as a factor, while each variant of one of the object features can be seen as a different level of the factor. Let's consider for example the conjoint analysis study applied to a GPS device exposed by Houser (Hauser, 2007). In this example only three features of interest (plus price) were taken into account, so that four factors were studied, each varying on two levels. In particular, the factors and the levels were:

• Accuracy – the GPS can locate your position within either 10 feet or 50 feet

• Display color – the screen either displays colors (for a map) or is black and white

• Battery life – the battery lasts either 12 hours or 32 hours

• Price – the price can vary between $250 and $350

In the simplest conjoint analysis experiment, we would create all the 2x2x2x2 = 16 possible combinations, and ask participants to rate each combination (for example on a 100 point scale). The analysis of the data for such sort of experiment is relatively easy. Still taking as example the Houser experiment, the data for a single participant could be shown in a table similar to the Table 2.1 below:

Preference	**Accuracy**	**Battery**	**Color**	**Price**
Rating	10 vs. 50 feet	12 vs. 32 hrs	Color vs. B-and-W	$250 vs. $350
4	0	0	0	0
41	0	0	0	1
18	0	0	1	0
60	0	0	1	1
33	0	1	0	0
74	0	1	0	1

49	0	1	1	0
86	0	1	1	1
11	1	0	0	0
55	1	0	0	1
27	1	0	1	0
66	1	0	1	1
41	1	1	0	0
85	1	1	0	1
58	1	1	1	0
99	1	1	1	1

Table 2.1: hypothetical results from a user asked to rate the different GPS from the Houser Example (from Houser, 2007)

The first column indicates the consumer's preference for a particular combination of features and price (in italics). The next four columns indicate whether or not the rated GPS has that feature-price combination. A '1' indicates the feature is at its "high" level (i.e., 10 feet rather than 50 feet), and a '0' indicates a feature is at its "low" level (i.e., 50 feet rather than 10 feet). As one might expect, the least preferred option in terms of GPS is represented by an inaccurate GPS, with low battery life, a BandW screen, and high priced. By contrast, the same consumer prefers an accurate GPS, with a long battery life, a color screen, and low priced the most.

As previously stated, the aim of conjoint analysis is to determine the role that each feature plays in determining the overall preference ("partworth" of the feature). In this simple example, it is possible to use ordinary least-squares (OLS) regression to analyze the data. In particular, we can interpret the user preference as the dependent variables, and the factors as independent variables. It is important to note that in the case in which the factor has more than a level (i.e., Accuracy of the GPS = 10, 30, 50 feet) this representation of the model would be still possible by means of dummy coding. Hypothetical results from the OLS model are shown in the Table 2.2 below:

	Coefficients	***Standard Error***	***t-statistic***
Intercept	2.7	1.0	2.7
10 feet vs. 50 feet	9.6	0.9	10.9
32 vs. 12 hours	30.4	0.9	34.5
Color vs. BandW	14.9	0.9	16.9
$250 vs. $350	40.6	0.9	46.1

Table 2.2: Hypothetical OLS results (from Houser 2007)

The regression's coefficients are called "partworths", and give information about the importance of a single factor in the object. For example, the pat-worth of Accuracy (10 feet vs. 50 feet) is 9.6. This actually indicates that the consumer gets 9.6 "utils" if the accuracy of the GPS is improved. Similarly, the regression estimates that the consumer gets 40.6 "utils" if the price is reduced from $350 to $250.

From the coefficients we can actually see the relative importance of each attribute. Indeed, while rice and battery life has a huge impact on the participant evaluation (relatively high coefficients), the accuracy is relatively unimportant (relatively low coefficients). Another things we can achieve from the model is the willingness to pay (WTP) for each feature. In fact, we can estimate the price of each util knowing that the consumer gets 40.6 "utils" when the price is reduced by $100, the value of each single "util" can be computed as : $100/40.6 = $2.46. Thereby, if we want to compute the WTP for the accuracy factor, it is sufficient to multiply the "utils" associated with the factor for the effective value of each "util" (in the example 9.6 *2.46 = $23.65).

Different versions of the conjoint analysis can be found in the literature. Despite the one exposed above is the easiest and the most intuitive, other versions are more used, and generally lead to a different analysis and more accurate results. For examples, Vag used conjoint analysis to assess the stability of the user preferences among time merging conjoint analysis with multi-model simulation (Vag, 2007). In another case, the ratings judgment referred to the variants of the product can be expressed in a non-scalar way. In other words, in many of the conjoint experiments, a ranking is obtained by comparing two or more versions of the same product. In this case, Hierarchical Bayesian (HB) analysis is usually applied to the results (Allenby, Rossi, and McCulloch, 2005). Despite the statistical analysis are not the aim of this doctoral dissertation, the objective of this methodology is also to give to the designer the tools to understanding the way to optimize the product, so that he (she) will be able to choose the one retained considered more appropriate. Therefore, in the next sections, we will linger on the design for a ranking experiment analyzed by means of HB.

In his study, Allenby, Arora and Ginter (1995) applied the conjoint analysis to the demand of a regional bank wishing to offer credit cards to customers outside of its normal operating region, labeled as "out-of-state" hereafter. The factors of the variant of the credit card tested were:

- Interest Rate : High, Medium, Low - fixed Medium variable
- Rewards : The reward programs consisted of annual fee waivers or interest rebate reductions for specific levels of card usage and/or checking account balance. Four reward programs were considered.
- Annual Fee - High, Medium, Low
- Bank - Bank A, Bank B, Out-of-State Bank
- Rebate - Low, Medium, High
- Credit line - Low, High
- Grace period - Short, Long

Comparisons between different variants of card were asked by telephonic interview to participants. The different variants of the cards were presented in the form:

The first card has a medium fixed annual interest rate and a medium annual fee, and

The second card has a high fixed annual interest rate and low annual fee.

And participants were asked which one they preferred. Each respondent provided responses to between 13 to 17 paired-comparisons involving only a fraction of the possible attributes. As a result it was not possible to obtain fixed-effect estimates, based on OLS of the entire vector of partworths for any specific user interviewed. In total, 14,799 paired-comparisons from 913 subjects were available for analysis. Since not all the participants assessed all the variants, and since relatively few observations were disposable for any combination, a HB analysis was used to interpret the data and spot the users' preferences. Bayesian inference statistics had been known by statisticians for many years. Instead of basing on the concept of frequencies, Bayesian stats is based on the probability of an event to occur based on the concepts of sensitivity and likehood, both expressed in terms of probability. In other words, if for the classical statistics it is possible to approximate the probability of an event counting among a sufficiently large number of trials the number of the time the event occurs, the Bayesian statistics compute the likeability of an event to occur given the reliability of the system in which the event occurs, and on all the previous occurrences of the events (for more information of HB analysis, see Allenby, Rossi, and McCulloch, 2005).

Despite Bayesian statistic is an elegant way to deal with not complete data, and usually leads to more accurate results, results are also more difficult to compute. Luckily, software now in commerce, helps (through Monte Carlo simulation (Lagoa and Barmish, 2002)) in computing the Bayesian estimation of the probabilities (Ming-Hui, Shao, and Ibrahim, 2000), and allows to see the distribution of the estimations of the partworths computed by the HB model. Since the distribution of probability is obtained for HB models with Monte Carlo simulation, the partworths will not be point estimates, but will be represented by a set of value converging to the real estimate of the partworth distribution (Figure 2.1).

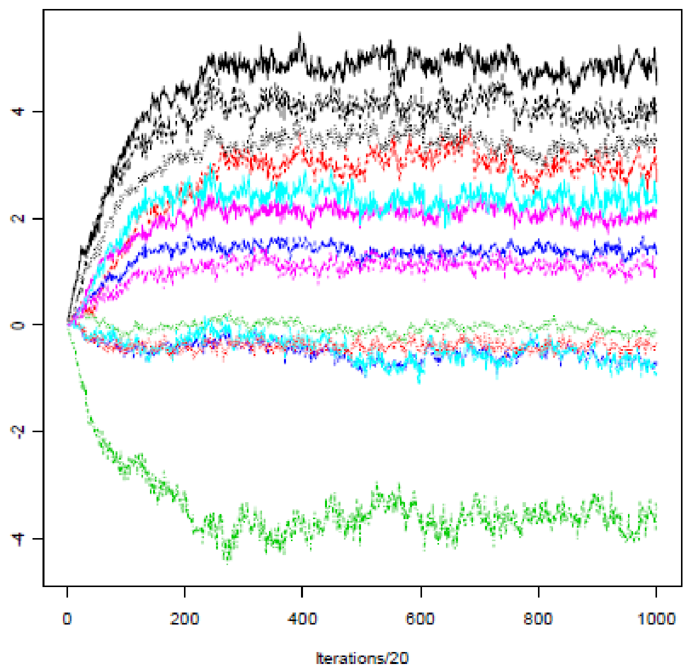

Figure 2.1: partworth computed by means of the Monte Carlo simulation. The number of interaction is displayed on the x axis, the value of the partworth on the y axis. Different colours stand for different levels of the factors (Allenby, Rossi, and McCulloch, 2005).

As it is possible to see from the graphs in figure 2.1, the partworths tend to converge after 6000 interactions. Concluding with the example, then, Allenby and co-authors extracted the relative importance of each single factor by HB modeling. The results are reported in Table, which shows 2.4 reports the partworths for each variable of the model, related with the factors of average income, age, and gender.

Attribute-Levels	Intercept	Age	Income	Gender
Medium Fixed Interest	2.449	-0.011	0.012	0.132
Low Fixed Interest	4.775	-0.017	0.023	0.369
Medium Variable Interest	2.933	0.004	0.025	-0.280
Reward Program 2	-0.081	0.005	0.001	-0.243
Reward Program 3	-0.572	0.021	0.014	-0.218
Reward Program 4	-0.575	0.018	0.016	-0.277
Medium Annual Fee	2.031	-0.002	0.005	0.568
Low Annual Fee	3.968	-0.003	0.010	1.166
Bank B	-0.403	0.000	0.003	0.192
Out-of-State Bank	-3.614	-0.007	0.010	0.131
Medium Rebate	1.392	-0.002	0.004	0.118
High Rebate	2.362	-0.010	0.021	0.256
High Credit Line	1.079	-0.009	-0.003	0.364
Long Grace Period	3.296	-0.021	0.023	0.263

Table 2.4: partworth coefficients and effect of age, income, and gender on the partworth itself .

The intercept estimates indicate that, on average, users penalized out-of-state banks by 3.614 "utils". This penalty can be overcome by offering low fixed interest rates (relative to high fixed interest), low annual fees, and long grace periods (associated with positive pat-worths). In addition, older respondents assigned less importance to changes in interest rates and other product attributes, while richer respondents are more likely to respond to the same incentives. Moreover, the coefficients for gender indicate that females are particularly responsive to lower annual fees.

Concluding, either performed through rating or ranking, analyzing data with OLS or HB modeling, conjoint analysis is one of the most useful and most used method to relate product features to the consumer preference and achieve information on what is considered important in the product. Conjoint analysis is based in creating alternative versions of the product, varying for given features. The different version are subsequently rated or ranked by a pool of consumers. Data are analyzed in order to compute the effect of each feature on the obtained ranking/ratings. Bigger is the effect, bigger is the value associated with the particular feature.

MULTI-DIMENSIONAL SCALING (MDS) FOR THE PERCEPTUAL SPACE

Among what we called "explicit methods", one of the most interesting approaches is surely represented by the application of multi-dimensional scaling in order to create a perceptual space able to tell the designer how participants perceive and categorize the product. Recently, MDS for the creation of the perceptual space has been related to the user preferences, becoming even more informative (Petiot, Grognet, 2002).

Multi-dimensional scaling (MDS) was used originally to study the psychological state of people (Cox and Cox, 2001). Starting from a set of objects, a matrix of dissimilarities, expressing how objects are different among each other's, is constructed by studying each possible pair of objects. After the construction of the matrix, perceptual dissimilarities are transformed into distances in a metric space. This method has the main advantage that the dimensions extracted from the space result directly from the subjects' perception of the stimulus and, as opposite to the conjoint analysis, allow the study of products from the real market, not created ad-hoc for the optimization process. An application of this method to study the semantic dimension of various products, intentionally very different, is presented in (Lin, Lin, and Wong 1996).

Multi-dimensional scaling (MDS) uses dissimilarity assessments to create a geometrical representation of the perceptual space related to a family of objects. MDS has been developed in the psychology realm, in particular for psychometric analysis (Torgerson 1958). In psychophysics, it has been often used to create a perceptual space involving the human senses and some of their aspects (i.e., it has been used in psychoacoustic for the characterization of timbre perception (Krumhansl, 1989). In the design realm, MDS representations take as input data a family of N objects. Each user must evaluate the degree of similarity of each pair of the objects belonging to the N population. The similarity judgment can be directly asked to users, typically on a scale varying from 0 (maximum similarity) to 10 (minimum similarity) in the case of a metric MDS.

The first step in MDS scaling is then to construct a similarity matrix by means of all the comparisons between objects. In fact, for a set of N objects, it is possible to obtain N (N-1)/2 perceptual dissimilarities for each user. The next step of the method is to make the average perceptual dissimilarities correspond to distances in a metric space. Technically, what MDS does is to find a set of points (Xi) i=1,…, N in a K-dimensional space such that the distances among them correspond as closely as possible to the dissimilarity (or a function of it). In fact, higher is the dissimilarity value, bigger will be the distance in the multidimensional space. To decide the number of dimensions the space is composed of, a measure called stress is computed. The stress represents the "badness of fit"; lower is the stress value, better is the fit of the model. The stress decreases augmenting the number of dimensions, until it reaches an asymptotic value. It is common to select the number of dimensions when the value is close to reach the asymptote, that is, basing on a graphical representation, called Scree Plot, when the stress trend forms an "elbow" (Figure 2.2a) (Borg, 2005). It is possible to compute the stress as:

$$stress = \left[\frac{\sum_i \sum_j (d_{ij} - D_{ij})^2}{\sum_i \sum_j d_{ij}^2} \right]^{1/2} \quad \text{where} \quad d_{ij} = \sqrt{\sum_{k=1}^{K} (x_{ik} - x_{jk})^2} \qquad (2.1)$$

Where Dij is the average perceptual dissimilarity between object i and j, dij the Euclidean distance, xik the coordinate of object i on dimension k, K the number of dimensions of the perceptual space, selected by the experimenter. After computation, each object is represented in the Euclidean space by a point Xi(xi1, …,xiK). The set of points (Xi)i=1,…,N provides a visual representation of the pattern of proximities among the objects.

A further advantage of MDS is that it is based on instinctive dissimilarity assessments, which do not impose any criteria or predefined semantic scale. The assessment of the dissimilarity is performed according to implicit criteria, and no assumption is needed about the "function" which relates them. In other words, the user is free to use non-linear assessments and interaction effects between criteria. Furthermore, the dissimilarity provided by the tester does not have to fulfill the properties of a "distance", and the method is robust according to irrational assessment. This allows avoiding the main disadvantage of semantic differential methods (that we will see in the next section), which introduces errors due to the interpretation of the user, and due to the fact that the proposed semantic items do not necessarily cover all of the perceptual space. On the other hand, multidimensional scaling provides perceptual dimensions that we cannot describe with words; by consequence there is no direct physical interpretation.

Nonetheless, a technique called "property fitting" (PROFIT) allows the representation of the "vector model" of the semantic attributes in the perceptual space and thus infer the meaning of the axis (Carroll and Chang, 1964). This technique performs a multiple regression using the perceptual axes as independent variables and a series of pre-determined semantic attribute as the dependent variable. The outputs of the method are the correlation coefficient and the direction cosines (rescaling of the regression coefficients). The vector model of the semantic attribute can then be plotted in the perceptual space (Figure 2.2b). The origin of the vector is located arbitrarily in the origin of the frame, the values of the direction cosines give the orientation of the arrow, the arrowhead points in the direction of increasing attribute values and the norm of the vector is proportional to the regression coefficient.

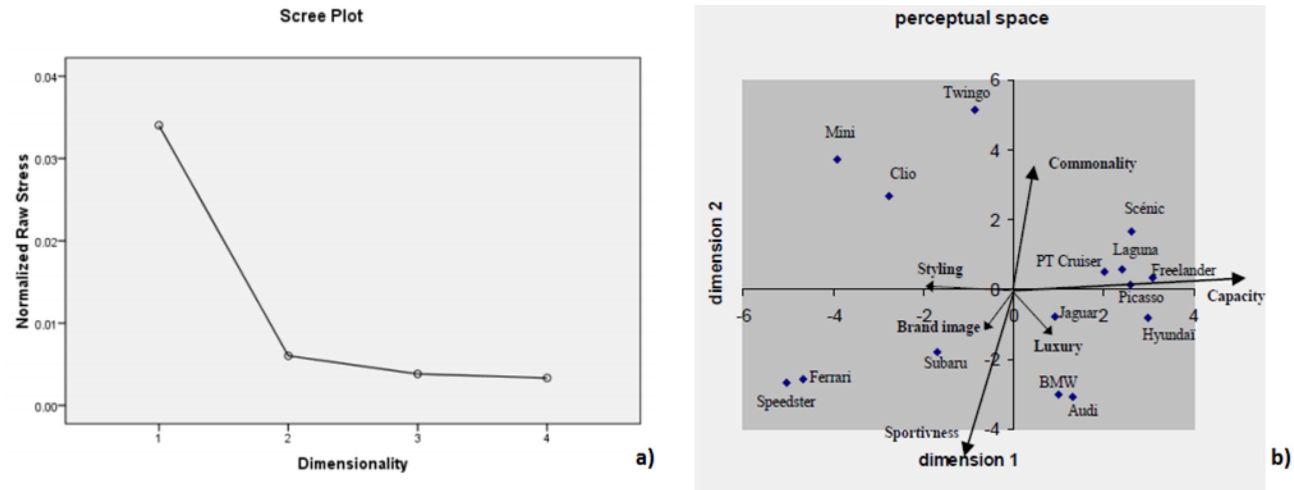

Figure 2.2: a) Screen plot, representing a typical trend for Stress. In this case, the correct number of dimensions to select in order to plot the metric relationship between data is equal to 2. b) The multidimensional representation of the cars from (Petiot, 2002). Two Cartesian axes represent the two dimensions, while the vectors represent the PROFIT graphical representation.

In Figure 2.2 (b), it is possible to see the multidimensional representation of the results from (Petiot, 2002), complete with the ROFIT fitting. In this studies, the authors performed multiple comparison on 15 different models of cars, obtaining a two dimensional perceptual space. They subsequently performed semantic differentials on Capacity, Sportiveness, Commonality, Styling, Luxury, and Brand image, in order to regress them on the dimensions obtaining the PROFIT representation. Results show how participants categorized the stimuli (cars) in two main dimensions, and how these dimensions were related to the capacity and to the commonality/sportiveness of the cars.

In the paper authors also work to relate the sensory mapping of the product with the user preferences, introducing a way to map preferences based on pairwise comparisons. In their study indeed, participants were asked to give a feedback on which car they preferred, together with the dissimilarity judgment. Preference judgment could be formalized in a scale from -5 to +5, where: 5= I like the most the first object in the comparison, -5= I like the most the second object in the comparison, 0=I do not have a preference. From these data, authors computed a vector field expressing the preference of the consumers in a graphical way, superimposing the preference representation to the perceptual mapping. In particular, the vector field was obtained by dividing the perceptual space in sub-sectors, in which the vectorial space was supposed to be constant. For each sub-sector, the vector field was obtained by means of function optimization, minimizing the following energy function of the 2N2 design variables:

$$E(V_{ij}) = \alpha E_1(V_{ij}) + \beta E_2(V_{ij})$$

$$E_1 = \sum_{i<j} (P_{MiMj} - Pc_{MiMj})^2$$

$$E_2 = \sum_{i=2}^{M-1} \sum_{j=2}^{M-1} (V_{ij} - V_{(i-1)j})^2 + (V_{ij} - V_{(i+1)j})^2 + (V_{ij} - V_{i(j-1)})^2 + (V_{ij} - V_{i(j+1)})^2 \quad (2.2)$$

Where: N was the number of products, Mk the point in the perceptual space which represented a product k (with k=1 to N), PMiMj indicated preference between Mi and Mj, given by the users, PcMiMj the preference between Mi and Mj, given by the model, Vij the vector of components (Vijx, Vijy) for the cell labeled (i, j), and M number of rows and columns of the mesh. The first term E1 represented the sum of the squared error between the exact preference and the predicted preference, computed as:

$$Pc_{MiMj} = \sum_{\Phi} \vec{V}_{ij} \cdot \frac{\overrightarrow{MiMj}}{\overline{MiMj}} \quad (2.3)$$

The second term E2 represented instead an evaluation of the “smoothness” of the vector field. In fact, in order to use the model of the vector field as a predictive model, the vector field was expanded into the entire perceptual space. This was done under the assumption that the variation of the preference had to be “regular” in the perceptual space. It is important to note that because E(Vij) (the preference vector field) was bounded below, the minimization of E leaded to a local optimum, for which the vector field was able to satisfy as much as possible all the given preferences. Finally, it is worth to note also that the balance between these terms was given by the weighted coefficients α and β. A gradient descendent was used for the minimization of E.

Apart for the technical matters, this procedure can allow the designers to relate the perceptual space of the product with the individual preferences. On the graphs in Figure 2.3, it is possible to see the preference mapping according to the two dimensions achieved with the MDS, relative to car #5 (Clio). The highest preference is for car #9, the lowest for cars #8 and #11. In fact, this representation provides perceptual location to the designer where preference is greater (or lower) than the current product #5. Furthermore, the vector model of the subjective attributes in the perceptual space tells the designer how the subjective attributes have to be modified to increase the preference. For example, in the case of the car #5 (Clio), preference can be augmented by increasing the capacity, and keeping the sportiveness constant (this attribute seems to have a negative influence on the preference of our subject).

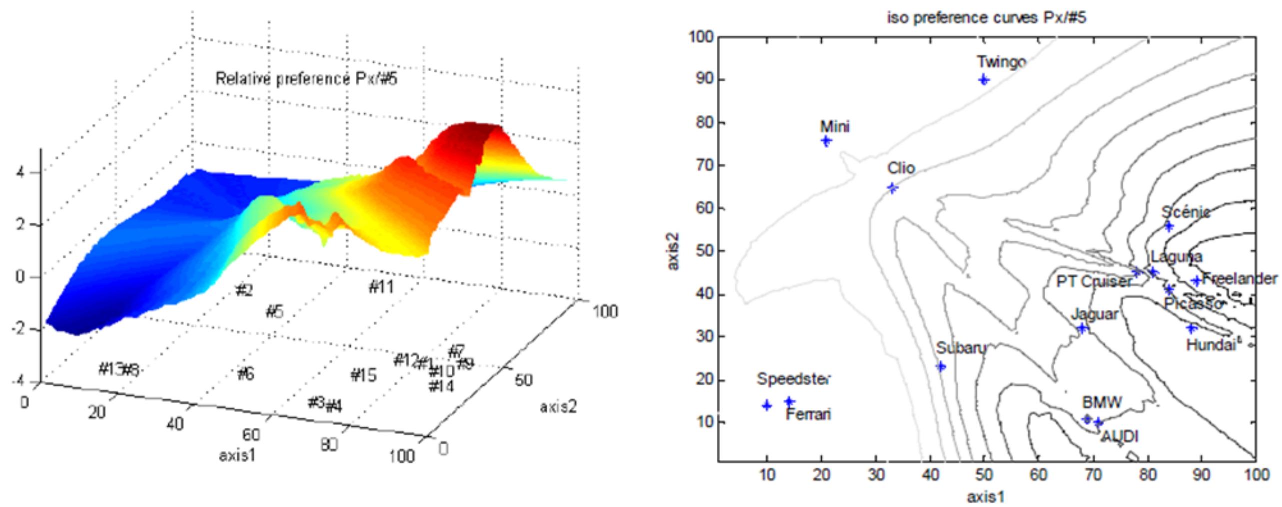

Figure 2.3: representation of the superimposed preference mapping on the perceptual representation of the products examined in (Petiot, 2002). Axis 1 and 2 represent the two dimensions spotted through MDS, while the surface indicates the preference surface relative to the product # 5.

Another way to connect consumer preferences to the perceptual mapping obtained by MDS has been exposed by (Lin, Lin, and Wong, 1996). In particular, in their works the authors applied a PREFerence MAPping (PREFMAP) (phases III and IV) analysis on the MDS representation. In fact, PREFMAP expects as input two different matrixes: a matrix defining the configuration of stimulus points (from a previous MDS mapping), and a matrix of subjects' preferences (obtained by multiple comparisons). In PREFMAP analysis (phase III) each subject's data is evaluated to fit the multi-dimensional space. In particular, within the multi-dimensional space each subject is represented as a point located by his/her most preferred position on each of the constituent dimensions of this space(that is: each subject is placed at his/her ideal point). In other words, the distances from each stimulus to the ideal point are linearly related to the preference expressed by the subject. In PREFMAP (Phase IV) a further step is performed. Each subject's rating for the meaningful attributes of the object is represented as a vector directed towards their region of maximum preference. The projections of the stimulus points onto the vector reproduce the subject's preference values. Moreover, the angle which the vector makes with each dimension can be thought of as representing the salience of that dimension in the preference judgment, in a way analogous to the PROFIT analysis (Figure 2.4 and 2.5).

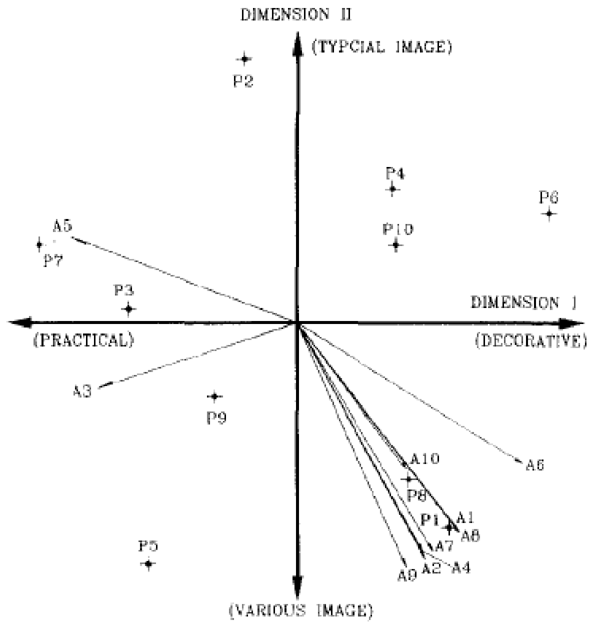

Figure 2.4: multidimensional representation of the data after PROFIT analysis from (Lin, Lin, and Wong,1996).

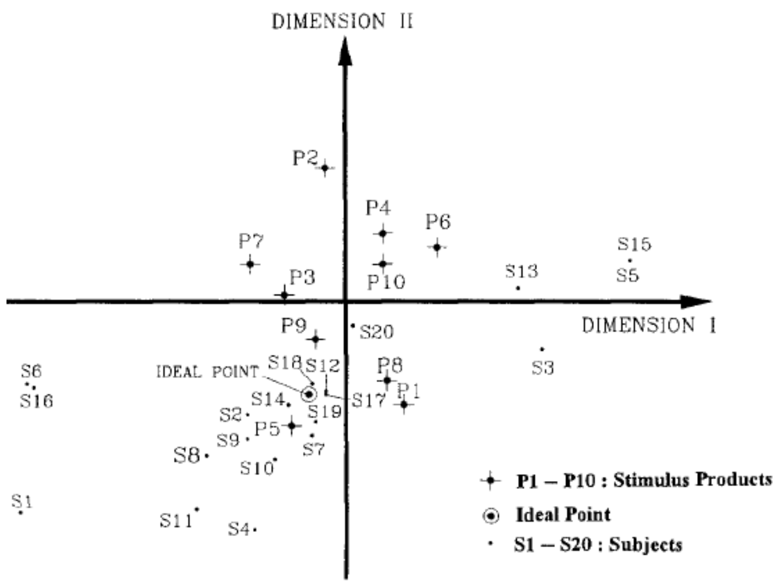

Figure 2.5: superimposition of the participant preferences on the MDS plotting. From (Lin, Lin, and Wong,1996).

SEMANTIC DIFFERENTIALS METHOD (SDM)

One of the most used procedures to investigate the users' perception of product form is the semantic differential method (SDM) (Osgood, 1964). In this method, the subject's perception of product features is quantified on a Likert scale. A Likert scale is a composition of Likert items, which are in turn scales composed by a statement which the respondent is asked to evaluate; it is considered symmetric or "balanced" because there are equal amounts of positive and negative positions relative to the agreement of the statement (Carifio and Perla, 2007). Often the item's scale is composed by 5-7 points, as recommended by (Reips, and Funke, 2008). However, in the semantic differential method the Likert items are composed by two bipolar adjectives (for example: "Adequate-Inadequate", "Good-Evil" or "Valuable-Worthless"). The user is asked to place his (her) evaluation of the product in the continuum between the two items, providing in this way the designer with semantic information about the product. An example of Likert scale used in the semantic differential method is shown in Figure 2.6. In the Figure is also reported a comparison with a semantic scale, which is a single labeled Likert scale.

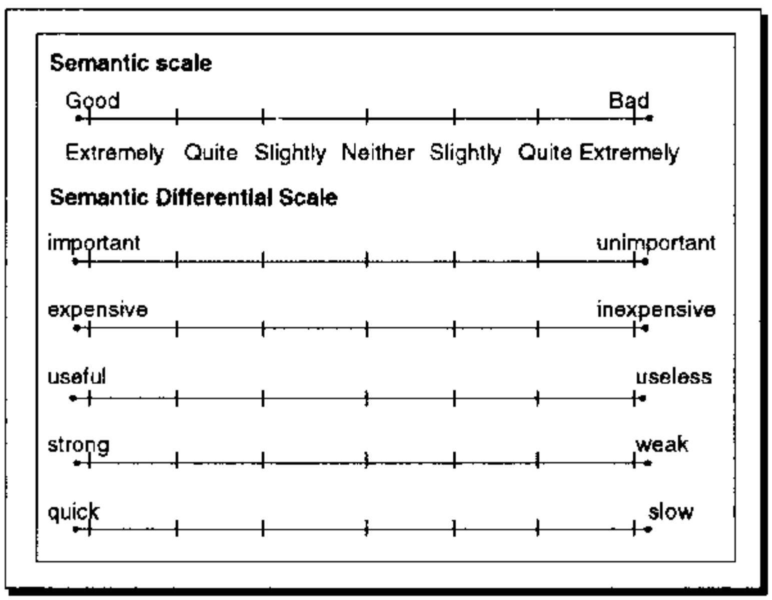

Figure 2.6: Semantic differential scale and semantic scale (from Crawford 1997)

However, the application of semantic differential scale alone does not suffice for a complete understanding of the product. By itself, the semantic differential method is composed by more stages although the semantic differential scale is, of course, the core of the method itself.

The first step in the SDM is probably the harder. In this step the designer must have the feeling of how users grasp the product meaning and semantic. It is indeed crucial that the designer have clear the user's mental image of the object, in order to select meaningful adjectives for the semantic differential scale. Traditionally this step is fulfilled by projection method. For example, in (Hsu, Chuang and Chang, 1999), users were tested on their perception of telephones. Each subject was asked to look at a telephones sample composed by 10 images of telephones and verbally express his or her perceptions about the telephone image. The descriptions of their perceptions were recorded, and the adjective pairs with higher distribution frequency were then classified and saved as semantic meaningful adjectives. In this first step authors collected a series of meaningful adjectives by means of projection method.

Once achieved the meaningful adjectives, a semantic differential scale was constructed and 24 real telephone samples were presented to 40 subjects (20 designers and 20 users) for subjective evaluation on the Semantic Differential (SD) scale (second step). Participants were also asked to give a reference rating on the different product's samples. In the paper, a linear regression was used to relate the preferences with the results from the projection method. Preference was indeed used in the model as dependent variables, and the adjectives were used as independent variables, with a procedure conceptually similar to the conjoint analysis (see above), where preferences are related with different aspects of the object. However, this approach can be considered qualitatively different, because the products are real, and the independent variable of the model are chosen by the user himself, rather than being set a priori by the experimenter.

The last step is constituted by the analysis of the information obtained by the semantic differential scale. The analysis is usually done by means of multivariate statistics, conceptually not dissimilar to the MDS (see above). In particular, factor analysis is usually performed in these cases. As multidimensional scaling, factor analysis allows us to find a small number of dimensions important in driving the categorization and conception of the objects. In particular, factors analysis applied to SD scale's results check for correlations among the selected attributes. In fact, if the ratings on two or more attributes are highly correlated, that means that the information of these attributes can be well expressed by only one dimension, that is in factor analysis, by one factor. Applying factor analysis to the SD data leads to a creation of a perceptual space. With factor analysis it is also possible to see how much a given adjective of the SD scale is explained by the achieved factors. Moreover, extraction methods, like the Bartlett method (Yong and Pearce, 2013), can allow the designers to look how much is the score of each object evaluated by means of SD on each factor. Finally, this allows the designer to assess for correlations between preferences and factor's scores, still utilizing linear regression and putting the preference as dependent variable and the scores of the factors as independent variables.

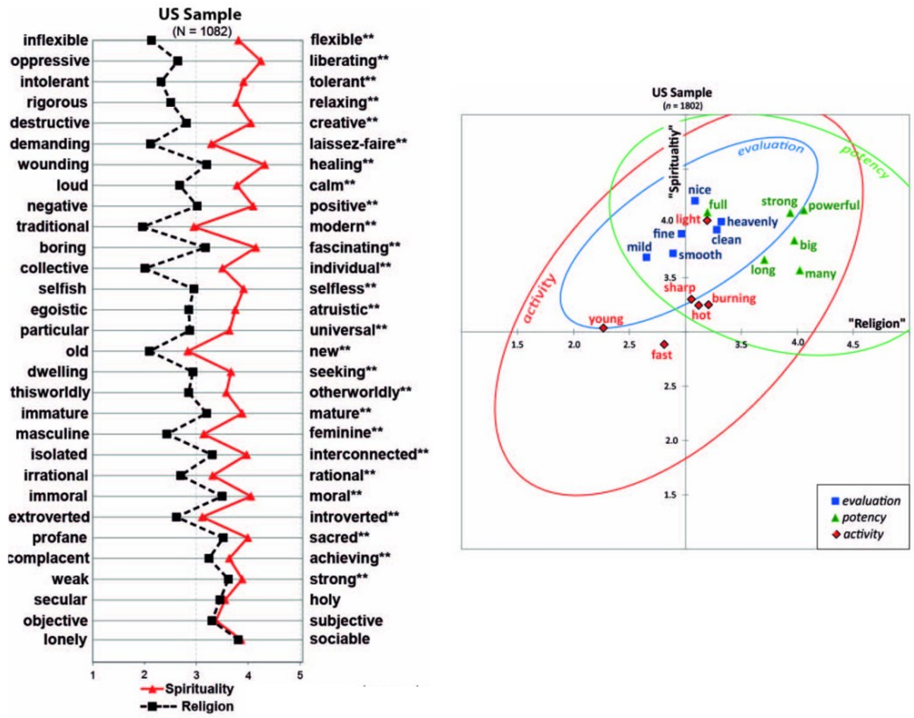

Figure 2.7: scores of semantic differential scale and plotting of the factor analysis results applied for SD attributes. http://www.unibielefeld.de/ (en) /theologie/ forschung/ religionsforschung /forschung / streib / spiritualitaet/ semantics.html).

Many researchers have used this method to study specific aspects of product form, including styles, colors, and other attributes in product design. For example, Maurer, Overbeke, and Smets (1992) conducted a study on the form of street furniture and explored the dimensions upon which the subject's judgment was based. Moreover, Espe (1992) performed an image study on the symbolic quality of watches and identified three judgment dimensions; namely, material and social representation, functional and logical representation, and aesthetic representation. These results provide the analytic support for designers and product managers. In addition, much research has been performed under the name of Kansei Engineering, which will be better explained in the next section.

KANSEI ENGINEERING

Kansei engineering is an approach for the product development strictly related with the semantic differential methods. However, since it has a strong tradition by itself, and since it differs in some extent from the simple application of the SDM, it is worth to treat it in a separate section.

Kansei engineering (KE) is nowadays one of the best known and most applied concepts in product development. Introduced in the product engineering field in 1989 by Mitsuo

Nagamachi (Nagamachi, 1989), the word Kansei means literally sensibility/sensitivity and reflects, according to Nagamachi, the involvement of the feelings and of the hedonic sensations in the product development process (Schutte, 2005). In years, different types of KE have been developed, and different methods to relate the user's inner states to the product features have been adopted (Nagamachi 2008). Particularly, three main types of KE have been defined. Each Kansei type is strictly related to a different way in which it is possible to interpret and formalize the relationship between product and user, although the method of semantics differential (i.e., Llinares, 2007) applied to KE and KE type I and II are the most common and used KE paradigms, as previously said.

Kansei type I consists in finding the main Kansei attribute related to the product (often called Type 0 concept in literature) and brakes it in sub-concepts, subsequently relating this sub-concepts to the physical features of the product. In other words, Kansei engineering Type I aim is to find the feelings (or the sensations) that those customers want to achieve from an interaction with the product, and relate them with the product characteristics. This first part of this process is usually due questioning the target users of the products, through survey or interview, and noting keywords on paper. Subsequently, the noted keywords are analyzed, in order to find the main Kansei concepts. It is important to note that the Semantic Differential (SD) technique (See the previous section) is the most used to spot the Type 0 concept, despite questionnaires, interviews, panels and physiological measurements have been also recently used in any Type and step of the KE process (Nagamachi, 2001). However, after its definition, Type 0 concept is subsequently broken into sub-concepts that, in turn, are broken in sub-concepts as well, until a number of very simple concepts (supposed to be concurrent in composing the Type 0 concept) are found. Each concept is then matched to a simple product feature (usually through usability and ergonomic questionnaires), giving in this way useful indication to the designer in terms of shapes, sizes and colours which, implemented in the product, would allow the consumers or the designers in achieving the desired Kansei.

KE Type II instead refers to the implementation of the Kansei theory in a computer automatic system (referred as Kansei Engineering System, KES). In fact, at its first steps, KE type II is rather similar to KE type I. Indeed, in KE Type II, after a collection of Kansei word, SD scales are constructed. SD scales are subsequently analyzed through factor analysis, achieving the Kansei word meaning space that is used to constitute a database of concept words for the KES. Once obtained the results from the SDM application, however, results from SD are analyzed by Hayashi's Quantitative Theory Type I (Hayashi, 1976), which is a form of multiple regressions applied on qualitative data. This kind of analysis sets the link between the terms in the KES databases and the physical features of the product. This system allows the consumer, or the designer, to input in the system the desired Kansei word, obtaining back the appropriate pattern of shapes and colours (note that the colours and the shape are analyzed independently and stored in two different databases). Is important to note that, how stated in (Nagamachi, 2002), the KES serves both a consumer-supporting function, guiding the consumer through the choice of the right product, and a designer-supporting function, providing insight to these designers that want, with their product, suggest (or even elicit) a given Kansei concept.

Finally, Kansei engineering Type III can be considered a mathematical formalization of the link between the product features and the consumer, not dissimilar from KE type two, but for the final interpretation of the results. In fact, as the first two Kansei Types, a previous identification of the Kansei concepts is achieved mainly by interviews and SD methods. Quantification theory is applied as well to the SD results. This allows, in KE type III, a parameterization of the product features, and the consequent formalization of the parameters in a model. The model can be based on Boolean logic as well as on fuzzy logic (Nagamachi, 1995), and its aim is to give to the designer predictive power on how the changes he (she) will perform on his(her) product will impact on the desired Kansei concept.

A further classification that characterizes the works in the Kansei field concerns the direction of the Kansei process. In particular, when designers start wondering about a Kansei concept, to relate it subsequently with the physical characteristic of the product, this is called Forward Kansei Engineering. On the other hand, the process that flows in the opposite direction, from the object features to the Kansei concept expressed is referred in literature as Backward Kansei engineering (Nagamachi, 1995). Hybrid KE is possible when both forward and backward KE are implemented at the same time. For example, Nissan utilized a Hybrid approach on KE type II to develop a new steering wheel for a passenger car, and other many examples of company using different methods belonging to the KE can be cited. In cosmetic industry, Shiseido, Noevia, Milbon, and Ogawa Fragrances are reported to have implemented the KE approach in their product development (Marghani, da Silva, Knapik, and Verri, 2013), as well as several car companies (such as Mazda, Toyota, and Ford (Nikov 2002)). Kansei approach has been also adapted to suite the issues related to the packaging of products (Nagamachi, 2002) and in house assessment (Nagamachi, 2002).

Summarizing, KE differs from the methods listed so far, because represents not just a method, but a methodology, including different methods for product development. It represents also the choice of systematically relating the features of the product to the inner states and to the desires of the consumer. However, it is worth to include it in this section of the dissertation, given the unique approach of breaking down the product to relate each single feature with a Kansei concept. Given that, it is not trivial to arrange KE in methods that relate the user's perception to the product. Moreover, combining the physical features of the product to the consumer concepts means, in some extent, relating physical perceptual stimuli with their emotional and cognitive interpretation by the users. In fact, there is evidence in literature where KE is actually defined as a sensory engineering, and the Kansei processes are clearly used to achieve a sensory evaluation of the products. For example, Zhang and Shen used insight from KE to perform a sensory evaluation of commercial truck interiors (1999). Even more interesting, Henson and Lillford (2010) integrated the Kansei Types I and II into a weighted averaged model of visuo-tactile integration of textures (corresponding to the actual functioning of the sensory systems, according to the authors' data). The improvement of the Kansei methods claimed by the authors is actually a further prove of the intrinsic connection between KE and human perceptual system, and finally, between KE and sensory design.

ATTRAKDIFF

As we highlighted in the previous chapter of this doctoral dissertation, the design model we took as reference in the development of this methodology is the experience design framework. As we previously pointed out, according to the experience design framework, users perceive products according to two main dimensions: Pragmatic and hedonic. The pragmatic qualities of a product refer to its ability in accomplishing "do-goals", that are the purposes for which the object has been created for (for example, a do-goal for a pen is "write"). Hedonic qualities refers to the product's perceived ability to support the achievement of "be-goals", that means the accomplishment of the hedonic and symbolic needing of the customer (referring to the example of the pen, a be-goal for an elegant-shaped pen could be "be professional, or "be elegant") (Craver and Scheier, 2001). In Hassenzahl (2008) has been proposed a product classification based on the pragmatic and hedonic dimensions. According to this classification a product can be considered as an ACT product if its pragmatic characteristics are able to fully accomplish its do-goal. Interaction with ACT products usually results in the user's satisfaction. A SELF product is, instead, a product that can well accomplish the be-goals it was intended for. Interaction with SELF products usually results in pleasure for the users. It is worth to note that the hedonic and the pragmatic dimensions have been proved to be independent each other (Hassenzahl, 2001). This assumption results in the possibility to have purely ACT or SELF products, but do not exclude the possibility to have products that are both ACT and SELF (DESIRABLE product) or neither ACT nor SELF (UNWANTED product).

The Attrakdiff method is the one that reflects the most this idea of user-product. Relationship. The method assesses the type of product (either SELF, ACT, DESIRABLE OR UNWANTED) based on semantic differentials (Hassenzhal, 2001). Software tool to apply the method can be accessed at *http://www.attrakdiff.de/* and allows us to compare two products in the pragmatic-hedonic dimensions or evaluate a single product. During the "single product" evaluation, users are asked to judge the product on a 7 points scale, where the two extremes of the scale are represented by opposite adjectives (Figure 2.8, left). The output of the Attrakdiff evaluation, basing on the participant answer to the semantic differentials, position the product in a two-dimensional space, in which the two dimensions are represented by the pragmatic and the hedonic qualities of the product. The space is subdivided in 9 districts, indicating the category of products whereby the product examined by the users belongs (Figure 2.8, right).

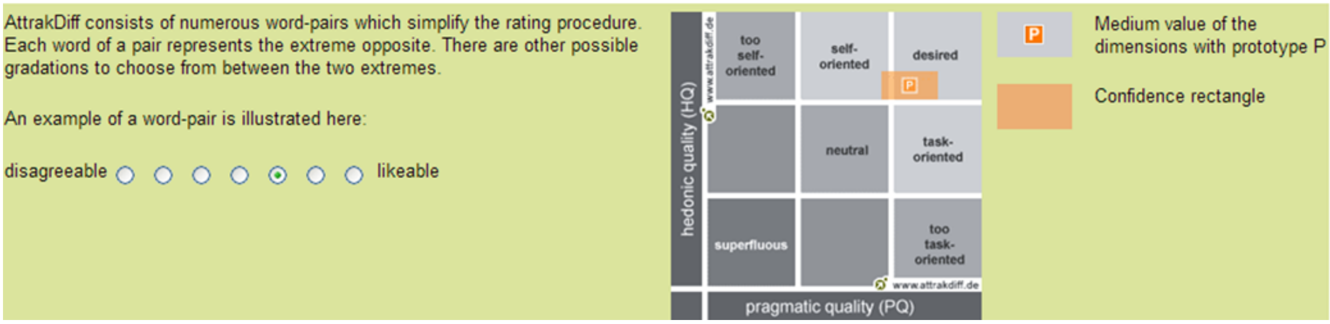

Figure 2.8: on the left, an example of semantic differentials from http://www.attrakdiff.de/. On the right, an example of the output that the Attrakdiff software tool provides.

Although useful in understanding how much a product can be considered pragmatic or hedonic, the Attrakdiff has the relevant drawback of considering the product on its integrity, without discerning between different product's features. For this reason, it is advisable to use the Attrakdiff as complementary with MDS or conjoint analysis. Results of the Attrakdiff related to different products and prototypes can be indeed compared, in order to see the contribution of each feature to the hedonic and pragmatic quality of the product.

SENSORY SNAPSHOT

The sensory snapshot method has been used for years in the realm of marketing and design and it basically refers to the assessment of the user's perceived importance of the different sensory modalities in the product's usage (Moskowitz 1974). Although different modes and different levels of complexity have been applied over years, the concept underneath the sensory snapshot technique is always the same: associate a rating on each of the 5 sensory modalities (vision touch, audition, smell, taste). Users are typically asked to report their assessment on a scale (usually 5-7 points, where the lower value corresponds to a null importance of the judged sense, while an higher value corresponds to the maximum importance of the judged sense). Results are often reported on a spider diagram (Figure 2. 9).

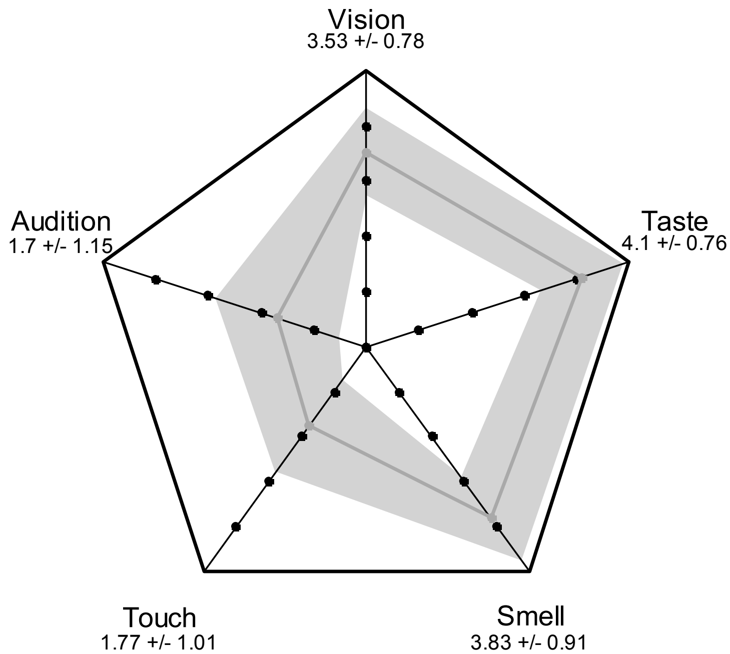

Figure 2.9: Results from the application of the sensory snapshot technique on 30 users, evaluating the importance that each sense has on a coffee from a particular brand. The dark gray line represents the mean of the assessments, while the light gray shade represents the standard deviation.

Sensory snapshot is often used to compare different brands or products (Gentile, Kodak, and Intel). In (Schifferstein, 2006) two different studies were performed, both applying the sensory snapshot method, first on the product itself, and subsequently on some functions of the product. In fact, the first experiment was performed in order to find out respondents reported how important they found vision, audition, touch, taste, and smell during the use of 45 different products. Subsequently, the participants of the study were asked to sensory snapshot evaluation of the safety, ease of use, and enjoyment experienced for 15 further products. A multiple way ANOVA was used to compare types and products. Results concerning the comparison between the snapshots allowed the researchers to prove that the importance ratings for the sensory modalities differed considerably between the products. Noteworthy, differences due to the types of evaluations were smaller. Finally, averaged over products and evaluation types, vision was the most important sensory modality for product evaluations, followed by touch, smell, audition, and taste. However, for about half of the individual products, the importance ratings for vision were lower than for one of the other modalities, proving that vision is not always the most important sense in the product interaction (at least according to the users' self-report).

Sensory snapshot has been used also to see how the importance that users give to each sense change in time. Fenko Schifferstein, and Hekkert, (2010) asked 243 participants to describe their experiences with consumer products in various situations: while buying a product, after the first week, the first month, and the first year of usage. Their data, analyzed again by means of a multiple way ANOVA, suggested that the dominant sensory modality depends on the period of product usage. At the moment of buying, indeed, vision was rated as the most important modality; however, during the usage, all the other sensory modalities gained importance, in particular touch and audition.

QUALITY FUNCTION DLOYMENT (QFD)

Quality function deployment (QFD) is a method born in the early seventies in the field of ship-building in Japan (Akao, 1994). QFD is a systematic approach that pays heed to the consumer desires and perception of the product. In fact, it consists in translating customer desires (for example, the ease of writing for a pen) into design characteristics (then, in our example, pen ink viscosity, pressure on ball-point, etc.) for each stage of the product development (Rosenthal, 1992), from the study of the user's need, to the need's translation on technical characteristics, until the delivery of the product to the market. Using the words of its own creator, QFD:

> *"Is a method for developing a design quality aimed at satisfying the consumer and then translating the consumer's demand into design targets and major quality assurance points to be used throughout the production phase. ... [QFD] is a way to assure the design quality while the product is still in the design stage."* (Source Wikipedia)

Interestingly, the application of QFD has been seen to be extremely useful in terms of shortening the product development process reducing its time by approximately one third (Akao, 1990). The QFD method is composed of 4 different phases. Relationships between elements are evaluated for each phase, by different actors supposed to have different competencies. On each phase the most important aspects concerning the product are selected, and subsequently deployed into the next matrix (phase). However, since the methods exposed in this section refer to the study of the interaction between user and product, only the first two phases of the QFD methods are particularly relevant for us. In fact, in lot of studies implementing the QFD method, only the first and second phases are applied. Roughly, the four phases are described as follow:

- Phase 1 - Product Planning: the main step of this phase is represented by the building of the House of Quality. This is the most representative step of the QFD method, and the one we are more interested in given the aim of this part of the methodology described in this doctoral dissertation. As a matter of fact, many organizations only get through this phase of a QFD process. Phase 1 aim is to document the customer requirements, the warranty data, and all the competitive opportunities, together with the product measurements, the competing product measures, and the technical ability of the organization to meet each customer requirement Phase 1 has been considered crucial in the QFD process by many authors.

- Phase 2 - Product Design: This phase 2 is supposed to be led by the engineering department. Product design requires creativity and innovative team ideas. In particular, during this phase, product concepts are created, and technical part specifications are documented. Parts that are determined to be most important to meeting customer needs are then deployed into process planning, or Phase 3. This phase is extremely relevant given the aim of the exposed methodology as well.

The phases 3 and four of the QFD method are less related with the aim of the methods exposed in this section.

- Phase 3 - Process Planning: Process planning comes next and is led by manufacturing engineering. During process planning, manufacturing processes are flowcharted and process parameters (or target values) are documented.

- Phase 4 - Process Control: the last phase is the less related to the current aim of the dissertation. In production planning, performance indicators are created to monitor the production process, maintenance schedules, and skills training for operators. Also, in this phase decisions are made as to which process poses the most risk and controls are put in place to prevent failures. The quality assurance department in concert with manufacturing leads Phase 4.

As mentioned above, the core of the QFD method is the implementation of the house of quality (Sullivan, 1986). The house of quality is basically a collection of the technical characteristic of the product, matched with the user's needs and demands. The final shape of the table representing this matches has a peculiar shape (Figure 2.9) and gives the name to the table itself, that is, indeed, house of quality. The house of quality is easily doable following 12 brief steps. On each step, a different "part" of the "house" is built. Figure 2.9 shows the different part of the house in different colours. We will address to a different colour each step, in order to make clear the procedure and the sequence of steps needed to create the house (Becker and Associates, 2000).

- Step 1: Customer Requirements - "Voice of the Customer" (dark blue). The first step when building the house of quality consists in determining who the customers are. After selecting a population of interest, the designer or the design team (QFD is actually designed to be carried out by a multidisciplinary team) gathers information from customers on the requirements they have for the product (or the service). In order to organize and evaluate this data, the team usually uses simple qualitative tools (i.e., Tree Diagrams).

- Step 2: Regulatory Requirements (red). In this second step, the team must select only the requirements that are dictated by management or regulatory standards that the product must adhere to, in order to include in the house only what is feasible among the customer needs.

- Step 3: Customer Importance Ratings On a scale from 1- 5 (red). In this step customers are asked to rate the importance of each requirement. This number will be used later in the relationship matrix.

- Step 4: Customer rating of the Competition (dark green). Understanding how customers rate different versions of the same product can be extremely useful. In this step, customers are asked to rate different products (included the one the designer is asked to optimize) according to the needs selected by themselves. Ideally, additional rooms that identify sales opportunities, goals for continuous improvement, customer complaints, etc., can be added at this step.

- Step 5: Technical Descriptors - "Voice of the Engineer" (light orange). In this step, the technical descriptors are attributes about the product or service to optimize. There are plenty of reasons that could lead to the choice of technical descriptors. For this reasons, it is always advisable for the designer (in absence of a team) to face this step only if aware of all the technical needs and restrictions involving the creation of the product. Otherwise, supervision from an engineer would be strongly recommended.

- Step 6: Direction of Improvement (purple). As the design team defines the technical descriptors, a determination must be made as to the direction of movement for each descriptor. Downward arrows represent the descriptors that should be under-expressed. Upward arrows represent the technical parameter to increase in order to match the user demands.

- Step 7: Relationship Matrix (light blue). The relationship matrix is where the design team determines the relationship between customer needs and the practical possibility to meet those needs. In particular, the design team assesses the strength of the relationship between the technical descriptors and the customers' needs. Relationships can either be weak (expressed by a triangle), moderate (expressed by a circle), or strong (two concentric circles, the inner one bold). Relationship can also carry a numerical value, typically 1 (weak), 4 (medium) or 9 (strong).

- Step 8: Organizational Difficulty (light green). In this phase the design team rates the design attributes in terms of organizational difficulty, that is, in terms of feasibility. It is very possible that some attributes are in direct conflict. Increasing the number of sizes may be in conflict with the companies stock holding policies, for example.

- Step 9: Technical Analysis of Competitor Products (dark gray). To better understand the other version of the product to optimize (in the realm of QFD the competitor's products), the design team then conducts a comparison of other products technical descriptors. This process often involves a reverse engineering study of the similar products, in order to determine specific values for these products' technical descriptors.

- Step 10: Target Values for Technical Descriptors (light gray). At this stage in the process, the design team begins to establish target values for each technical descriptor. Quoting

(Brief, 2000) “Target values represent "how much" for the technical descriptors, and can then act as a base-line to compare against”.

- Step 11: Correlation Matrix (light yellow). In this stage the roof of the house is built. The correlation matrix is probably the least used room in the House of Quality; however, this room constitutes a big help second phase of a comprehensive QFD project. In this phase team members examine the influence of the technical descriptors on each other. The design team should document strong negative relationships between technical descriptors and work to eliminate physical contradictions. In the methodology developed in this PhD a way to overcome these conflicts is proposed in the second phase.

- Step 12: Absolute Importance (Bordeaux). In this last step, the team calculates the absolute importance for each technical descriptor as the product of the cell value and the customer importance rating. Numbers are then added up in their respective columns to determine the importance for each technical descriptor. This ultimately allows the design team to know which technical aspects of the product are important to the costumer, and their feasibility.

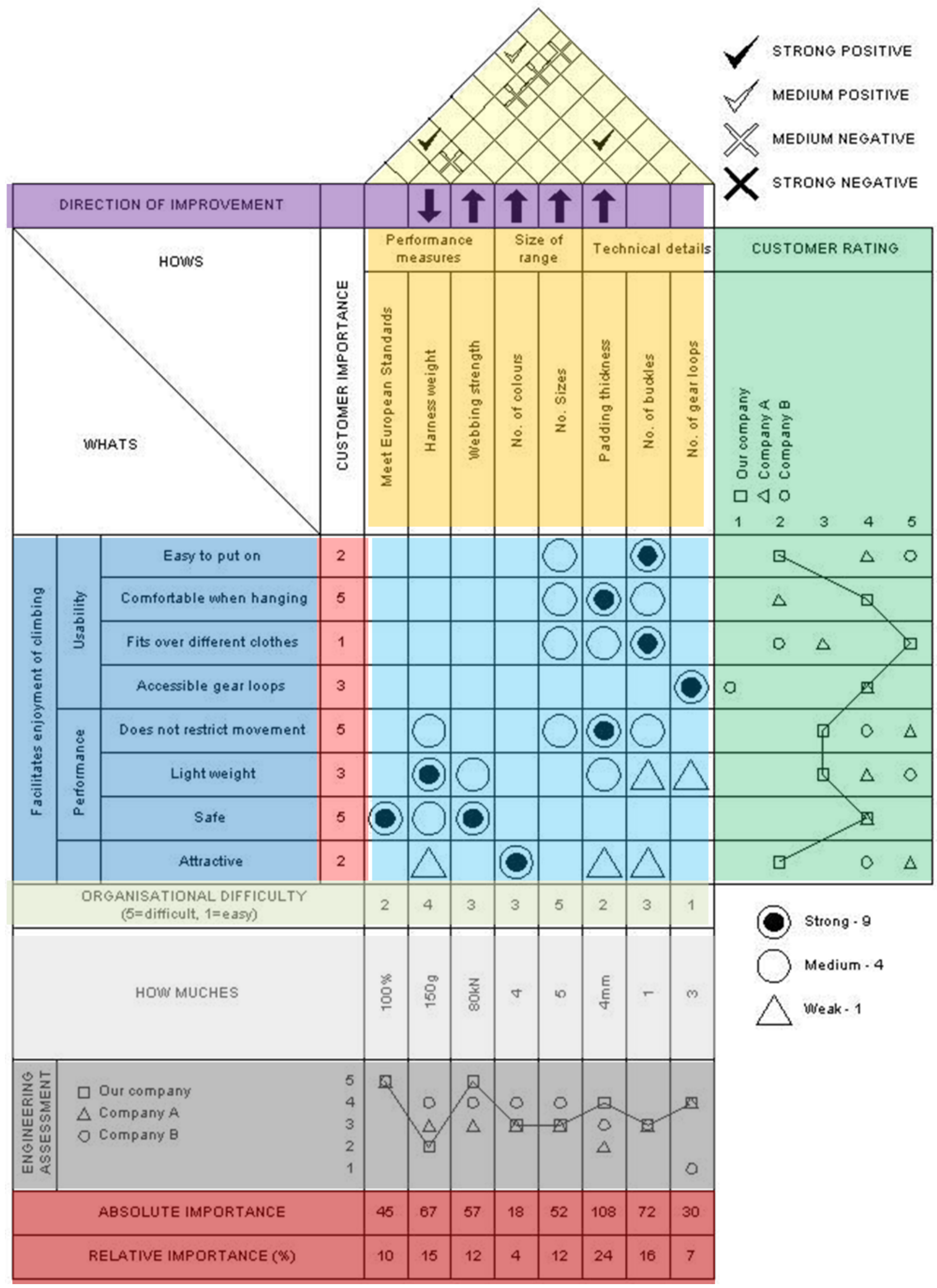

Figure 2.9: House of Quality. The different colours represent the different stages (see the text).

The next Phases, after the construction of the house of quality, are based on the information achieved from it. In particular, in QFD's Phase 2, the process becomes a translation of the voice of the engineer into the voice of the part design specifications. Then, in Phase 3, the part design specifications get translated into the voice of manufacturing planning. And finally, in Phase 4, the voice of manufacturing is translated into the voice of production planning.

TESTING THE EMOTIONS: PRODUCT EMOTION MEASUREMENT INSTRUMENT (PREMO), SAM, EMOTION WHEEL.

The PrEmo tool has been developed by Desmet (Desmet, 2005), in order to study the emotional reactions that consumers have with respect to given products. This tool is based on non-verbal self-reporting. A set of fourteen emotions is portrayed with an animated cartoon character, expressing the emotion by means of dynamic facial, bodily, and vocal expression. In the methodology, consumers can report their emotional reaction to a product by selecting those animations that correspond with their felt emotion(s) interacting with a computer interface (Figure 2.10). Noteworthy, the selection of the emotion is not limited to one, and so complex emotions can be selected by selecting more than one animation. The 14 animations are organized in still. The top section of this interface depicts stills of the 14 animations. Each still is accompanied by a (hidden) three-point scale. These scales represent the strength of the selected emotion, and in particular correspond to the statements: “I do feel the emotion,” “to some extent I feel the emotion,” and “I do not feel the emotion expressed by this animation.” In fact, a scale appears on the side of the animation frame only when the animation is clicked. The lower section of the interface displays a picture of the stimulus and an operation button. During the application of the PrEmo, the respondents are first shown a (picture of a) product and subsequently instructed to use the animations to report their emotion(s) evoked by the product.

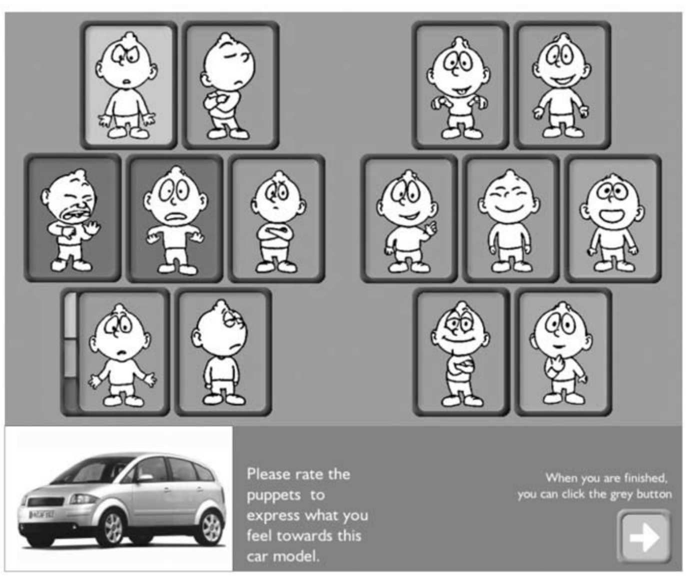

Figure 2.10: Product Emotion Measurement instrument interface

The animations used by PrEmo were proven to be reliable also across cultures. In a study (Desmet, 2005) 120 participants from Japan, United States, Finland, and The Netherlands were asked to recognize a given emotion among three given animations. Results proved the validity of the animation with a high level of significance. The PrEmo had been used in experiment involving the evaluation of different products. In (Desmet, 2005) a study on six different types of chairs has been performed. In fact, results of this study were relevant in the sense that proved strong correlations between verbal descriptors for emotions (also used in the product judgment), and animations of the PrEmo. The study also proved the validity of the test in test-retest conditions. A cross cultural study, evaluating 6 different models of cars has been also performed comparing data obtained from 32 Japanese participants and 36 Dutch. To analyze the results, on each emotion a two-way repeated measures MANOVA was performed with Car (six levels) as within-participants factor, Culture (two levels) as between-participant factor, and the emotion as dependent variable. Some interesting culture effects have been found. For three emotions, cultural differences independent of car model were found. Japanese participants showed higher mean scores on the following emotions: admiration, satisfaction, and fascination.

Despite the PrEmo is the most indicated when investigating the emotional reaction of the consumer to the product (given the fact that it has been designed explicitly for the design purpose), other self-assessment techniques have been used by adaptation to the design field. For example the Self-Assessment Manikin (SAM) developed by Bradley and Lang (1994) has been used is different design studies. The self-assessment manikin is a pictorial representation of a semantic differential scale investigating three main dimensions proved to describe (although other emotion theories can be considered equally valid (Myers, 2004)) which are: Valence, Arousal, and Dominance.

Valence generally indicates the intrinsic attractiveness (positive valence) or averseness (negative valence) of an event, object, or situation. However, the term is also used to characterize and categorize specific emotions. For example, the emotions popularly referred to as "negative", such as anger and fear, have "negative valence". Joy has "positive valence". Positively valenced emotions are evoked by positively valenced events, objects, or situations. The term is also used about the hedonic tone of feelings, affect, certain behaviors (for example, approach and avoidance), goal attainment or nonattainment, and conformity with or violation of norms. Ambivalence can be viewed as conflict between positive and negative valence-carriers. Theorists taking a valence-based approach to studying affect, judgment, and choice posit that emotions with the same valence (i.e. anger and fear or pride and surprise) produce a similar influence on judgments and choices. For example, based on this theory, the negatively valenced emotions anger and fear are likely to result in more negative judgments. In the SAM, the valence dimension is tested asking participants to mark the representation of a manikin which shows to have either a sad expression (in the beginning of the scale, very low valence) or a happy expression (in the end of the scale, very high valence). (Figure 2.11).

Arousal. Arousal indicates the physiological and psychological state of being awake and well reactive to stimuli. Physiologically, it involves the activation of the reticular activating system in the brain stem, the autonomic nervous system and the endocrine system, leading to increased heart rate and blood pressure and a condition of sensory alertness, mobility and readiness to respond. In fact, there are many different neural systems involved in what is collectively known as the arousal system. Four major systems originating in the brainstem, with connections extending throughout the cortex, are based on the brain's neurotransmitters, acetylcholine, norepinephrine, dopamine, and serotonin. When these systems are in action, the receiving neural areas become sensitive and responsive to incoming signals. In the SAM, the arousal dimension is tested asking participants to mark the representation of a manikin which shows to have either a normal condition (in the beginning of the scale, very low arousal) or a looking-like exploding stomach (in the end of the scale, very high arousal). (Figure 2.11).

Dominance. The dominance is a dimension somehow related to the arousal, and it expresses how much a person is in control with the emotion he (she) is feeling. Interestingly, in most of the studies (even those performed to Bradley and Lang, who first invented the SAM) it is not considered, likely because of its correlation with the arousal dimension. In the SAM, the arousal dimension is tested asking participants to mark the representation of a manikin that grows in dimension, from very small (in the beginning of the scale, very low dominance). The small person represents the participant “feeling little” compared with the emotion, therefore is a representation of the lack of control on the emotion) to very big (in the end of the scale, very high dominance). (Figure 2.11).

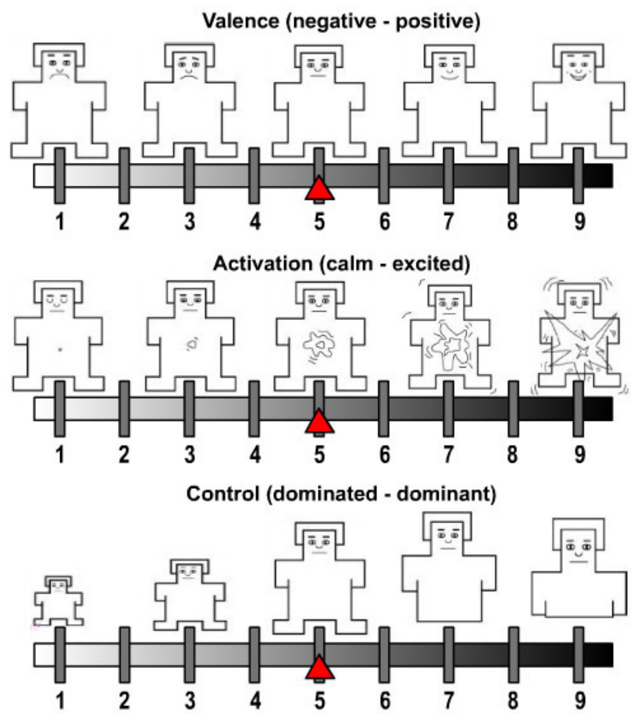

Figure 2.11: representation of the SAM on a 9 point Likert scale. In some cases, SAM has been associated with 5 point scale and 7 point scale.

A further way to investigate emotions has been recently developed in Geneva. The Geneva Emotion Wheel (GEW) is an instrument to measure emotional reactions to objects, events, and situations, derived from the work of (Scherer, 2005), and further tested by Scherer, Shuman, Fontaine, and Soriano (2013). During the application of the method, the respondent is asked to indicate the emotion he (she) experienced by choosing intensities for a single emotion or a blend of several emotions out of 20 distinct emotion families. The emotion families are arranged in a wheel shape with the axes being defined by two major dimensions of emotional experience which are: Arousal/dominance and valence. The intensity of the felt emotion is expressed in five degrees of intensity, represented by circles of different sizes. In addition, "None" (no emotion felt) and "Other" (different emotion felt) options are provided (Figure 2.12).

Reader and McMahon (2013) implemented a system for the assessment of products based on the GEW. The system is based on data collected by over 100 on-line reviews. In the system, a web crawler was used to download all the reviews, which were then processed using text mining software to identify the most frequently used words and phrases. These were then mapped to a faceted classification scheme for emotions based on the Geneva Emotion Wheel. Software allows the classification scheme to be browsed rapidly. The results from the system allowed in fact an effective method for designers to go directly to relevant reviews, emotionally coded on the GEW.

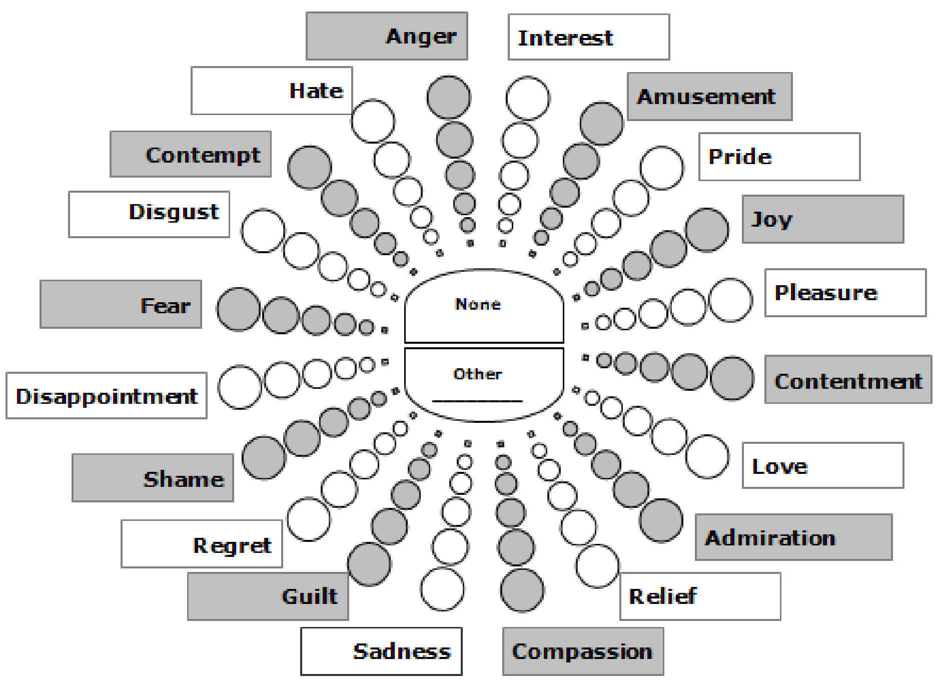

Figure 2.12: example of a blank Geneva emotion wheel (GEW)

IMPLICIT EXPERIMENTS

With Implicit experiments, we refer to those methods that connect the user and the product without necessarily asking the user a feedback about the interaction or the product itself. Most of these experiments come from the usability and ergonomy realms, but thanks to the fast development of the imaging technologies recently neuroscientific and physiological methods have been adopted as well. In this section we will describe each of the methods by mean of practical instructions and examples. In the last part of the paragraph a framework to record the physiological activation of the users in different context developed during this PhD will be described, together with its potential application on the product optimization.

PERFORMANCE MEASUREMENT

One of the most common ways used to investigate the relationship between product and users is to measure the performance of the participants while interacting with different version of a product. Performance measures can be related to the number of error the user makes when using an object for a given purpose (Nielsen and Levy, 1994), to the time taken to perform a given task by using an object (Hornbæk, 2006), or even to the time that takes the user to learn how to properly use the object (learnability) (Jeng, 2005). The performance measures are traditionally associated with the study of the usability of a product. Nonetheless, they constitute an important factor in other disciplines such as knowledge engineering and ergonomy (Bititci, Turner, and Begemann, 2000; Brookhuis, Waard, and Mulder, 1994). In this PhD thesis the measures of performance are not related with any of these disciplines in particular, and are considered only as a further tool to achieve information about what features of the object are considered important by the consumer. However, there is no doubt on the fact that performance measures are mainly related (referring to the experience design framework) to the pragmatic components of an object. The use of these techniques is then recommended when the aim of the optimization includes some pragmatical improvement.

The application of the performance measurements is conceptually simple, but it requires a certain amount of time and a basic knowledge of the experimental practice and procedure. For example, it is important to select which variables to test and isolate, according to the design question and the client demands. It is also important to decide which kind of performance to measure (either precision, time, or learnability), and the number of participants needed in order to make the data reliable. On this matter, the philosophy “the more the merrier” is recommended, in order to obtain more statistical power and being able to extend the obtained results with more reliability to the whole population (Olejnik, and Algina, 2003). However some argument in favour of a small number of participants to a performance study has been advanced by the “father” of the usability theory Nielsen (Virzi, 1992). In particular, Nielsen argued that “five is enough” when it comes to test the usability of a device through performance testing, describing the relationship binding users and problems spotted by the usability/performance experiment as:

$$U = 1-(1-p)^{n} \qquad (4)$$

Where U indicates the proportion of problems uncovered by the experiment, and p is the probability of one subject identifying a specific problem and in the number of subjects (or test sessions).

Given the major relation with the usability, performance studies have been principally applied to the study of interfaces and new technologies. In a study investigating the interaction of users with a 3D menu for Virtual Reality (VR) application, Caruso, Gatti, and Bordegoni (2011) evaluated the importance of different features on the learnability of the menu, which was activated by the user by pressing a button posed on the handle of the haptic device used to interact in the VR space.

In the experiment, 8 different versions of the three dimensional haptic menu (3DHM) were designed. The first four versions were named: no-haptic, normal, contextual and contextual no-snap. The no-haptic version did not provide the user with a haptic feedback and the menu item selection was only highlighted by means of a different illumination of the item. The normal version only returned the magnetic points as haptic feedback. In the contextual version torus and magnetic points were enabled and the position of the menu was defined according to the haptic master (HM) end effector position, i.e. the first menu item position is the same of the HM end effector. The high external stiffness of the torus compelled the HM end effector to move only into the menu. The contextual no-snap version was similar to the contextual one but only the torus haptic feedback is rendered. In all the first four versions the of the menu were represented in different colours, carrying a different number.

To assess the effect of the colour on the user interaction, all the first four versions of thee 3DHM were then reproduced with the only difference of having a black and white layout, achieving then 8 versions off the same menu. The experiment then investigated the influence of position, haptic feedback, and colour in the interaction with a 3D menu for VR applications. In other world, it assessed the importance of these features in the product-user relationship.

To this aim, eight different users' groups, one for each 3DHM version, were asked to perform a simple task (between group experimental designs). Each group consists of 5 users (40 users in total), 30 males, right handed and aged between 24 and 35, recruited within the mechanical engineering department building at the Politecnico di Milano, Italy. All the users were naïve to the task, and had no previous experience with the haptic menu. The tests were repeated in 6 different sessions, to evaluate whether and how the users' ability in interacting with a particular version of the menu changed over time. The task consisted in a simple menu item selection. When a user selected one of the menu items a white sphere appeared in the 3D space and specifically in a position related to the item selected. Then, the user had to reach that sphere and select it with the cursor. The sequence of menu items to select has been read from a list by the experimenter. After this selection, the white sphere disappeared and the experimenter read from the list the number corresponding to the next item that the user had to select. The session ended when the user selected all the 30 items listed in the experimenter's list. The number of items in the list was balanced per item (6 items per 5 repetitions) and randomized. The users have to complete all the sessions within a week.

The chosen task was really easy and intuitive: no one of the testers made selection errors during the testing sessions. The learnability of the menus was assessed by analyzing the selection time during the six sessions. The time needed to complete the task was considered irrelevant, therefore only the time in which the testers were able to select the right menu item was computed, that was: only the time occurring between the click of the white sphere and the successive menu item selection has been elaborated. Those intervals were summed for each session, in order to have the total selection time that resulted equal to the time that the user spent in selecting the right menu item during the entire session. During the testing sessions also the user's trajectory path was recorded. Figure 2.13 shows a trajectory path elaborated from a very brief part of a testing session.

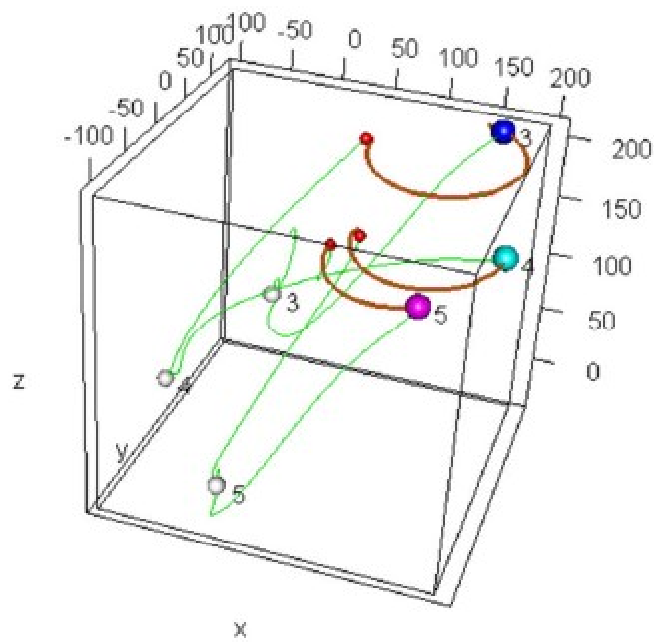

Figure2.13: A trajectory path elaborated from a very brief part of a testing session.

In particular, the red sphere in the figure indicates the position where the user activates the menu, the colored spheres are the menu items selected and the white spheres are the target spheres. This path was used to extract some general information about user's movements. In order to evaluate the memorability in using the different menus, authors evaluated how the total selection time varied per each tester and per each menu during the six sessions. The sphericity of the data set was assessed through the Mauclhy test and then a two way repeated measures ANOVA were applied to analyze the variation of the selection time along the sessions. The ANOVA's factors taken into account were the position of the menus (contextual vs. fixed), the presence of the snap feedback (present, absent), and the colour of the menu (B/W vs. colorful). The kind of torus has not been considered, because the conditions (absent vs. high) were collinear with the position factor. That has been a forced choice, since to the choice enabling a torus in a fixed menu where users directly reached the item did not make sense, whereas in a contextual menu the presence of the torus could be useful. The analysis showed a statistically significant interaction between the haptic feedback and the position of the menu between users. In particular, post-hoc t-test comparisons at 95% of confidence interval showed a highly statistical difference between the fixed no haptic menu and other versions. A strong effect of repetition and an effect of the interactions repetition: haptic feedback and repetition: menu position has been found within participants. No effect of the colour was found.

Concluding, in the study the authors assessed the importance of features as position and haptic feedback in the learnability with a VR menu, while assessed the relative unimportance of the colour of the icons. As it is clear from this example, studies on performance are really related with the aspect of the object/ product/ interface the designer intend to improve (in this case, learnability) and to the physical characteristic the product is able to express (in this case haptic feedback, position, and colour). In general, when designing an experiment investigating the product performance is good practice follow the step illustrated in Figure 2.14.

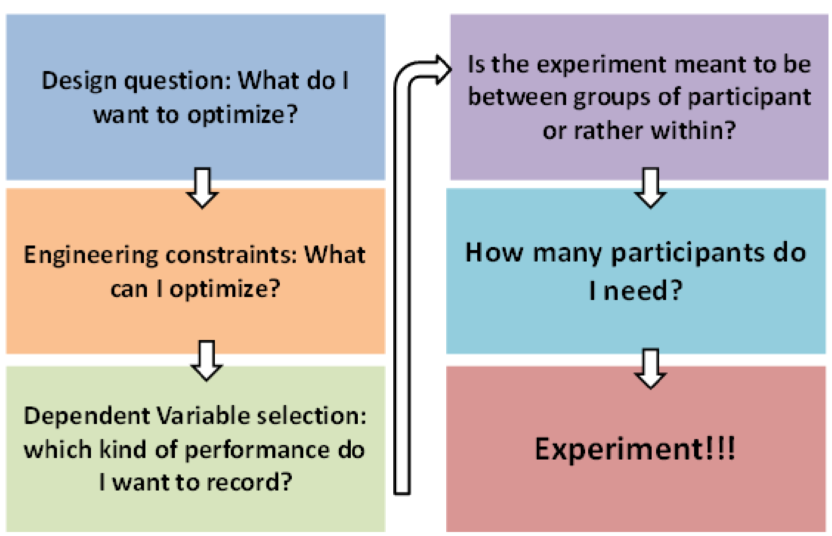

Figure 2.14: Step to be performed in order to start designing an experiment measuring the performance of the participants

- Design question: In this stage of the experimental design it is crucial to have clear in mind what we want to test, which is: what do we want to optimize in the design product. As previously mentioned indeed, the performance experiment will give information about the pragmatical aspects of the product. It is then a good practice to know the kind of product we are working on, in order to answer to questions as: Is it more important for the user to be precise when using the product? Or would be rather better for the user to be fast? Basing on these questions the variables will be selected.

- Engineering constraints: in this phase it is important to know which characteristic of the product can be modified. In particular, once selected the design question, it is important to see what is possible to change in the product, before proceeding to the test which will tell us which changes are actually important, given the interaction of the user.

- Dependent variable selection: It is important to select the dependent variable accordingly with the design question. The variable to test represents the way the participant performance is measured. Depending on the product to optimize the designer could be interested in what is important for the user when interacting with the object in order to perform a task as fast as possible. In other cases learnability and precisions might be more relevant.

- Between groups or rather within?: Whether to adopt a between or within experimental design largely depends on the time at the designer's disposal and on the product we want to test. In the between groups design, each participant takes place in only one experimental condition (that is: different participants take part in different conditions). This experimental design presents some advantages, for example the absence of practice/fatigue effects and there are fewer chances of participants working out exactly the aims of the experiment. However, a large sample is required, and here is not much control of eventual confounding variables (Cunningham, and Wallraven, 2011).

- In the within group design instead, participants take part in all conditions. Thus, different groups of scores are obtained from the same sample of participants. In this kind of experimental design, since participants take part in all conditions, they allow us to control for many inter-individual confounding variables. Moreover, the requested sample size is smaller. However, drawbacks like fatigue, practice, and order effect may influence performance. Therefore, in this experimental design counterbalancing between conditions is extremely important (Cunningham, and Wallraven, 2011). For example, let's imagine an experiment in which the performance is measured on the use of two prototypes. In this case we would have two conditions: interaction with prototype I and interaction with prototype II. Counterbalancing the condition in this case means ask half of the participants to interact first with prototype I, and then with prototype II, while the other half will interact with the prototypes in the inverted order.

- How many participants do I need?: The number of participants is always a problem. In general, within groups studies require less participants, although the rule "the more the merrier" is always the most important when taking participants. A number of 30 participants per group is the one usually required to have a reliable normal distribution of the data, which allow us to perform all the major statistical tests (i.e., ANOVA, t-test).

Once clear all the answers to these questions, it is possible to start the experiment.

TRACKING EXPERIMENTS

Tracking experiments represent one of the most common used procedures when it comes to record and study user interaction. With tracking experiments we refer to all the experiments involving the extrapolation of information from the recorded activity of the participants. The kind of data and information obtained in this kind of experiments, as well as their interpretation, strongly depends on the tracker system used.

Eye tracking: With eye tracking it is possible to measure and record the point of gaze (where one is looking to) of users. It is moreover possible to record the motion of an eye relative to the head. Eye tracking is performed by means of an eye tracker (a device for measuring eye positions and eye movement). Eye trackers have been used in research on the visual system (Binda, Morrone, Ross, and Burr, 2011), psychology (Allopenna, Magnuson, and Tanenhaus, 1998).), cognitive linguistics (Tanenhaus, Spivey-Knowlton, Eberhard, and Sedivy, 1995), and, more recently, product design (Goldberg, Stimson, Lewenstein, Scott, and Wichansky, 2002; McCarthy, Sasse, and Riegelsberger, 2004; Koivunen, Kukkonen, Lahtinen, Rantala, and Sharmin, 2004). There are a number of methods for measuring eye movement.

- Eye-attached tracking: this kind of eye tracking records the eye movements by means of special contact lens with an embedded mirror or magnetic field sensors (Robinson, 1963). This is likely the most sensitive way for record the eyes movements, and has been widely used in studying the dynamics and underlying physiology of eye movement. It allows the measurement of eye movement in horizontal, vertical and torsion directions (Duchowski, 2007).

- Optical tracking: In optical tracking infrared light is reflected from the eye and sensed by a video camera or some other specially designed optical sensor. The information is then analyzed to extract eye rotation from changes in reflections (Crane, Steele, 1985). Video based eye trackers typically use the corneal reflection (the first Purkinje image) and the center of the pupil as features to track over time.

- Electric potential measurement: This kind of eye tracker exploit the variation of the electromagnetic field generated by the relatively strong dipole composed by cornea and retina, in order to record the movement of the eye. This kind of eye tracker is not adequate for measuring slow eye movement and detecting gaze direction, due of the characteristic of the signal. However, it is proven to be a very robust technique for measuring saccadic eye movement associated with gaze shifts and detecting blinks (Lutzenberger, Rockstroh, Birbaumer, 1985).

Without regard on the kind of technology underneath the eye tracking system, eye-tracking experiments have been employed in several fields of the design realm, and in particular in interface design. The main assumption underneath the eye tracking experiment is that the most salient features of the product-interface will draw the attention of the user, which will direct his (her) gaze on them (Shagass, Roemer, and Amadeo, 1976). Noteworthy, eye tracking studies are strongly associated with usability measures. For example, Goldberg and colleagues (Goldberg, Stimson, Lewenstein, Scott, and Wichansky, 2002) used eye tracking in order to evaluate specific design features for a prototype web application. The application tested displayed independent web content through separate, rectangular, user-modifiable portlets on a web page. Seven participants took part of the study. Each of seven participants navigated across multiple web pages while conducting six specific tasks. In particular, the study investigated whether eye tracking-derived parameters depended somehow on the order of the visited pages, whether users' exploration of the pages was mainly horizontal or vertical, and whether specific sub-features of portlets were gazed with a major frequency and/or following a particular order.

When referring to eye tracker parameters, we mean those parameters identified firstly by Goldberg and Kotval (1998), and that still constitute the main information that a designer can extract from an eye-tracking experiment:

- Total scanpath length on the interface (spatial measure indicating efficiency of scanning behaviour);
- Convex hull area (spatial measure of the maximum area covered by the scanpath indicating efficiency of scanning);
- Number of backtracking saccades (spatial measure indicating whether interface matches user's expectations);
- Spatial density (spatial measure of viewing coverage of interface indicating efficiency of search);
- Transition density (spatial measure of frequency of transitions looking between objects);
- Number of saccades (temporal measure of search efficiency and ease of processing of interface);
- Number of fixations (tied to the number of saccades and so indicates similar things);

- Scanpath duration (temporal measure mainly indicating processing complexity, as proportionally more time is spent in fixations than in saccades).

- Average saccade length/amplitude (spatial measures that, used in conjunction with others, indicates extent of search and quality of layout);

- Average fixation duration (temporal measure indicating depth of processing required to understand individual objects);

- Fixation/saccade duration ratio (temporal measure indicating relative percentages of time spent processing and searching the interface).

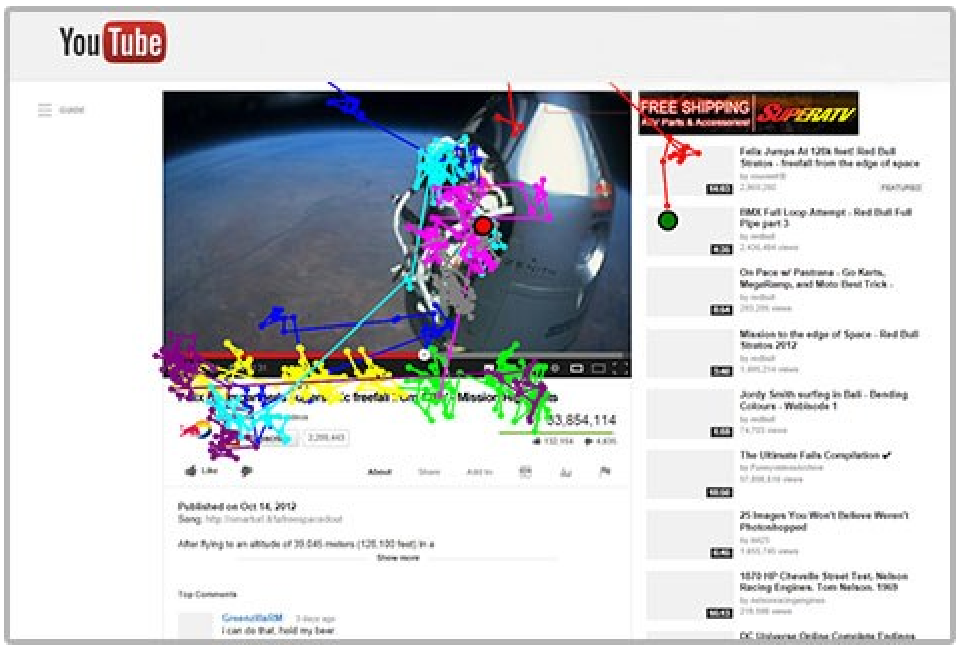

Figure 2.15: An example of representation of eye tracking data on a web page. (Source Wikipedia)

Jacob and Karn (2003) offered a systematic review of the eye-tracker studies, listing a number of works in the field of human computer interaction and highlighting, for each work, the features extracted from the eye tracking system in the study. They concluded their work stating the potential uses of the eye tracking, in terms of usability, and HCI. Recently, eye-tracking has been used in association with conjoint analysis, proving the value of a mixed approach combining the two methods (Meißner, and Decker, 2010).

Mouse tracking: with mouse tracking (also known as cursor tracking), it is possible to collect users' mouse cursor positions on the computer screen. The concept of mouse tracking is similar to the one underpinning the eye tracking. In their study, Chen and Anderson (2001) compared results from mouse tracking and eye tracking, finding strong correlations between the results achieved with the two methods. However, rather than to highlight what users “pay attention to", mouse tracking underlines what people "interact with". As obvious, mouse tracking is possible only when the product to optimize is an interface involving the use of the mouse. However, on assessing the interaction with computer interfaces, it has been proved to be complementary with eye-tracking (Chen and Anderson, 2001). Indeed, if the eye tracking can show what the subject pays attention but doesn't interact with, the mouse tracking can actually show buttons or windows that trained users' use without paying much attention.

Body tracking: Another way to study the interaction between product and user is to track part of the body (or even the whole body) when the user is interacting with the product (Slater, and Usoh, 1994). In particular, the study of the exploratory procedures of the hand when touching an object has been object of research for cognitive psychologists since years. Lederman and Klatzky (93) in particular studied the hand's patterns of exploration, called exploratory procedures (EPs), when people explore the surface of objects with their hands. These exploratory patterns are linked to specific object properties, in two respects. First, the EP associated with an object property is executed spontaneously when information about that property is desired. Second, it appears to optimize information uptake about that property. Hand tracking in nowadays possible by means of infrared tracking systems like the Vicon and Elite system (Murradius, Goulermas, and Fernando, 2003; Ferrigno, and Pedotti 1985), as well as less expensive tools like fluorescent gloves and Kinect cameras (Xia, Chen, and Aggarwal, 2011). The tracking of the user hands while interacting with object has been object of several research (Oikonomidis, Kyriazis, and Argyros, 2011; Hamer, Schindler, Koller-Meier, andVan Gool, 2009), but this research seems to focus more on the technical aspects rather than on the possible hand tracking applications in product design. As for mouse and eye tracking, hand tracking have been studied as possible way of interaction in the field of HCI (Rehg and Kanade, 1994). In this regard, the study of the exploration pattern of the hand is not dissimilar from the study of the patterns achieved by the mouse tracking.

The resulting path from the tracking of the whole body has been studied in psychology in order to spot emotional activation and mood of the subject (Bianchi-Berthouze, Cairns, Cox, Jennett, and Kim, 2006). On this extent, the body tracking could be extremely important to assess the satisfaction of the user during the interaction with a given product. In their paper, Bianchi-Berthouze and colleagues (Bianchi-Berthouze, Cairns, Cox, Jennett, and Kim, 2006) even came to argue that inducing particular postures by mean of specific HCI applications or objects can predispose the user to given emotions. Nowadays, it is possible to capture the movement and the posture of users by different systems.

- Passive optical system use retro-reflective markers to reflect light that is generated by emitters posed near the cameras lenses. The reflected light is then collected by the cameras, and the body structure of the participants is obtained by an algorithm triangulating the 3D position of each marker and matching the relative position of the marker to a stereotypical body preloaded by the computer managing the cameras (Sementille, Lourenço, Brega, and Rodello, 2004). Typically a system will consist of around 2 to 48 cameras.

• Active optical systems, instead, can triangulate the user position by illuminating one LED at a time very quickly, and identifying them by their relative positions. In fact, rather than reflecting light back that is generated externally, the markers themselves are powered to emit their own light (Maletsky, Sun, and Morton, 2007).

• Marker-less tracking systems represent a recent trend in the HCI, boosted by the video-games market (Genc, Riedel, Souvannavong, Akinlar, and Navab, 2002; Attygalle, Duff, Rikakis, and He, 2008). The major example of this kind of systems is surely represented by the Kinect by Microsoft. Kinect working is bases on a range camera technology developed by Israeli developer PrimeSense, which is able to interpret specific gestures, by using an infrared projector and camera and a special microchip to track the movement of objects and individuals in three dimensions (i.e., Frati and Prattichizzo, 2011).

Unfortunately, the potentials of the tracking of the whole body are still quite ignored by the design and interaction world. However, some significant work has been carried out in the study of the body posture to study the design of environment meant to suggest given emotions to users (i.e., Bianchi-Berthouze, Cairns, Cox, Jennett, and Kim, 2006).

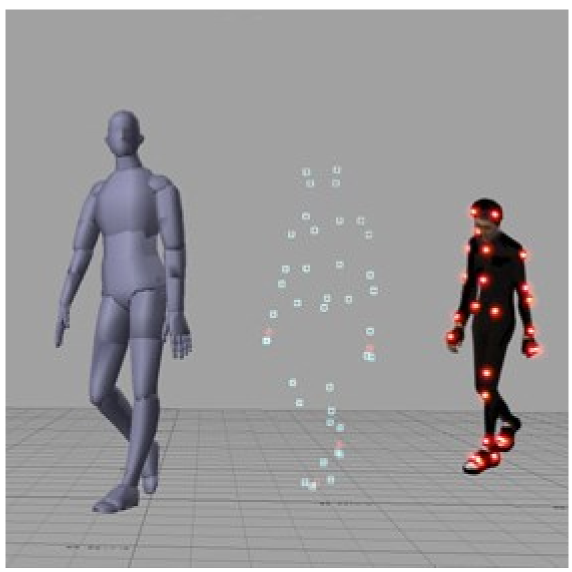

Figure 2.16: Working stages of a motion tracking system. The relative position of each marker on the user body is recorded and extracted subsequently, the body shape is re-constructed matching the position of each marker with a stereotypical body.

Finally, probably the most important tracking technology when it comes to emotions is constituted by the face tracking. Face tracking has been used to recognize emotions of users by means of facial expression recognition in several different cases, adopting different tracking techniques, from the markerless tracking (possible by means of morphing algorithms (Blanz, Basso, Poggio, and Vetter, 2003) to the adoption of active and passive optical systems. The features extracted from the tracking pattern are typically based on local spatial position or displacement of specific points and regions of the face (see for a review McKenna, Gong, Collins, 1996). For example, Kenji (1991) based his emotion recognition system on the movements of specific facial muscles. In particular, 11 windows were manually located in the face, and the muscle movements were extracted by the use of optical flow. The system was able to classify, with an accuracy of 80%, four basic emotions: happiness, anger, disgust and surprise. Yacoob and Davis (1994) proposed a dictionary to convert motions associated with edge of the mouth, eyes and eyebrows, into a linguistic, per frame, mid-level representation. They classified the six basic emotions using a rule-based system with 88% of accuracy. Tian et al. based their work on the concept of Actions Units (AU), proposed by Ekman and Friesen (1978), using permanent and transient facial features such as lip, nasolabial furrow and wrinkles (Tian, Kanade, and Cohn2000). Geometrical models were used to locate the shapes and appearances of these features. They achieved a 96% of accuracy.

However, despite the great attention given to the emotion in the modern product design, designers use to rely more in the self-assessment measures of the emotions rather than on the automatic emotion recognition by means of face tracking. This is probably due to the fact that the technology is not yet ready for a use of the facial recognition for design purposes. On the other hand, the reason could be found in the concept of Pleasure of mind (Kubovy 1999). According to this view, pleasure of mind is a hedonic emotional response raised by beauty and by interaction with pleasant objects. This kind of response is principally a cognitive conscious reaction, and therefore doesn't activate any particular recognizable physiological feature in the user.

IMPLICIT ASSOCIATION TEST

The implicit-association test (IAT) is a measure born in the late nineties in the realm of the social psychology (Greenwald, McGhee, and Schwartz, 1998). It was originally designed to detect the strength of a person's automatic association between two or more concepts.

In a typical session of IAT participants are asked to perform seven tasks (Greenwald, McGhee, and Schwartz, 1998). In the first task, a participant taking part at the IAT is asked to assign stimuli to one of two categories. For example, a person might be asked to assign a given number of names sequentially presented in the middle of the computer screen to either the word "Black" (appearing in the top left-hand corner of the computer screen) or the word "White" (appearing in the top right-hand corner of the computer screen). On the second task, the person would complete a similar experimental procedure, this time with different attributes. For example, the word "Pleasant" might now appear in the top left-hand corner of the screen and the word "Unpleasant" in the top right-hand corner. This time in the middle of the screen would appear a word to assign that would be either pleasant or unpleasant. On the third task, participants are asked to complete a combined task with both the categories and attributes from the first two tasks. In this example, the words "Black/Pleasant" might appear in the top left-hand corner while the words "White/Unpleasant" would appear in the top right-hand corner. Individuals would then see a series of stimuli in the center of the screen consisting of either names or words. They would be asked to assign them to one of the double categories written in the corners of the screen. The fourth task is a repeat of the third task but with more repetitions of the names, words, or images. The tasks from the fifth to the seventh would then be really similar to the previous, with the only exception that the words used in the first task would switch position, resulting in this way associated in different pairs in the sixth task. The seventh task is a repeat of the sixth task but with more repetitions of the names, words, or images.

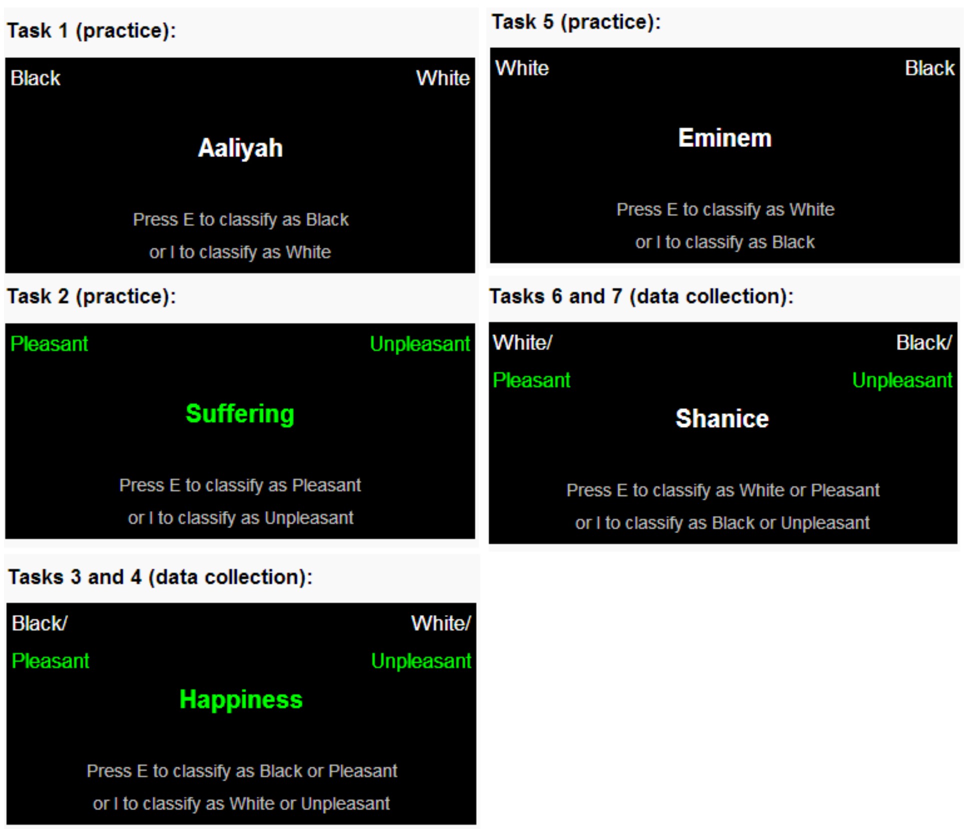

Figure 2.17: Example of the screen that might appear for each step of the Implicit Association Test

The Idea underneath the IAT is that participants to the IAT experiment would be faster to categorize items when the association between words is not “dissonant” to their implicit belief. For example in the Black/White-Pleasant/Unpleasant example (a real study, actually (McConnell, and Leibold, 2001)), a participant will be able to categorize more quickly when White and Pleasant are paired together than when Black and Pleasant are paired if he or she has more positive associations with White people than with Black people (and vice versa if Black and Pleasant are categorized more quickly).

Implicit association test has been used in the design realm in order to investigate the semantic of products and brands. For example, Parise and Spence (2012) performed a series of IAT experiments to investigate the association between packaging and specific brand attributes. In particular they tested the association of a series of attributes to bottles of mouthwash. The results highlighted the existence of an association between the bottle of Listerine mouthwash and the attribute ''powerful'' and between the bottle of Scope mouthwash and the attribute ''gentle''. The effect was confirmed by a second experiment when another group of participants were presented either with the silhouette of the bottles or the brand names and the same attributes as the first experiment.

Implicit association test has been used in association with eye tracking in (Piqueras-Fiszman, Velasco, Salgado-Montejo, and Spence, 2012), in order to collect attentional information and freely-elicited associations from consumers in response to changing specific attributes of jam jars packaging. Results of the study gave interesting insights demonstrating that certain elements of the product packaging could actually be used to drive visual attention to one element or another. However, the IAT results suggested that an important part of the associations that these formats elicited were related to the ridges or to unusualness of the packaging, suggesting that these "secondary" stimuli also captured attention.

PHYSIOLOGICAL ACTIVATION

With the development of the modern neuroscience scientific community has grown gradually more aware of the physiological signals that express (or are expressed, depending on the theory) cognitive states as awareness and involvement. Some of these measures, such as the heart rate and skin conductance, have been proven to be correlated with emotional activation in healthy people (Healey and Picard, 2005), and used to investigate the relationship between the users and the products in terms of emotional reaction (Picard, 2007).

In fact, in our every day's life we can experience the changes in our physiological states when feeling emotions. For example, fear will make our heart races, our breathing faster, our mouth drier, our muscles tense, our palms sweaty, and, in other words, our body ready to run. Biologically, these reactions are mediated by the autonomic nervous system, which controls heart muscle, smooth muscle, and exocrine glands (Kandel, Schwartz, and Jessell, 2000). The autonomic nervous system can be divided into sympathetic and parasympathetic system. The two systems are complementary, and with the somatic motor system regulate human behavioural responses, whether in normal or emergency situations. Emotional activation is most often reflected by the bodily reactions controlled by these systems. These reactions can be, thanks to the recent technology, monitored and measured achieving signals telling us the biological condition of the subjects (bio-signals). Typically, the biosignals used in order to identify the emotional states of the users are:

• Electromyography (EMG) : Electromyography provides information about the activity of muscles or about its frequency of tension. Usually this signal as interpreted as indicator of stress or high arousal states. Basically, high muscle tension is supposed to occur in stressful situation (Wei, 2013). Electromyography can use both surface sensors and needles, although for design and HCI purposes it is highly recommended the use of surface electrodes. The signal often depends on the electrodes positioning, so that the absolute level of the muscle tension and all the features related to the muscle activity depends on where the electrodes are posed on the muscle surface (Robertson, 2004).

• Electrodermal activity: the measure of the electrodermal activity (also referred to as skin conductivity (SC) or galvanic skin response (GSR)) basically represents the conductivity of the skin. Skin conductivity is mediated by the sweat of the palms, which increases under stressful situations, given the activation of the sympathetic system. This signal has been found to be sensitive in differentiating between conflict-no conflict situations or between anger and fear. Unfortunately, this signal, depending from the palm sweating, can be easily influenced by external factors such as outside temperature and therefore needs reference measurements and calibration (Lykken, and Venables, 1971).

• Skin temperature: Skin temperature is simply a measure of the temperature as measured on the surface of the skin. Skin temperature tends to slowly decrease in stressful situation, mainly because of the contraction of the blood vessels due by the muscle tension. The temperature signal is relatively slow compared with the other physiological features, and particularly sensitive to environmental factors as temperature and electrodes positioning.

• Blood volume pulse (BVP): The Blood volume pulse is the measure of amount of blood currently running though the vessels sited under a photoplethysmograph (PPG). Photoplethysmographs (PPG) consist of a sensor composed by a light emitter and a photo sensor able to record the reflection/deflection of the light emitted by the light source. Usually PPG are attached at the fingertip of the users or at their lobe, and therefore measures the change in the light that is differently deflected by the vessels running beneath the skin, accordingly to amount of blood running in the vessels. BVP can be used to measure vasoconstriction of the participant (higher under stressful situations) and its heart rate (faster and more periodic under stress) (Kandel, Schwartz, and Jessell, 2000).

• Electrocardiogram (ECG). The ECG signal represents contractile activity of the heart. It can be recorded either directly on the surface of the chest or alternatively on the limbs. In fact, recording ECG from the limbs can be more comfortable for the participants, but at the same time more vulnerable to artifacts. ECG can be used to measure heart rate (HR) and inter-beat intervals (IBI) to determine the heart rate variability (HRV). A low HRV can indicate a state of relaxation, whereas an increased HRV can indicate a potential state of mental stress or frustration (Haag, Goronzy, Schaich, and Williams, 2004).

• Respiration sensor: Respiration sensors measure how deep and fast a person is breathing. This is measured either applying a rubber band around the chest or by providing the participant with a mask around his (her) mouth and nose and recording the air flow through a sensor (Haag, Goronzy, Schaich, and Williams, 2004). Fast and deep breathing can indicate excitement such as anger or fear but sometimes also joy. Rapid shallow breathing can indicate tense anticipation including panic, fear or concentration. Slow and deep breathing indicates a relaxed resting state while slow and shallow breathing can indicate states of withdrawal, passive like depression or calm happiness.

Biosignals have been used to inspect the user reactions to products and interaction in many cases. Xian-kui and colleagues based their design methods on users' physiological signal (GSR rhythm of the heart, and the breath (Zhang, Wu, Zhang, Zhu, and Zhang, 2008) of 20 undergraduates while interacting with three different kinds of mice, achieving design information subsequently elaborated to optimize the product. Ward and colleagues used physiological reactions to evaluate web-design products (Ward, and Marsden, 2003). In particular, in their work they reported their results in their investigation focused in the recording of GSR and blood volume and heart rate (HR) in controlled computer-based situations, despite pointing out the difficulties in acquiring reliable data in uncontrolled situation as the interaction with products.

A FRAMEWORK TO RECORD PHYSIOLOGICAL ACTIVATION.

As introduced in the previous section it is possible, thanks to particular biosensors, to record the activation of our autonomic nervous system and therefore our arousal and emotional activation. In the course of this PhD research, a framework including four sensors (respiration, skin temperature, blood volume pulse, and electrodermal response) was developed in order to study the interaction between user and product in different environment.

Information about the participant physiological state was collected by four sensors (respiration, BVP, GSR, and skin temperature). Signals from each sensor were integrated by an 8 channel multimodal encoder and sent to a computer program by means of a USB connection. Both sensors and encoder were provided by Thought Technology Ltd.. The computer program was developed in the C# language and designed to collect data from the sensors at a sampling rate of 100 Hz. Data from the sensors were plotted in real-time on a main dialog window, from where the experimenter was able to control both the data acquisition and the signal quality, the sampling rate, the stimuli delivering, and finally the user feedback both via mouse and keyboard. Data plotting was accomplished using built-in functions from an open source library (ZedGraph (Yigang, 2009)). Signal management and calibration used functions included in the developer package provided by Thought Technology Ltd..

As additional feature, the program was able to open a second dialog window in a separate screen, in order to deliver visual stimuli to the users (in particular pictures, movie clips, and audio tracks). Moreover, the program was able to collect feedbacks from the participants about the feelings and sensations they were experiencing by means of different features. For example, if necessary, participants can answer to open questions or provide intensity judgment by interacting with the keyboard, and perform multiple-choice tasks using the mouse. All the user answers were stored in a buffer and printed in a text file at the program closure.

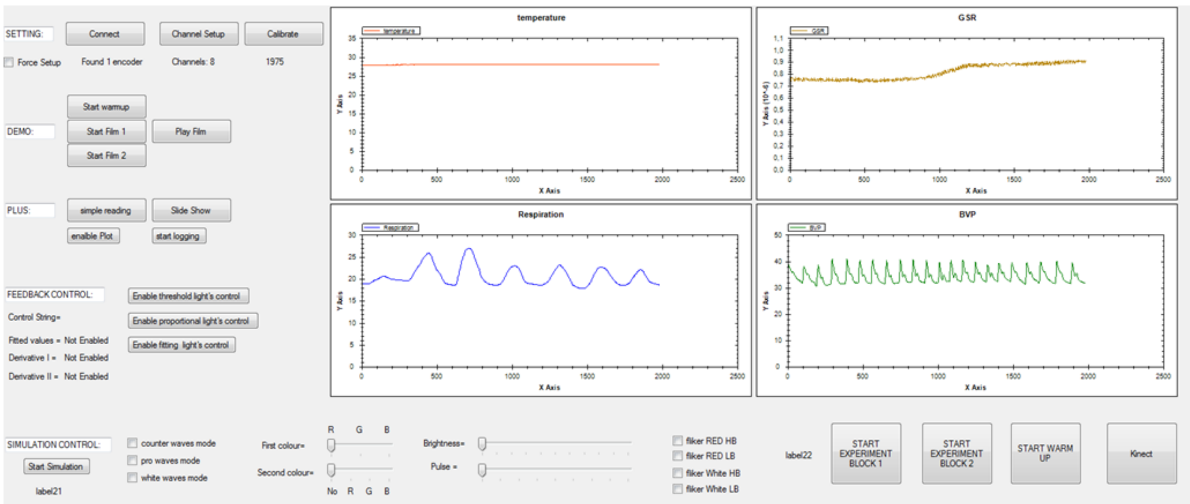

Figure 2.18: The control screen of the developed software

More interesting, the software was designed to communicate with devices able to modify the interaction experience of the users. For example, it was able to communicate through parallel port with a PHANTOM haptic device (Massie, and Salisbury, 1994). The functions to control the device were written using the OpenHaptic open source library. This particular feature of the software was used in a study investigating the effect of the haptic sensations on the emotional experience of users (Gatti, Caruso, Bordegoni, Spence, 2013). The study involved 36 participants, who were asked to complete a self-assessment test concerning their emotional state in reaction to some emotional picture, utilizing as a pointing device either a PHANToM device simulating a viscous force field while they were moving the stylus, or one with no force field. The software also recorded the various physiological parameters during the presentation of the emotional pictures. Interestingly the results revealed a significant difference in the self-reported arousal associated with the pictures but no significant difference in the physiological measures.

The software was moreover able to communicate with a led lamp through a parallel port. The lamp could change the colour of the environment and flicker at different rates, as well as synchronize (if required) with the BVP sensor in order to pulse and vary the flickering according to the heart rate. Different flickering rates and the colours of the light from the led lamp were on line changeable from the experimenter interface. Finally, it was possible to control an olfactometer using again a parallel control port. The olfactometer could open from one to eight ports, each diffusing different scents in the working environment of the user. Finally, the software could integrate the information coming from a Kinect device, in case of the experimenter was in need of perform a tracking experiment.

NEURAL ACTIVATION

As for the use of physiological reaction to products and computer interfaces, also the employment of neural imaging for the product design is an example of the merging between neuroscience and design. Again, the idea is that emotions and cognitive reactions to design products can be monitored recording the changes in our body (in this particular case, the changes in the metabolic activity in the human brain).

Nowadays different technologies are available to investigate what is going on in the human brain in terms of physiological activities. In Ariely, and Berns, (2010), a useful review of all the techniques is proposed, giving a quick introduction to functional magnetic resonance (fMRI), electroencephalography (EEG), Magneto encephalography (Meg), and transcranial magnetic stimulation (TMS)

The functional magnetic resonance (fMRI) uses an MRI scanner to measure the blood oxygenation (BOLD signal) achieving information on where and how much the brain is stimulated. The changes in the oxygenation are usually correlated with the underlying synaptic activity. fMRI is characterized by a high spatial resolution and relatively low temporal resolution. On the other hand, MRI has a substantial advantage in resolving small and deep structures of the brain. However, some important brain regions, especially the orbitofrontal cortex, are affected by signal artefacts that may reduce the ability to obtain useful information. The use of fMRI for the design of products and their packaging has been supported by different authors (Ariely, and Berns, 2010; Khalid, and Helander, 2006; Reimann, Zaichkowsky, Neuhaus, Bender, and Weber, 2010)

Another way to access the human brain activity is the electroencephalography (EEG). As opposite from the fMRI, EEG is characterized by a high temporal resolution and relatively low spatial resolution, which anyway largely depend on how many electrodes are applied in the scalp. Indeed, EEG uses electrodes applied to the scalp and measures changes in the electrical field of the brain region underneath. Jenkins, Brown, and Rutterford (2009), compared Thermographic, EEG, and Subjective Measures of during simulated product interactions, finding correlations between the three types of measures. EEG has been also associated with the Kansey engineering, together with other physiological measurements such as skin conductance, heart rate, and electromyography (Nagamachi, 1999).

Another way to monitor the brain activity is to measures changes in the magnetic fields induced by neuronal activity by magneto encephalography (MEG). Thus, MEG has the same advantage of high temporal resolution and, because the magnetic field is less distorted by the skull than is the electrical field, it has better spatial resolution than EEG. Like EEG, MEG is most sensitive to superficial cortical signals (primarily in the sulci). As a drawback MEG requires a magnetically shielded room and superconducting quantum interference detectors to measure the weak magnetic signals in the brain, which makes this tool extremely expensive.

Finally, transcranial magnetic stimulation (TMS): TMS uses an iron core, often in the shape of a toroid wrapped in electrical wire, to create a magnetic field strong enough to induce electrical currents in underlying neurons when placed on the head82. TMS can be used as a single pulse, paired pulse or repetitive stimulation, and the neuronal effects range from facilitation to inhibition of synaptic transmission. As a research tool, TMS has been used to study the causal role of specific brain regions in particular tasks by temporarily taking them 'offline'."

On summary, these imaging techniques have been proved to be of potential utility in understanding preference of user to different products, as associated to the conjoint analysis or even as a substitute of it. Evidence of this promise can be found in paper relating product and experienced pleasure. For example, Plassman, O'Doherty, Shiv, and Rangel (2007), proved how marketing actions can actually affect neural representations of experienced pleasantness. They used functional MRI on a group of participants while they tasted wines that, contrary to reality, they believed to be different and sold at different prices. Their results showed that increasing the price of a wine increased subjective reports of flavor pleasantness as well as blood-oxygen-level-dependent activity in medial orbitofrontal cortex, an area that is widely thought to encode for experienced pleasantness during experiential tasks. Willingness to pay (WTP) for a given product was also studied by fMRI. In particular, Plassman, and co-workers inspected the WTP of hungry users by means of fMRI. In the experiment, participants were offered to eat different foods. Results showed activity in the medial orbitofrontal cortex and in the dorsolateral prefrontal cortex of the subjects' WTP. Concluding, despite these studies are more related to the marketing than to the actual design of product, they show the potential in using brain imaging in order to spot some differences in the participants perception of the product, that has been indeed proven to change by changing some characteristic of the product (i.e. price) and being related with the WTP for the product itself.

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SENSORY OPTIMIZATION |THREE

This Chapter presents that part of the methodology that relates to the sensory optimization of the products. As mentioned in the previous sections, the methodology is composed by different phases. Chapter 2 presented some hints on how to ask a proper question in order to understand the demands of the client and develop a proper optimization on the product. Once the answer to the question is clear enough, the methodology suggests us to perform a study of the interaction between product and user, in order to understand what features of the product are involved in the characteristics of the product that will be the target of the optimization. The Chapter 3 lingered in explaining several methods that can achieve this purpose. The present chapter will introduce the sensorial experiment belonging to the sensory boost phase, needed to finally achieve an optimized product.

This part represents the core of the methodology. In fact, an optimized product would be able to be modified, optimized, and finally sold without going through the sensory boosting that we will expose in the present chapter. For example, it would be possible to reach an optimized product after the simple application of conjoint analysis or QFD, assuming the presence of some sort of trade-off between features to improve and/or add and the price of the product is present (Green and Srinivasan, 1978; Kowalewski, Arning, Minwegen, Ziefle, and Ascheid; Zarei, Fakhrzad, and Jamali Paghaleh, 2011). Let us imagine, for example, that the users preference for a cell-phone or a tablet was driven by the luminosity of the screen. The brighter the screen is, the more the users like the product. Let us then suppose that for each Watt of luminosity the battery of the tablet lasts a little bit less, which is obviously neither convenient nor appreciable for the user. In this case, a trade off analysis is usually performed, in order to maximize the benefit of adding luminosity and minimize the drawback of losing battery autonomy (De Corte, Sackett, and Lievens, 2011).

However, seems legit to ask: Is this trade-off that necessary? It is indeed well known in sensory sciences the relationship between background and perceived brightness (Whittle, 1973). It would be likely possible, then, instead of performing a trade-off on the tablet, change the colour or the size of the frame of the screen, augmenting its perceived brightness without influencing the battery's performance and last.

The present chapter will first introduce the five senses and how they work, to provide a complete understanding of each separate sensory modality. On this matter, the information has been majorly retrieved by the Kandel's "*principles of neural sciences"* (Kandel et al., 2001) which have to be taken as reference where not otherwise specified. Subsequently, the chapter will explain how to carry out experiments able to investigate the phenomena of perception, in order to achieve information allowing the designer to perform a product optimization of the design of the product both from a pragmatical and hedonic point of views, exploiting the integration of the information among different senses (by mean of crossmodal correspondences and psychophysical experiments) avoiding difficult trade-offs.

VISION

The visual perception of the surrounding world begins in the retina and it occurs in two main stages. At a first stage, the light reflected by objects enters the eye by the cornea and is subsequently projected onto the back of the eye, where it is transduced in an electrical signal by sensory receptors in the retina. On a second stage, signals are sent through the optic nerve to the higher centers in the brain for the further processing necessary for perception. This further processing takes place mainly in the cortex, while the first stage involves the thalamus and the eyes. The information achieved in these two stages is what allows human being to perceive form, motion, and color.

FIRST STAGE OF VISION: FROM THE RETINA TO THE VISUAL CORTEX

Vision is the most known and well-studied sense, due to the peculiar property of its sensory receptors and transduction mechanisms. In fact, rods and cones (the receptors which allows the sensory transduction of the light in electric signals) are the better understood and more observed receptors. Moreover, the retina itself is not a peripheral sensory organ (like, for example, the cochlea) but is properly part of the central nervous system, and has a similar anatomical structure. This fact allowed scientists to focus their research on the sensory transduction in the eyes in order to better understand not only the mechanisms underpinning vision, but also the overall organization of the human central nervous system.

As start, it is fascinating to notice how the unique shape of the eye is designed to deflect the light on the retina with the minimal optical distortion. In a first stage the light is deflected by the cornea and the lens in order to eventually converge on the surface of the retina. The light not converging on the retina is absorbed by the black melanin filling the pigment epithelium. This prevents the light from being reflected back blurring the image of the surrounding world.

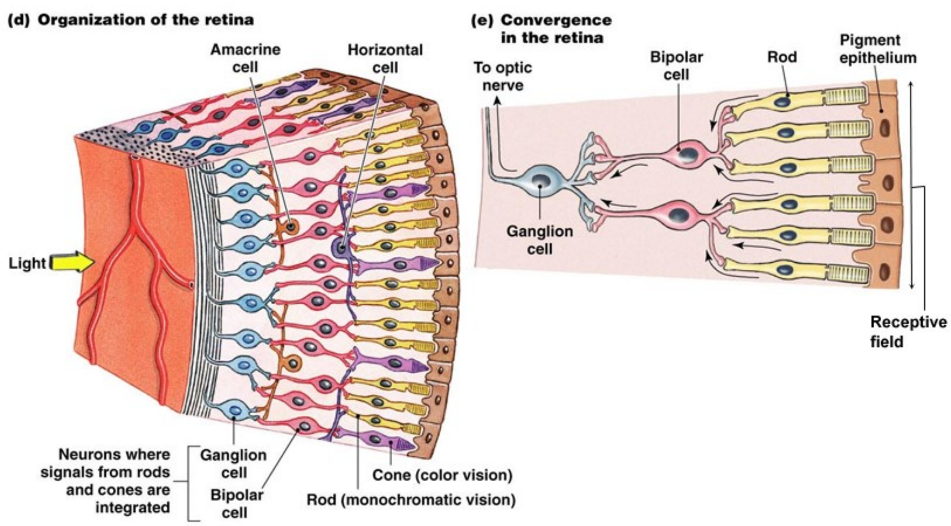


Figure 3.1: An image of the retina. Copyright Pearson Education 2007 ©. From Kandel, Schwartz, and Jessell (2007).

In the eye, the photoreceptors (the visual receptors, rods and cones) are positioned immediately in front of the pigment epithelium. All other retinal cells are in turn positioned in front of the photoreceptors, closer to the lens (Figure 4.1). In fact, light have to travel through two layers of retinal neurons before being collected by the photoreceptors. However, the axons of the neurons in the proximal layers of the retina are unmyelinated, with the result that these layers of cells are relatively transparent. This allows light to reach the photoreceptors without being absorbed or greatly scattered.

Noteworthy, concentration of receptors in the retina is not uniform. In the fovea, for example, the concentration of cones is higher than in the rest of the eye, and the cell bodies of the proximal retinal neurons are shifted to the side, enabling the photoreceptors to receive the visual image in its least distorted form. This shifting is even most pronounced at the foveola, the center of the fovea. The retina also contains the optic disc, a region where the fibers belonging to the optic nerves leave the retina. This region has no photoreceptors, and is therefore a blind spot in the visual field.

As previously mentioned, the human retina contains two different types of photoreceptors, rods and cones. Whereas cones are mainly responsible for daily vision, rods can work in conditions of poor light. Differences between cones and rods also involve their the colour sensitivity. Indeed, while rods respond really fast to any wavelength of light without any difference, in the eye three different kinds of cones respond selectively (although not so quickly) to different wavelengths in the lights spectrum, mediating the vision of colours. Moreover, cones are closer to each other than rods, and their distribution is particularly dense within the fovea, making them responsible for high spatial resolution vision.

When the light strikes cones and rods, these receptors send a signal to the bipolar cells, which in turn communicate with the ganglion cells which axons compose the optic nerve. Noteworthy, ganglion cells are characterized by a center-surround receptive field, which make them respond weakly to uniform illumination. Details about the structure of the cells in the visual pathways are not the aim of this section. However, it is useful to know that, in general, given their properties, report principally the contrasts in light, rather than its absolute intensity.

From the optic nerve, the neurons' signals run a rather complex pathway. Half of the fibers from each eye (the ones coming from the half of the eye closer to the nose), cross on the other side of the head, joining the fibers coming from the outer part of the other side's eye, creating the so-called optic chiasm. Different axons in the optic tract project to different layers of the right lateral geniculate nucleus (LGN) in the thalamus, creating a complete representation of the visual hemifield. (Figure 4.2). In the thalamus, morphological differences reflect functional differences. In particular, different layers of the LGN welcome axons from different ganglion cells, giving birth to the magnocellular (M) and parvocellular (P) pathways. The cells in the geniculate nucleus belonging to the parvocellular pathway respond to changes in color (red/green and blue/yellow) regardless of the relative brightness of the colors, whereas the ones belonging to the magnocellular pathway respond weakly to changes of color when the brightness of the color is matched. From the LGN of the thalamus the axons of the neurons finally reach the primary visual cortex.

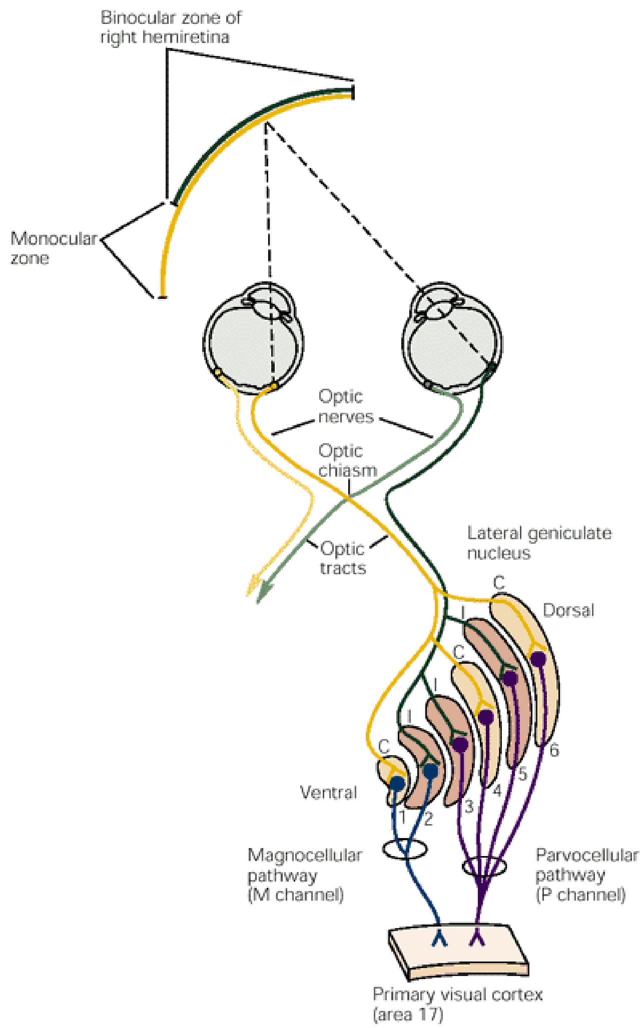


Figure 3.2: the visual pathway from the eye to the primary visual corte. From Kandel, Schwartz, and Jessell (2007).

THE SECOND STAGE OF VISION: VISION IN THE CORTEX

At its first station in the cortex, the visual signal is processed by cells which present significant differences from the ones constituting the visual pathway coming from the retina. These cells are enclosed in a region of the brain called primary visual cortex (V1, or striate cortex because of its aspect). This region appears to be composed by lighter and darker stripes, an appearance given by the stria of Gennari (made by unmyelinated fibers) running through it. As it happened in the LGN, in the visual cortex each cerebral hemisphere receives information concerning the contralateral half of the visual field. However, it has been proved that cells in the layers 5 and 6 of the visual cortex respond preferentially to stimuli that are more complex than those able to elicit a response in the previous stages of the visual processes.

Cells in V1 belong to two main groups, simple and complex. Simple cells properties make possible for them to best respond to bars of light with specific orientations. For example, a cell that responds optimally to a vertical bar will not respond, or will respond only weakly, to a bar that is horizontal or even oblique. That means, that primary visual cortex has cells responding in a different way to the same stimulus presented in the retina. Moreover, the response of these cells (organized in arrays), allows V1 to recognize potentially every orientation of the stimuli presented in the visual field.

On the other hands, although complex cells' receptive field also have a critical axis of orientation, their receptive fields are usually larger, and the precise position of the stimulus within the receptive field is less crucial, making them able to generalize and discharge for a higher number of visual stimuli. These cells are organized in columns, so that neurons with similar receptive fields are all grouped in the same column. More columns can be grouped within a hypercolumn, so that hypercolumn is responsive to lines of all orientations from a particular region in space, representing, in fact, whole regions of the visual field.

From V1 then the information collected by the eyes splits into two main pathways. The two pathways reflect the division between magnocellular and parvocellular pathways present in the thalamus. This division is meaningful also from a functional point of view, since the two pathways relate to different properties of the visual stimuli. In fact, M pathway (dorsal or parietal pathway),is the responsible for the movement and the temporal information related to the visual field. The inputs from the P pathway are instead coded in the temporal region of the brain (ventral pathway), and are more responsible for the spatial information of the object in the visual field. P pathway also codes for shapes, colours, and object recognitions. However, it is important to note that the cross connections between the ventral and dorsal pathways does not completely reflect the division between P and M cells. In fact, the parietal pathway also receives input from the P pathway, as the temporal pathway receives some inputs from the M pathway (Figure 4.3).

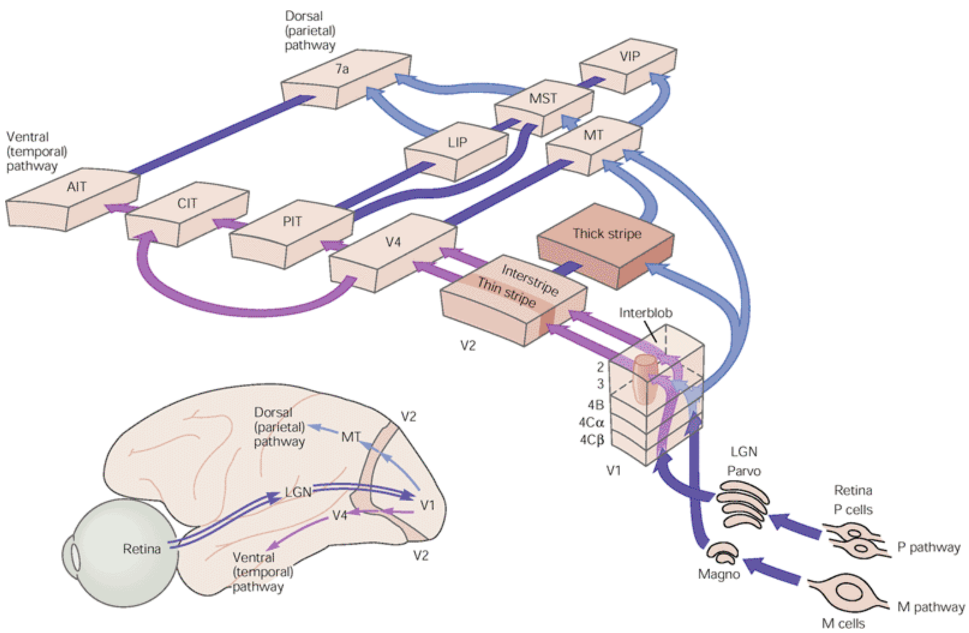


Figure 3.3: the complete visual pathway from the ganglion cells to the cortex. From Kandel, Schwartz, and Jessell (2007).

VISION AS A CREATIVE PROCESS

It is extremely important, apart from the neural pathways and the fashion the visual information is represented in our brain, to keep in mind that the visual process (and, more in general, all the perceptual processes) is actually a creative process. The gradual elaboration of the visual field and the specialization of dorsal and ventral pathways (with the dedicated areas for shape, motion, colour, etc.) just reflect the immense complexity of the visual system.

When we move, drive a car, or even when the ambient illumination slightly changes, also the size, shape, and brightness of the images that are e projected on our retina change. Yet under most conditions humans are not able to perceive a change in the object. In fact, we have a stable perception of the object. When an object is moving toward us, we perceive it as “coming closer”, while what is happening on our retina is actually the object “growing larger”. If from outdoor in a sunny day we move into a camping tent, or even into a house, the intensity of the light reaching the retina may vary by thousands of units. Yet the colour of our shirt will still look the same. Our ability to perceive an object's size or color as constant illustrates the remarkable flexibility of our visual system, which does not simply record images passively like a camera, and is instead able to transforms transient light patterns on the retina into a coherent and stable interpretation of a three-dimensional world.

This process is clearly active rather than passive. In the modern view, perception is not atomistic but holistic. Visual perception is indeed an active and creative process that involves more than just the information provided by the retina. This evidence was first emphasized in the early twentieth century by the German psychologists Max Wertheimer, Kurt Koffka, and Wolfgang Köhler, who founded the school of Gestalt psychology.

The term Gestalt literally means configuration or form. According to the Gestalt's psychologists perception is not just a passive process, but what we see reflects instead the organization of sensations in the brain. The Gestalt psychologists sustained the hypothesis that the brain actively creates three-dimensional experiences from two-dimensional images. This process is achieved, according to their theory, organizing sensations into stable patterns (called Gestalts) constant despite the variability of the information received. In particular, the visual system accomplishes this "effect" by processing sensory information about the shape, color, distance, and movement of objects according to computational rules that are inherent in the system. That means that the brain makes certain assumptions about what is to be seen in the world, expectations that seem to derive in part from experience and in part from the built-in neural wiring for vision.

Gestalt psychology is well known for grouping the rules guiding our way to see the world, and for organizing them into principles. In particular, they explained such principles referring to optical illusions, which are defined by gestalt's psychologists as "misreadings" of visual information by the brain. For example, in the classic Müller-Lyer illusion two lines of equal length look unequal. As it is characteristic of many illusions, knowing that the lines are equal does not prevent us from being fooled by this illusion time and again. We perceive the lines to be unequal because the brain uses shape as an indicator of size. Gestalt psychology is still valid, and most of the rules and illusions can be explained looking at the neuroanatomical structures in our brain (i.e.: Hain, 1964).

IMPLICATIONS FOR PRODUCT DESIGN

Although the information contained in this section can be incomplete from a neuroscientific point of view, and even too detailed from the point of view of a designer, this is extremely related to the design realm and the product development and optimization. As a matter of fact, it might be important for a designer to know that our brain perceives the surrounding world separating spatial and temporal information. At the same time, the organization in column and hypercolumns should suggest to the designers that edges and contrasts are extremely important for perceiving objects in our visual system, and this importance is highlighted by the very early specialization of the cells.

TOUCH AND PROPRIOCEPTION: THE HAPTIC SENSE

With the term "haptic" we refer to the sensory system that uses sensory information derived both from mechanoreceptors and thermoreceptors embedded in the skin ("cutaneous" inputs) together with the information achieved from mechanoreceptors embedded in muscles, tendons, and joints ("kinesthetic" inputs). It is important to note the differences from the simple touch, which involves only the application of various stimuli (hairs, sharp probes, warm and cool metal tips, etc.) to the skin of a passive observer, limiting inputs to those of the cutaneous receptors.

This distinction was first pointed out by J. J. Gibson (1962). Gibson distinguished between two tactual experiences: the passive touch, which is being passively touched, and active touch, which is the act of touching. In passive touch, people tend to focus on their subjective bodily sensations. During the active exploration, instead, the observer's attention is directed to the properties of the external environment. Inputs from the cutaneous receptors seem suffice to explain the perception of the passive-touch sensations, and also have a crucial role when active exploration is involved.

Cutaneous receptors are located across the entire body surface, beneath both hairy and hairless skin. However, the majority of studies on haptic perception have focused on mechanoreceptors located within the hairless ("glabrous") skin, and in particular on the human hand (Jones and Lederman, 2006). In the glabrous skin, humans have four main types of receptors, located at different depth, each having different characteristics in terms of receptive field and adaptation (i.e., response to onset/offset of skin deformation vs. continued response during sustained skin deformation). Figure 4.4 shows the receptors location in the skin. Each receptor is associated with different fibers carrying the information about the deformation of the skin that actually make the receptors discharge. In particular, Merkel receptors are connected with Slow-adapting type I (SA I) fibers, and cover a small receptive area. Meissner receptors share with the Merkel receptors the small receptive area, but are instead connected with Fast-adapting type I (FA I) fibers. Slow adapting fiber and large receptive fields are instead typical of Ruffini receptors, while Pacian receptors are characterized by Fast-adapting type II (FA II) and large receptive field.

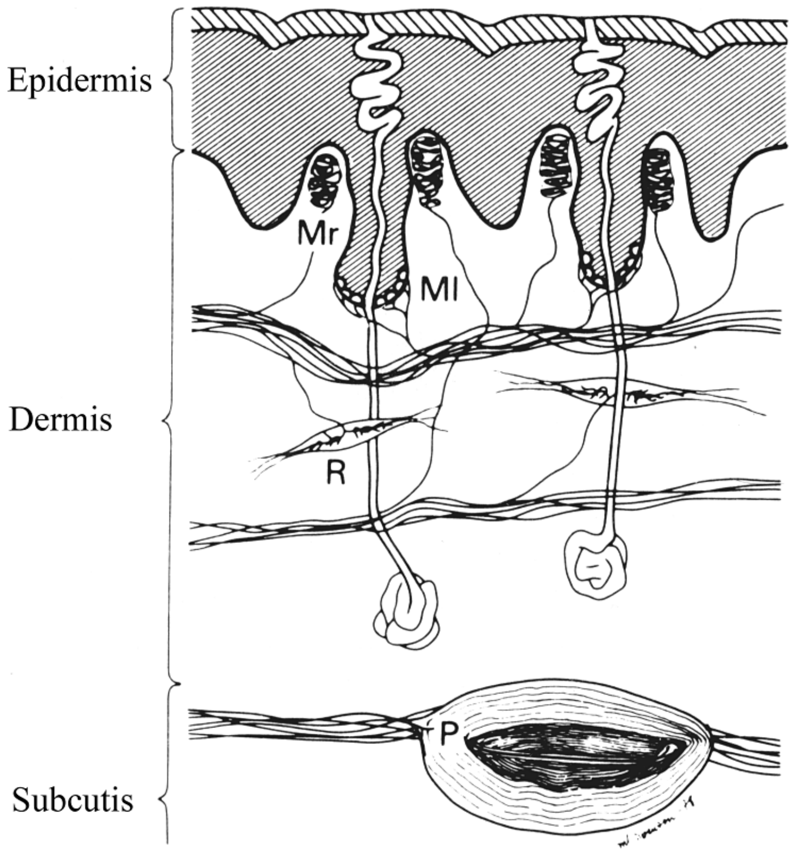


Figure 3.4. Vertical section through the glabrous skin of the human hand. Schematic depiction of the two major layers of the skin (epidermis and dermis), and the underlying subcutaneous tissue. The locations of the organized nerve terminals are also shown. Mr, Meissner corpuscle; Ml, Merkel cell complex; R, R Ruffini ending; P, Pacian corpuscle. From "Tactile Sensory Coding in the Glabrous Skin of the Human Hand," by R. S. Johansson and A. B. Vallbo, 1983, Trends in Neurosciences, 6, p. 28. Copyright 1983 by Elsevier. Reprinted with permission.

The two additional peripheral receptor populations known as thermoreceptors (Stevens, 1991) respond to increase or decrease in skin temperature, and mediate the human experiences of warmth and cold, respectively.

Finally, the kinesthetic inputs from mechanoreceptors in muscles, tendons, and joints contribute to the human perception of limb position and limb movement in space (see for a review Gandevia, 1996; Taylor, 2009). In particular, two main populations of kinaesthetic receptor have been found: Golgi Tendon Organs (GTO) and the muscle spindles (MS). The Golgi tendon organs are strands of collagen connected at one end to the muscle fibers and with the other end merged into the tendon. Each tendon organ is innervated by a single type sensory nerve fiber (Ib afferent) that branches and then terminates with several endings wrapped in a spiral around the collagen strands. When the muscle stretches, its stretching deforms the terminals of the afferent axon, evoking the sensory signal. Golgi tendon organs allow us to sense changes in muscle tension, and are particularly sensitive when the muscle is stretched. They respond primarily to the passive stretching of the muscle.

Muscle spindles are instead located within the belly of the muscles, embedded in the muscle fibres and, as the Golgi tendon organs, primarily detect changes in the length of this muscle. However, muscle spindles are particularly sensitive to active muscle stretching. The anatomical composition of a muscle spindle is rather more complex than the GTO's one. The muscle spindle is composed of several intrafusal muscle fibres. Two different types of afferent sensory endings, (group Ia group II) coil around the non-contractile central portions of the intrafusal fibres. When Gamma motoneurons activate the intrafusal muscle fibres, they change the resting firing rate and stretch-sensitivity of the afferents, informing the brain of the muscle stretch.

HAPTIC REPRESENTATION IN THE BRAIN

Information from the mechanoceptors in the skin travels within the fibers until the spinal cord, where they cross creating a chiasm. After the crossing, fibers run to the thalamus, and finally end up in the somatosensory cortex, on the parietal lobe.

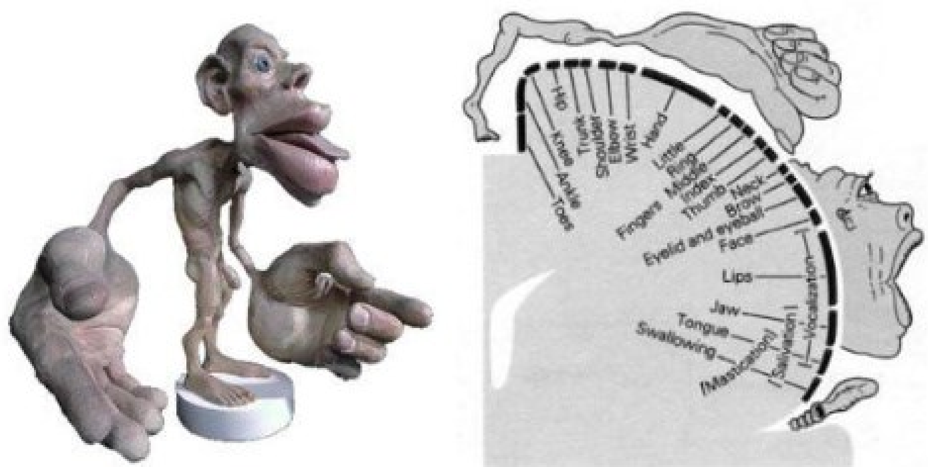


Figure 3.5: the Penfield homunculus. From Kandel, Schwartz, and Jessell (2007).

In a rather fascinating way, information originally achieved from receptor close to each other's project to close neuron in the brain, so that the somatosensory area can be divided into different zones, each one collecting information from the same part of the body. A representation of the body can then be achieved from the cortical representation of the somatosensory perception. However, since not all the part of the body has the same density of receptors, the obtained figure is far from resemble a human being (Figure 4.5).

Moreover, apart from the somatosensory representation of the tactile perception (which is, actually, more related to passive touch), a recent debate evidenced how the cortical representation of haptic stimuli might reflect the same organization seen in vision, showing a preferential pathway for spatial information ("what" pathway), and another one for temporal information (the “where” pathway). Indeed, touch scientists have been recently and vigorously debating whether, like vision (and audition), the somatosensory system is served by two subsystems, a “what” system that deals with perceptual (and memory) functions, and a “where” system related to movement that deals with the perceptual guidance of action. Evidence supporting a “what/where” distinction for the somatosensory system includes, for example, fMRI and behavioral studies by Reed, Klatzky, and Halgren (2005) and by Chan and Newell (2008).

Respectively Reed and colleagues (Reed et al., 2005) showed that haptic object recognition and object localization activated inferior and superior parietal areas respectively, suggesting a correlation with the distinction between dorsal and ventral visual streams made earlier by Ungerleider and Mishkin (1982). Chan and Newell (2008) showed behavioral evidence for a task-dependent what/where distinction that transcends modalities by using a dual-task paradigm. Simultaneous “what” or “where” tasks were found to mutually interfere more than crossfunction asks in both intramodal and crossmodal conditions, indicating resource pools that depended on the task demands but not on the modality (vision, haptics) used to execute the task. Dijkerman and De Haan (2007) have comprehensively evaluated the neural and behavioral literatures for evidence of separate processing streams used for somatosensory perception versus action (“what” vs. “where” systems), as well as for distinguishing between haptic processing of external targets and sites on the body.

EXPLORATORY PROCEDURES IN HAPTIC

Ledermann and Klatzky deeply studied the interaction with objects, and in particular the way people explore surfaces using the haptic sense. This kind of research can represent a very useful source of information for the designers, which always have to deal with the interaction between user and object.

Lederman and Klatzky (1987) have described a systematic relationship between exploration and object properties in the form of a set of exploratory procedures (EPs), of which the most intensively investigated are depicted in Figure 4.6.

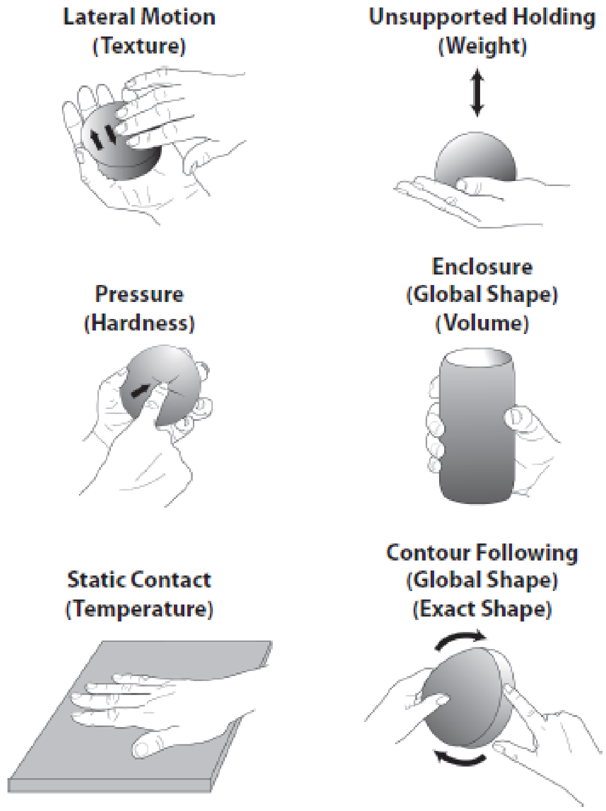


Figure 3.6: Depiction of six manual "exploratory procedures" and their associated object properties (in parentheses). From "Hand Movements: A Window Into Haptic Object Recognition," by S. J. Lederman and R. L. Klatzky, 1987, Cognitive Psychology, 19, p. 346. Copyright 1987 by Elsevier.

In their view, an EP is a stereotyped pattern of manual exploration, which is observed when people are asked to learn about a particular object property. It occurs during voluntary manual exploration, both with and without vision, although vision has been found to alter some of the EPs. For example, the EP associated with queries about apparent warmth or coolness is "static contact," which involves put in contact a large skin surface against an object without motion. Other EPs that have received most attention in the haptic research literature are "enclosure" (volume; coarse shape) ,"pressure" (associated with compliance), "contour following" (precise shape), "unsupported holding" (weight), , and "lateral motion" (texture), .

A further classification of Exploratory Procedures is characterized not by their stereotyped motor actions, but by what those actions accomplish at neural and computational levels. In general, the EP associated with a property tends to optimize the activation of a set of associated neural receptors, thereby facilitating the computational mechanisms invoked by those receptors. An example of this relationship between EPs, neural output, and computation, is the perception of roughness. As EP, the lateral motion of the finger moves the skin tangentially across a surface, therefore enhancing the responses of SA I mechanoreceptors (Johnson and Lamb,

1981) and creating deep vibrations that activate the PCs (Bensmaïa and Hollins, 2003). These two precise neural systems are thought to provide the input to the computation of perceived roughness at the SA I in a macro scale, PCs I a micro scale (Bensmaïa and Hollins, 2005; D. T. Blake, Hsaio, and Johnson, 1997).

IMPLICATIONS FOR PRODUCT DESIGN

The implications for product design are extremely relevant when it comes to haptic sense. As first, haptic technology plays a major role in virtual prototyping (Seth, Vance, and Oliver 2011). In particular, haptic products can help touching virtual prototypes, making the interaction with the virtual object more realistic. Moreover, understanding the haptic sensory system means to understand the principal channel costumers use to relate with products. haptic information has been seen to be relevant in the choice of products and in the assessment of the quality of products. Understanding and knowing how to elicit a given haptic sensation in the user could mean to the difference from an appealing and successful product and a design fail.

HEARING

When people hear sounds from the surrounding world, what they do is nothing else than transforming small variation of the pressure of the air in meaningful information. This process starts from the external ear, and especially from the prominent auricle, which focuses the sound into the external auditory meatus. The alternating decreases and increases in the pressure of the air provoke the vibrations of the tympanum. These vibrations are conveyed across the middle ear by three linked bones: the malleus, the incus, and the stapes. Vibration of the stapes stimulates the cochlea, the proper sensory organ of the inner ear, where the sensory transduction happens (Figure 4.7).

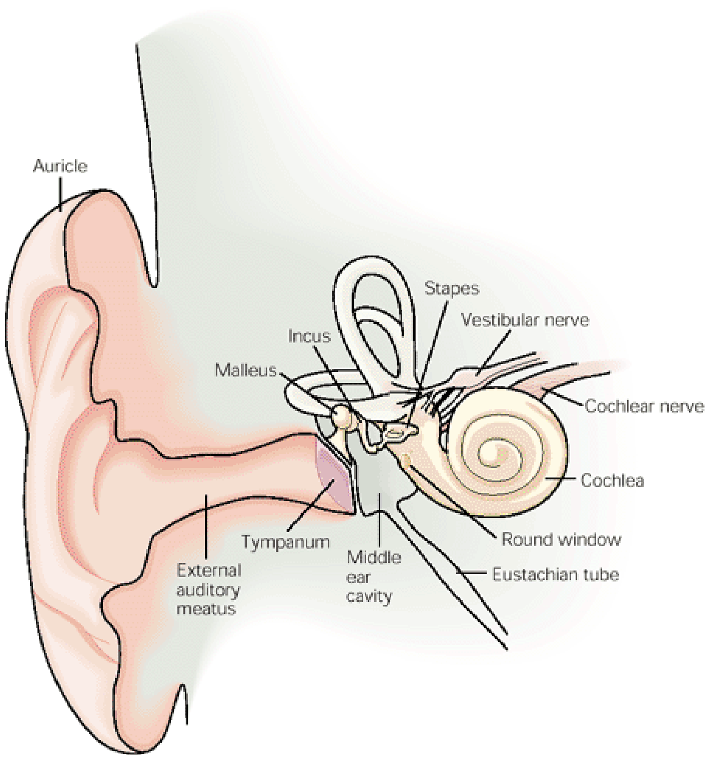


Figure 3.7: structure of the ear (Adapted from Noback 1967). From Kandel, Schwartz, and Jessell (2007).

In particular, in the cochlea, the sensory transduction happened in the organ of Corti. The organ of Corti contains the principal sensory receptors for the hearing function (the hair cells) plus different kinds of other supporting cells. Its structure can be seen in figure 4.8. The hair cells in each organ of Corti are innervated by about 30,000 afferent nerve fibers, which carry information into the brain along the eighth cranial nerve. Interesting, along the basilar membrane, hair cells in given positions are optimally sensitive to particular frequencies, which are logarithmically mapped in ascending order from the cochlea's apex to its base. This means that the hair cells human cochlea is tonotopically organized.

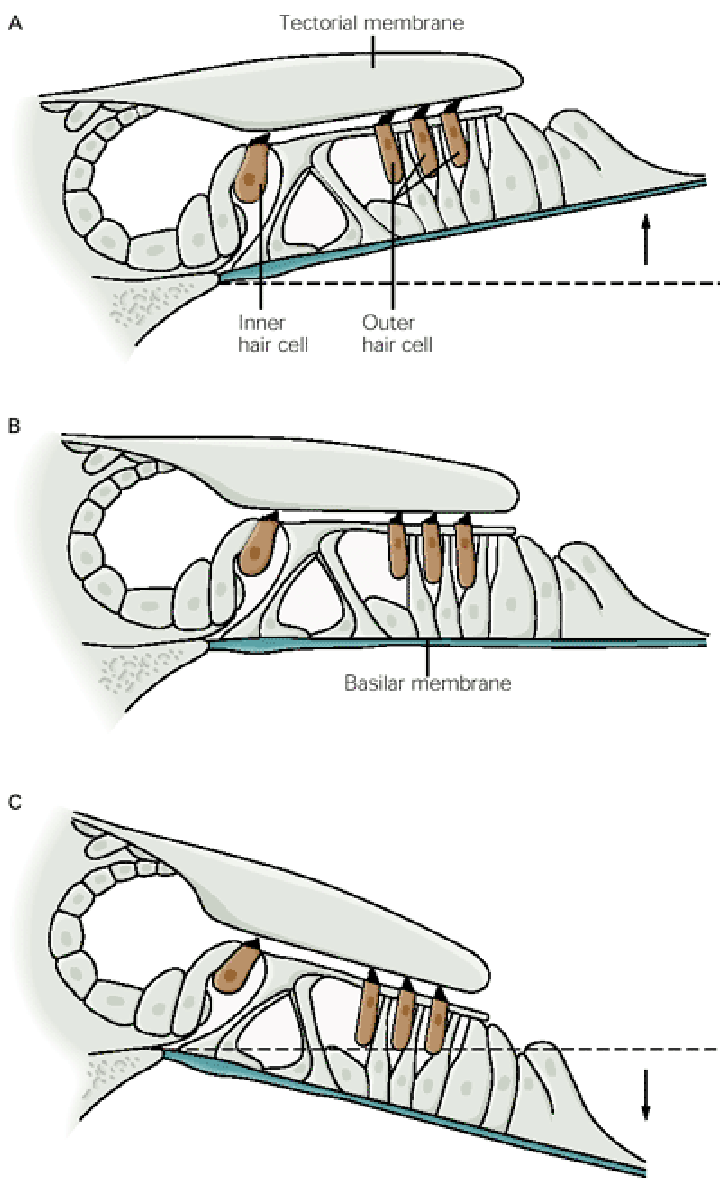


Figure 3.8: The organ of Corti and its deflection after mechanical stimulation. (Adapted from Miller and Towe 1979.). From Kandel, Schwartz, and Jessell (2007).

In the organ of Corti there are two varieties of hair cells. On its inner part, the organ of Corti a single row of approximately 3500 hair cells. Farther from the helical axis of the cochlear spiral, instead, lie about 12,000 hair cells organized in three (sometimes four) rows. The principles of functioning of hair cells have been studied for many years. By evaluating the geometry of the inner ear, scientists have come to the conclusion that, when the basilar membrane vibrates in response to a sound, the organ of Corti and the overlying tectorial membrane are carried with it. Since the basilar and tectorial membranes pivot about different lines of insertion, their displacements are accompanied by back-and-forth motions between the upper surface of the organ of Corti and the lower surface of the tectorial membrane. The bundles of the air cells bridge that gap, being therefore deflected by the oscillations.

The mechanical deflection of the hair bundle is able to excite the hair cell of the cochlea. In fact, this deflection is transduced into a receptor potential. again basing on the morphological characteristics of the organ of Corti, researchers hypothesized that an upward movement of the basilar membrane depolarize the cells, whereas a downward deflection elicits hyperpolarization, making them less sensitive.

HEARING IN THE BRAIN

Axons from the neurons in the cochlear nucleus run on three main pathways: the trapezoid body, the intermediate acoustic stria, and the dorsal acoustic stria. Information regarding the inputs from both the two ears meet in the superior olivary nucleus, which receives input via the trapezoid body. This allows the medial and lateral divisions of the superior olivary nucleus to accont for the localization of sounds in space. In particular, this nucleus' function is basically to compute the delay from the signal coming from the two ears, triangulating the position of the sound source in space.

From the superior olivary nucleus, along with axons from the cochlear nuclei, axons project to the midbrain (in particular to the inferior colliculus) via lateral lemniscus, which collects axons delivering input from both ears. From the midbrain neural inputs travel to the medial geniculate nucleus of the thalamus. The geniculate axons then terminate in the primary auditory cortex (Brodmann's areas 41 and 42), a part of the superior temporal gyrus (Figure 4.9).

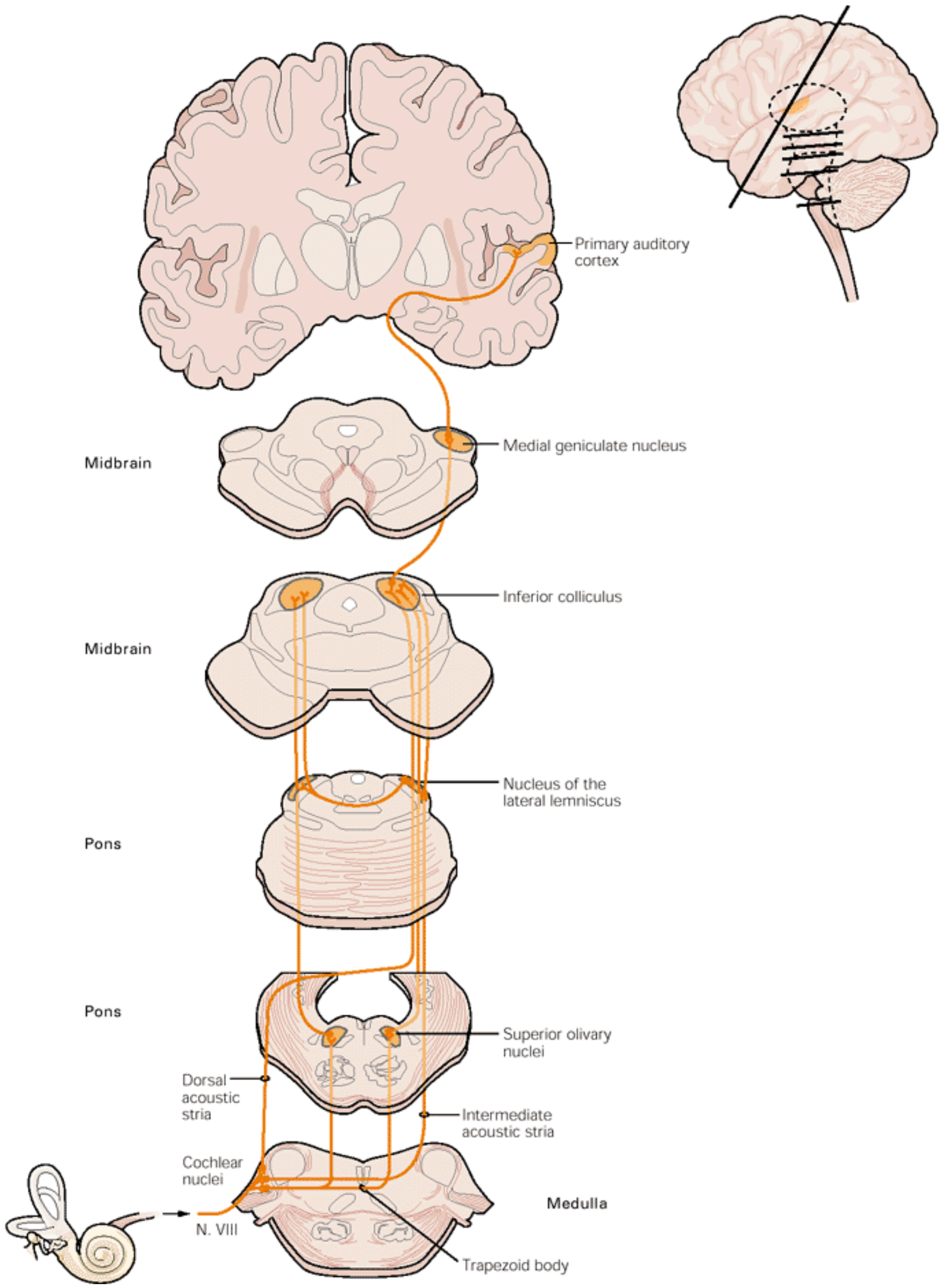


Figure 3.9: from the cochlea to the primary auditory cortex. From Kandel, Schwartz, and Jessell (2007).

In the primary auditory cortex, neurons are mostly responsive to stimulation through either ear. However, these neurons does not have identical sensitivity. In particular, in half of these strips (known as "summation columns") neurons are excited by stimulation of either ear (EE cells), though the contralateral input is usually stronger than the ipsilateral contribution. The other kind of neurons instead, grouped in "suppression columns", are excited by a unilateral input but inhibited by stimulation of the opposite ear (EI cells). In fact, hypothetically dividing the primary auditory cortex in two axis, it is possible to have the summation and suppression columns extending at right angles to the axis of the tonotopic mapping, showing that the primary auditory cortex is partitioned into columns responsive to every audible frequency and to each type of interaural interaction.

The primary auditory area is surrounded by several distinct regions involved with the elaboration of particular types of auditory information, most of which are organized in tonotopic maps reflecting the frequencies of different stimuli. However, despite some aspects of the human auditory perception in the brain have been unfolded, there is still a lot of debate on some of the major cognitive functions involving sound processing. In particular, one of the most important aspect of hearing is its role in processing and understanding language. Although we know pretty much about the neural processing of sound in general, little is known, in comparison, on how speech sounds are processed: This also because it is not possible to test language processing in any experimental animal.

IMPLICATIONS FOR PRODUCT DESIGN

The implication of the physiology of hearing for the product design mainly involves the device cable of producing sound, like MP3 reader, speaker, and devices that are designed to carry the sound, like headphones. It has wide application on virtual prototyping to, in case the prototype of the object to build had an important acoustic component. Let’s take for example the case of a washing machine, which produces noise when working. It is important for the designer to know which frequencies of the sound are perceived by the human brain, which are considered more annoying, and, in case, how to suppress them. At the same time a virtual prototype could be designed as fixed in space, and in order to make the virtual experience the most real possible, it is useful to know that the location of the sound depends by the delay of the input between the two ears.

SMELL

Humans and in general other mammals are capable of discriminating between lot of different odors . Although the olfactory capability of humans is relatively limited, if compared with that of some other animal, we are nevertheless capable to perceive thousands of different odorants (odorous molecules). For example, perfumers, who are highly trained to discriminate odorants, claim that they can distinguish about 5000 different types of scents, as some wine tasters report to be able to distinguish between more than 100 different components of taste, recognizing different combinations of flavor and aroma.

The perception of odorants starts in specialized sensory cells that relay information to the brain. These sensory cells are the olfactory sensory neurons. Olfactory sensory neurons lie in the back of the nasal cavity, within a specialized neuroepithelium (the olfactory epithelium), which is a small patch of specialized epithelium covering, in humans, a relatively big region in the back of the nasal cavity about 5 cm^2 in size. In the human olfactory epithelium, a great number of olfactory sensory neurons are interspersed with specialized supporting cells. A peculiar characteristic of olfactory neuronsis their average life span: Only 30-60. Indeed, Olfactory neurons are continuously replaced from the basal stem cell population.

In fact, the olfactory sensory neuron is, morphologically, a bipolar nerve cell. Its apical pole presents a single dendrite connected to the epithelial surface. The end of this dendrite expands into a large knob, and this knob thin cilia protrude into the layer of mucus that cover the olfactory epithelium. The axon of each olfactory neuron project through the bony cribriform plate above the nasal cavity to the olfactory bulb, forming synapses with olfactory bulb neurons that send signals to the olfactory cortex (Figure 4.10).

Interestingly, the olfactory system has been shown to be a highly specialized system, with the cilia having specific receptors for odorants. Moreover, each receptor is in turn connected with a specialized olfactory neuron, allowing a segregation of the olfactory information, so that all the receptors connected to a neuron will be of the same kind. The appropriate molecular and ionic environment for odor detection is provided by the mucus, which has also been proved to contain soluble odorant-binding proteins, which might help the cilia and the receptors to perceive the odours in the same way the melanine on the back of the eyes helps the visual perception.

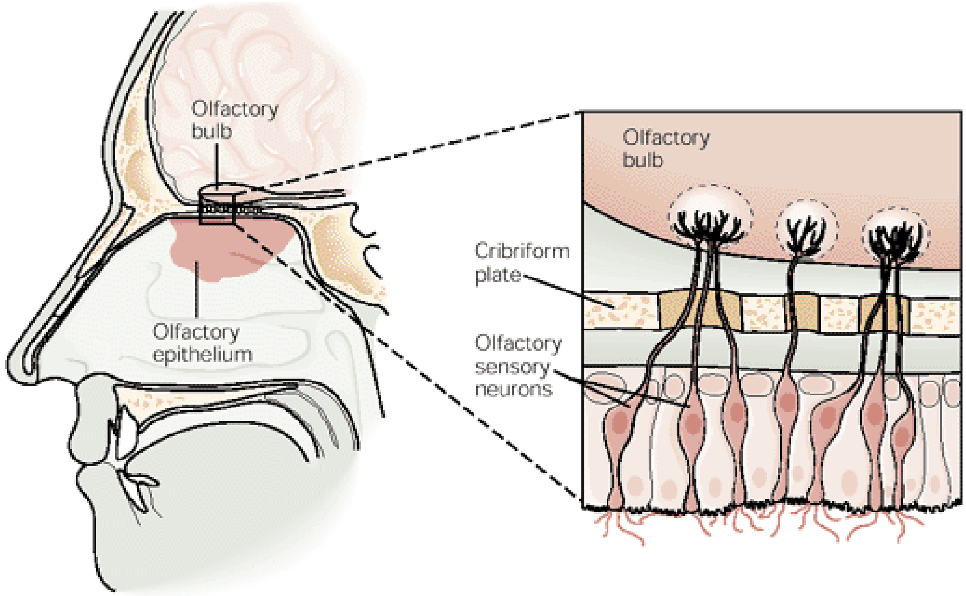


Figure 3.10: Olfactory sensory neurons are embedded in a small area of specialized epithelium in the dorsal posterior recess of the nasal cavity. These neurons project axons to the olfactory bulb of the brain, a small ovoid structure that rests on the cribriform plate of the ethmoid bone. (from Kandel et al. 2000). From Kandel, Schwartz, and Jessell (2007).

SMELL IN THE BRAIN

Above and behind the nasal cavities lie the olfactory bulbs, where the sensory information from the nose is transmitted. In particular, neurons from the olfactory tract connect to structures called glomeruli in the bulbs. The role of glomeruli has being thought to serve as functional unit, in the sense that information concerning different odorants could be mapped onto different glomeruli. This hypothesis is supported by experimental evidences on animals from in-vivo recordings. Animals were indeed exposed to different odorants while recording the activity of a single mitral cell (a typology of cells in the glomeruli that receive information from the axons of olfactory receptor neurons). Recordings showed that mitral cells do respond to a variety of odorants, but also that usually mitral cells connected to different glomeruli respond to a close set of odorants. Therefore, it appears that each glomerulus may receive input from only one type of receptor. Remarkably, glomeruli which differs in the type of olfactory stimuli they respond to have the same relative locations in the olfactory bulbs of different animals. Thus, it seems that at the level of the olfactory bulb, sensory neurons express a stereo-typed spatial map of sensory information, which is formed by different odorant receptors projecting to different glomeruli.

From the olfactory bulb, neurons relay through the lateral olfactory tract to the olfactory cortex. The olfactory cortex can be roughly defined as the portion of the cortex that receives a direct projection from the olfactory bulb. The olfactory cortex is divided into five areas: The anterior olfactory nucleus, which connects the two olfactory bulbs through a portion of the anterior commissure; the olfactory tubercle; parts of the amygdala; the piriform cortex; part of the entorhinal cortex. From the latter four areas, information is conveyed to the orbitofrontal cortex from the thalamus. However, the olfactory cortex also makes direct contacts with the frontal cortex. In addition, olfactory information is transmitted from the amygdala to the hypothalamus and from the entorhinal area to the hippocampus, areas related to the creation of memories.

The afferent pathways through the thalamus to the orbitofrontal cortex are thought to be responsible for the perception and discrimination of odors. Indeed, people with lesions of the orbitofrontal cortex are unable to discriminate odors. Moreover, olfactory pathways leading to the amygdala and hypothalamus appears to mediate the emotional and motivational aspects of smell as well as many of the behavioral and physiological effects of odors.

IMPLICATIONS FOR PRODUCT DESIGN

There are not many objects that take advantage by stimulating the olfactory modality, but for those products which do it, the olfactory feedback play a crucial role in the acceptance. In the cases of soap, perfumes, and food, the perception of the smell is very important. It is therefore important to know how the olfactory cortex is strictly related to the emotional neural circuitry in the brain. Moreover, the high specialization of the sensory receptors is something to ponder on, when it comes to design a new product. Finally, the fact that the odour source can be located in the surrounding environment could suggest some idea for ambient odorant and similar products.

TASTE

Taste is, like smell, a chemical sense. When we taste something, the molecules composing what we taste are detected by specialized taste cells clustered in taste buds on the tongue, but also in palate, epiglottis, pharynx, and upper third of the esophagus. On the tongue, which is principal location of the taste buds, buds are located primarily in the papillae, clusters of cells embedded in the epithelium. In humans three morphological types of papillae have been found. Each type of papillae is typically located in a different region of the tongue. In particular, several hundred of fungiform papillae, (having a peg-like structure) are located on the anterior two-thirds of the tongue. Large circumvallate papillae (each of which is surrounded by a groove) are instead located on the posterior third of the tongue. Finally, on the posterior edge of the tongue are located the foliate papillae (leaf shaped structures, also surrounded by a groove). The number of buds in every papilla depends on the type of papilla. For example, while fungiform papillae contain about five buds, circumvallate or foliate papillae can contain hundreds of taste buds.

Each taste bud contains four morphologically distinguishable types: light cells, dark cells, intermediate cells , and basal cells. As for the olfactory receptors, taste cells are continuously regenerated . Noteworthy, basal cells, which small round cells located at the base of the taste bud, are probably the stem cells that serves as base to develop all the other kinds of cells. Moreover, has been thought that the three non-basal cell types may represent various stages of differentiation of the developing taste cell, (from dark, to intermediate, to light cells). Another explanation might be that, the light, intermediate, and dark cells could represent different cell lineages. However, all three types are referred to as taste cells, and all have an elongate, bipolar shape extended from the epithelial opening of the taste bud to its base.

Each taste bud has a taste pore, which is a small opening on the surface of the epithelium. The taste pore serves as a “door” to the taste cells, which extend their microvilli into them. The microvilli are the only parts of the taste cell that are exposed to the oral cavity, and are actually where sensory transduction takes place. The taste cells are innervated by the primary gustatory afferent fibers at their basal pole. Although taste cells are just epithelial cells, the contacts they have with the sensory fibers is comparable to the mechanisms of the chemical synapses between neurons. In fact, taste cells, like neurons, are electrically excitable cells with voltage-gated Na+, K+, and Ca2+ channels, and therefore are capable of generating action potentials.

The gustatory system is able to distinguish between four basic stimulus qualities: bitter, sour, salty and sweet. Monosodium glutamate (umami) have been indicated as a fifth category. The molecular mechanisms by which taste stimuli are transduced have been explored in studies using different experimental techniques, such as biochemistry, electrophysiology, and molecular biology. Results from these studies showed that different transduction mechanisms underpin the perception of each type of taste stimulus. Moreover, two stimuli may elicit the same taste sensation by mean of different mechanisms.

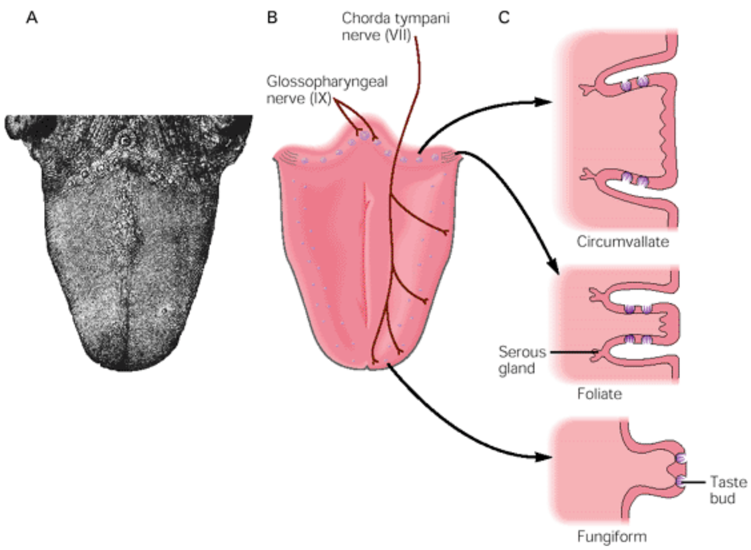


Figure 3.11: A. Surface of the dorsum and root of the human tongue. (From Bloom and Fawcett 1975.); B. The taste buds of the anterior two-thirds of the tongue are innervated by the gustatory fibers that travel in a branch of the facial nerve (VII) called the chorda tympani. The taste buds of the posterior third of the tongue are innervated by gustatory fibers that travel in the lingual branch of the glossopharyngeal nerve (IX). (Adapted from Shepherd 1983.); C. The main types of taste papillae are shown in schematic cross sections. Each type predominates in specific areas of the tongue, as indicated by the arrows from B. From Kandel, Schwartz, and Jessell (2007).

Some evidences showed that different taste cells actually respond to different taste stimuli. However, it is still uknown whether each cell responds either to one tastant or instead a combination of tastants. From a strictly physiological point of view the second option seems to be the more likely, since each taste cell is innervated at its base by the peripheral branches of primary gustatory fibers. Each sensory fiber branches many times, innervating a variety taste buds and, for each taste bud, a number of taste cells.

TASTE IN THE BRAIN

The taste buds in the fungiform papillae (anterior two-thirds of the tongue) (are innervated by sensory neurons of the thalamic geniculate ganglion. Those axons travel in the chorda tympani, which is branch of the seventh cranial nerve. In the posterior third of the tongue taste buds are instead innervated the petrosal ganglion's sensory neurons, whose branches travel in the ninth cranial nerve. On the palate, taste buds are innervated by the greater superficial petrosal branch of the seventh cranial nerve Buds on the epiglottis and esophagus instead by the tenth cranial nerve X. Interestingly, some of these cranial nerves also carry somatosensory information from the regions of the tongue surrounding the taste buds. The sensory fibers receiving inputs from the taste cells and running in the seventh, ninth, and tenth cranial nerves enter the solitary tract in the medulla, to subsequently form synapses in the gustatory area of the rostral and lateral part of the nucleus of the solitary tract.

From the gustatory area, sensory information travels to the thalamus, where terminates in the parvocellular region of the ventral posterior medial nucleus. In the thalamus taste related cells are grouped apart from neurons regarding other sensory modalities that yet are connected with the tongue. From the parvocellular region of the thalamus, taste inputs project to neurons along the border between the frontal operculum in, the anterior insula, and the ipsilateral cerebral cortex. This region is close and rostral to portion of the somatosensory cortex representing the tongue. This projection is believed to provide for the conscious perception and discrimination of taste stimuli.

IMPLICATIONS FOR PRODUCT DESIGN

As for smell, taste is rare in product design, but when needed and implemented it represents the crucial aspect of the product. Physiologically, the distribution and the multiple connections between fibers and buds suggests the fact that flavour is a combination of the activation of multiple receptors, which inputs are merged since the very first stages of the sensory process. However, the perception of flavour is extremely multisensory. Taste interacts with smell and somatosensory perception, and even with vision and audition, giving us a percept that is totally different than the simple sensorial activation of the taste receptors. Later in this chapter we will treat the topic of crossmodal correspondences and multisensory integration, where the flavour has been coupled with the other senses, in order to achieve better and more profitable products.

INVESTIGATING PERCEPTION WHITHIN A SENSORY MODALITY: CLASSIC PSYCHOPHISICS

So far, in the present chapter, we exposed a survey on the five senses. In these short sections we focused on their physiology and functioning, leaving apart the matter of what human being actually perceives, that is, the answer of our brain, or better our cognition, to the chain of physiological events that arise from a physical or a chemical stimulus in the outer world. In years, psychologists and neuroscientists paid lot of attention to the sensory processes and the sensation arising from them. All these studies have been then collected under the name of "sensory sciences". In the following section we will focus on psychophysics, which is one of the first and most represented sensory sciences.

INTRODUCTION TO PSYCHOPHYSICS

Psychophysics has been used in years in order to test the resolution of our perceptive systems (in particular hearing, haptic, and vision). For decades the main objective of psychophysics has been the establishment of threshold that could describe the sensitivity of our sensory systems in different conditions (Purghé, 1997). In particular, psychophysics focused on the definition of absolute limen (AL), and differential limen (DL). AL is defined as the minimum level of stimulation needed to elicit a sensation in the person. DL, instead, refers to the minimum difference needed to the person to distinguish between two stimuli of the same kind that appear to be one more intense than the other. Another main objective of psychophysics is the creation of scales regarding human sensations. Characteristic of such scales is the fact that they connect a given physical variable to a sensorial or psychological variable.

A crucial concept in psychophysics is the idea of connection between the sensory continuum and the physical one. According to the classic psychophysics, a physical stimulus elicits a series of impulses able to produce an effect in the nervous system. The connection between the two continuum is represented by the so called Psychophysical function (Treutwein, 1995), which is indeed defined as

$$P = \Psi(S) \qquad (3.1)$$

Where S is the physical stimulus and P the sensation in the psychological or sensorial one.

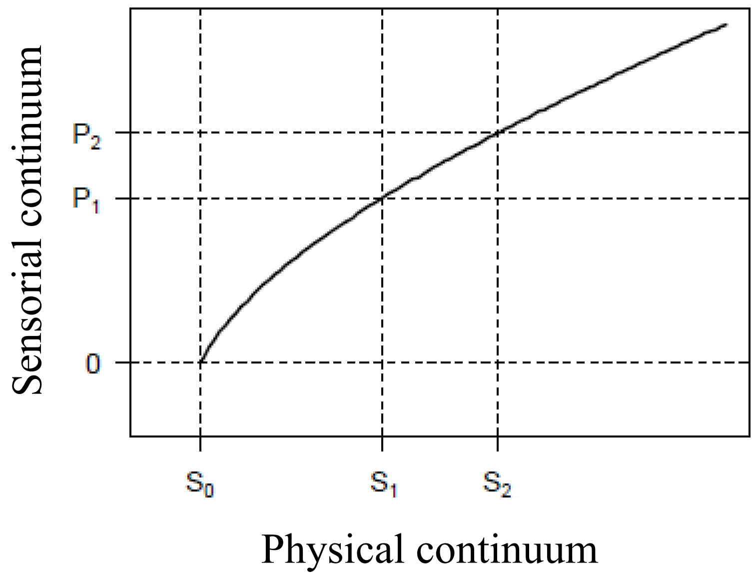


Figure 3.12: an example of psychophysical function.

Another important concept in psychophysics is that the physical stimuli can be described by two dimensions, according to the reaction that they elicit in psychological continuum: Prothetic and metathetic. Prothetic dimensions are the characteristic of the stimulus that when varying gradually elicits a gradual variation in the sensations of the person, on the same sensorial axes (i.e., luminosity). Metathetic dimensions are the characteristics of the stimulus that vary along one continuum eliciting in the person a different qualitative sensation (like variation in wavelength and colour perception).

THE ABSOLUTE THRESHOLD

As previously mentioned, the absolute threshold is the minimum level of a physical stimulus able to elicit a sensation in the person. Ideally, the subjective perception of a stimulus should be deterministic. That means, the subject should be able to detect the stimulus over a given intensity of it, and totally unable to detect it below the value of that intensity. In terms of probability, then:

$$\Pr(\text{“detected”} \mid \text{stimulus}) = \begin{cases} 0 \text{ if } S < AL \\ 1 \text{ if } S > AL \end{cases} \qquad (3.2)$$

The idea of a deterministic behaviour is based on the assumptions that it exists a fixed minimum level needed to elicit a sensation, and that the physical stimulus can have only one corresponding sensation on a given continuum P.

Actually, the deterministic behaviour is only theoretical. Usually, what happens when a physical stimulus shift from a value under the threshold to a value over the threshold, is that the probability to detect the stimulus grows together with the intensity of the stimulus, gradually changing rather than suddenly shifting from 0 to 1. This behaviour is a probabilistic behaviour. That means that by presenting several times a stimulus close to threshold to participant, it will be sometimes detected as sometimes not. The Psychometric function expresses the relationship between physical and psychological continuum around threshold.

F(S) = Prob("detected" | S) (3.3)

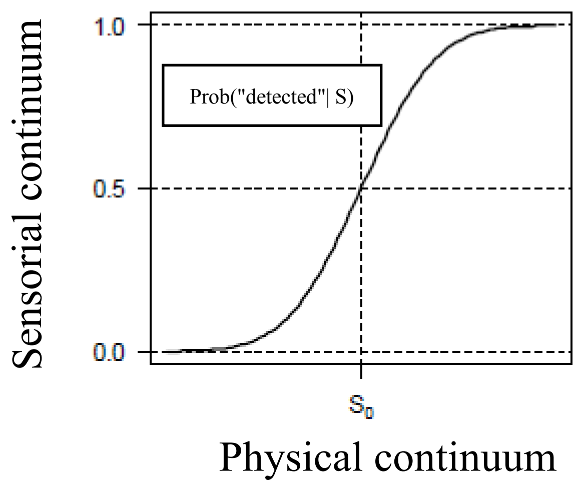


Figure 3.13: Psychometric function

The idea behind the probabilistic behaviour of the threshold is that it floats around a given value in the sensorial continuum. We can represent the variation of threshold as a Gaussian curve. In this case, the psychometric function can be represented as the integral of a Gaussian function (Figure 15, Gaussian distribution showed on top). Moreover, the whole function, and not only the threshold can vary depending on several factors (attention, health, and mood). This variation of the function can be assumed as to be normally distributed too, so that in practice there is no difference between the two explanations of probabilistic behaviour.

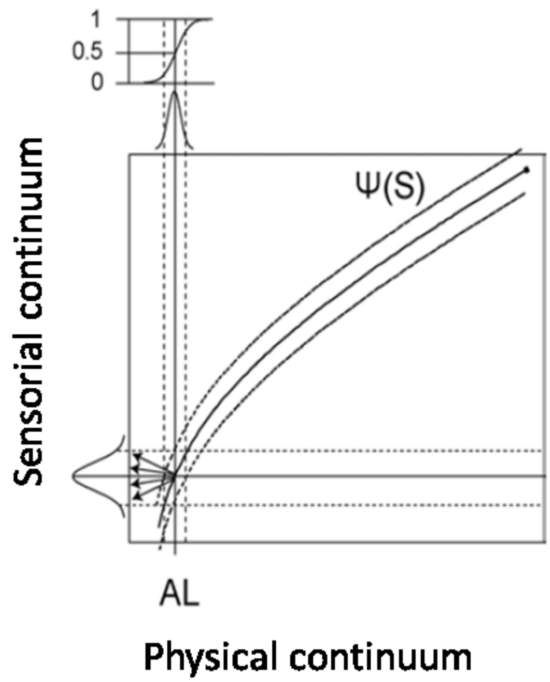


Figure 3.14: The probabilistic behaviour of the psychophysics function

Concluding, the AL is defined as the level of the physical stimulus able to elicit a probability of responses "detected" equal to 0.5:

$$F(AL) = Prob(R = \text{"detected"} \mid S = AL) = 0.5 \qquad (3.4)$$

THE DIFFERRENTIAL THRESHOLD

The differential limen (DL) is defined as the minimum difference in intensity between two physical stimuli noticeable by a person. The mathematical definition of the differential threshold depends on the method used to compare the two stimuli. In fact, comparison between two stimuli (typically a reference stimulus and a comparison stimulus) can be performed allowing only two kinds of answer ("bigger", "smaller") or three ("bigger", "smaller", "I don't know").

Before proceeding further it is better to define another concept related to DL, in order to avoid any confusion. A concept strongly related to the concept of DL is the JND, that is the Just Noticeable Difference in the sensorial continuum. Basically, to better grasp the difference, it is sufficient to look at Figure 16. In fact, while the DL refers to the physical continuum, the JND refers to the sensorial one.

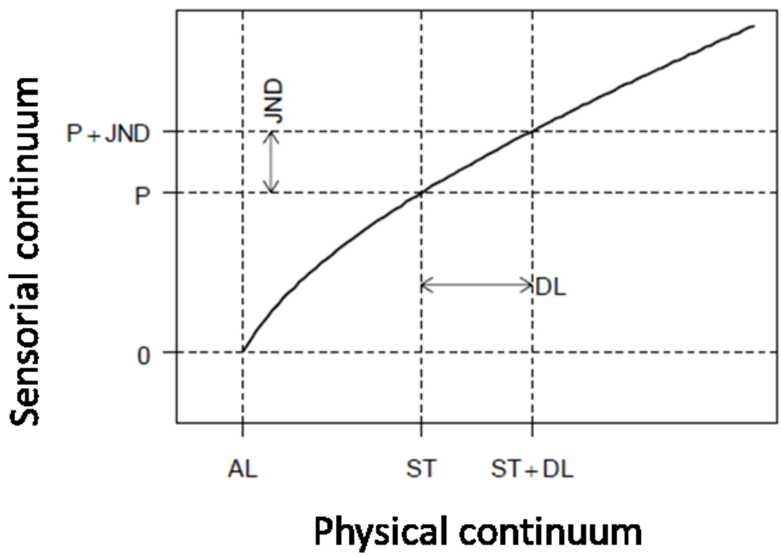


Figure 3.15: Conceptual difference between DL and JND

However, talking of DL, we mentioned that its definition depends on the way the stimuli are compared. When only two options are at disposal, what is usually done in psychophysics is to keep a stimulus constant (called standard stimulus, ST), and make vary a second stimulus (S) to be compared to the ST. Usually participants to psychophysical experiments are asked to indicate whether S is either bigger or smaller than ST. In this case, the psychometric function indicates the possibility that answer S is bigger than ST after a comparison. This function grows between 0 and 1, varying between a value of S clearly smaller than ST, to a value of S clearly bigger than ST.

This lead to another important concept in psychophysics, related to the psychometric function and especially to the part of the function between 0 and 1. In particular, since we are speaking of a probability function, there will be a point in the physical continuum in which the probability of judge S>ST will be equal to 0.5, then totally random. This point is called Point of Subjective Equality (PSE) and represents the point where the stimulus S is perceived as equal to the stimulus ST. Since this point can be shifted (that is, for some reason the point will not represent the physical equality between the two stimuli, but only the perceptive one), it is possible to compute the constant error of the perception, that is the distance between the value of ST and the value of PSE. In this framework, we can compute the differential threshold as the increase of the PSE value so that the stimulus S_π (which is equal to PSE + DL_{π}) elicit π=75% the answer “S is bigger than ST”; therefore:

$$DL_\pi = S_\pi - PSE \qquad (3.5)$$

A second definition of DL is more geometrical, and it is the half of the distance between S_π and $S_{1-\pi}$ that respectively elicit the 75% and the 25% of the answer “S is bigger than ST”;

$$DL = (S_{1-\pi} + S_{\pi})/2 \qquad (3.6)$$

Finally, a third definition of DL assumes as psychometric function a Gaussian distribution having the PSE as mean. In this context:

$$DL_{\pi} = u_{\pi}\,\sigma_{PSE} \qquad (3.7)$$

Where σ_{PSE} is the standard deviation of the PSE, and u_{π} corresponds to the probability π so that :

$$Prob(Z<u_{\pi})=\pi \qquad (3.8)$$

That means, for $\pi=75$ % that $u_{\pi}=0.6745$.

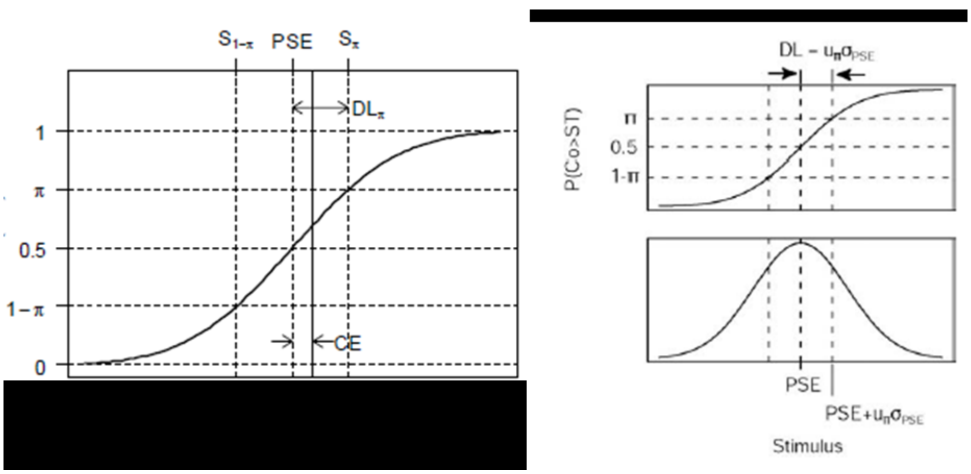


Figure 3.16: The definitions of PSE and DL considering the psychometric function as a Gaussian (right) or a cumulate Gaussian Function.

Finally, there are cases in which three responses are allowed in order to detect the differential limen ("S is bigger than ST", "S is smaller than ST", "I don't know"). In these cases two different thresholds are defined in order to find the DL: The lower threshold (LT) and the Upper Threshold (UT). LT corresponds to the value of the stimulus S needed to achieve the 50% of the answer S<ST. UT is instead equal to the value of the stimulus S needed to achieve the 50% of answer S>ST.

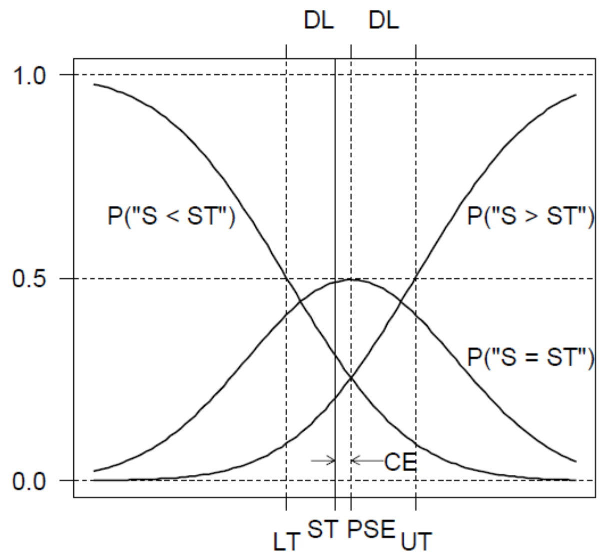


Figure 3.17: CE,PSE,LT,UT, and DL in the case of three possible answers

In this situation, it is necessary to compute the Interval of Uncertainty, which is equal to :

$$IU = UT\text{-}LT \quad (3.9)$$

Then, it follows that respectively, the differential threshold, the PSE, and the CE are equal to:

$$DL = (UT\text{-}LT)/2 = IU/2 \quad (3.10)$$

$$PSE = (UT+LT)/2 \quad (3.11)$$

$$CE = PSE - ST \quad (3.12)$$

THE METHODS OF THE CLASSIC PSYCHOPHYSICS

The following sections aim at helping the designers that need to achieve information about the sensitivity of the perception of the user to design an experiment in order to get such information. Among years, several paradigms have been tested in the psychophysics realm to spot AL and DL. On the structure of the experiment, no more worlds will be sent on the difference between within and between studies already mentioned in this thesis. In this section we will limit to point out that most of times psychophysical research uses within subject studies in order to see how a given condition is able to affect the perception of the subject. Since the variability among subjects is bigger than the bias that can occur within the same participant, at least when it comes to perception then within studies are preferred. In the next lines we will explore and explain different tasks participant have to perform in order to allow the experimenter to retrieve information concerning AL and DL.

THE METHOD OF LIMITS

The method of limits is one of the easiest and intuitive methods to determine AL and DL. The first step of the method is to choose a series of values at a given constant interval, which range reasonably include the threshold value. In order to find the AL, starting from the lower value in the range, all the values are presented in an increasing order, until the value $TA_{i,}$ which represent the first answer "detected" in the participant. At this point, a decreasing series is presented to the participant, starting from the higher value in the range, until the participant stops to detect the stimulus (value TD_i). The whole procedure is then repeated for M times.

In order to find the AL, for each of the M series, a threshold is computed as the mean of the two stimuli that encircle the change of answer of the participant (i.e., for a descending series the last "detected" and the first "not detected"). After that, two different thresholds are computed. The ascending threshold $T_{a,}$ which is the mean of the threshold computed from the ascending series. Vice versa, $T_{d,}$ is computed as the mean of the thresholds from the descending series. Finally AL is computed as the mean between T_a and $T_{d.}$

These methods, although easy and intuitive, can be really noisy. Several kinds of bias can be included in the subject answers. For example, a bias of habituation or perseveration could lead the participant to keep answering the same thing without paying the needed attention to the stimuli. At the same way, participants could switch their answer when they expect to switch it, basing on expectation of previous experiences (anticipation error). In these cases, a useful way to deal with these kinds of errors is to randomize the starting point in the presentation of the stimuli.

To compute the DL instead, the procedure is the following: If still a sequence of stimuli with a constant distance is selected, this time the stimuli will be compared to a ST, starting from a stimulus clearly smaller, to increase on the scale of the selected stimuli until the stimulus that will be considered bigger than ST. The same procedure will be applied in the descending way. The PSE will be then computed for each series of comparison, as the mean between the two values encircling the change of answer. The standard deviation among all the obtained PSEs will be then multiplied for a threshold value obtained by the Z distribution, so that, for example, being the threshold for the DL settled to 75% of probability of answering "S>ST", the formula for the DL will be:

$$DL_{\pi} = u_{\pi}\,\sigma_{PSE} \text{ that is } DL = 0.6745 * \sigma_{PSE} \qquad (3.13)$$

THE ADJUSTMENT METHOD

The adjustment method needs an experimental device allowing the subject to regulate the intensity of the stimulus. Typically, the adjustment method is used to compute the differential threshold. In particular the task of the participant to this kind of experiments is to adjust the intensity of the comparison stimulus (S) until he perceives it as equal to the standard stimulus (ST). As in the case of the method of the limits, this kind of method can present errors like habituation, perseveration, anticipation, and time order error (TOE, Allan, 1977).

The adjustment of the comparison stimulus in order to make it as intense as the standard stimulus is repeated several times, with the participant starting from a comparison stimulus alternatively more intense or less intense that the standard stimulus. The total PSE is computed as the mean of the value settled by the participant, in turn considered of the PSEs for each repetition. The DL is computed as in the limits methods as:

$$DL_{\pi} = u_{\pi}\,\sigma_{PSE} \qquad (3.14)$$

THE CONSTANT STIMULI METHOD

The method of the constant stimuli is likely the most used and also the most reliable among the methods of the classic psychophysics. When used to find the AL it is assumed that we know more or less where the threshold is. Around the threshold, then, a series of value at a given pace is chosen. This series will constitute the set of the comparison stimuli. The stimuli, as in the case of the method of the limits, will range from a stimulus impossible to detect ($P(\text{“detected”}|S_1) = 0$) and a stimulus impossible to miss ($P(\text{“detected”}|S_n) = 1$). After that, a number of repetition is chosen, so that each stimulus will be randomly presented M times to the participant. As results of this presentation, a series of proportions of “detected” associated to each of the stimuli S, ranging from 0 to 1 is obtained. The randomization process is very important in this method. It is actually advised to randomize separately each block of stimuli among one repetition. For example, assuming a series of stimuli starting from 4 to 25 at a pace of 3, we can expect to see results similar to those reported in Figure 19.

S_i	F_i
4	0.03
7	0.15
10	0.29
13	0.46
16	0.66
19	0.79
22	0.88
25	0.95

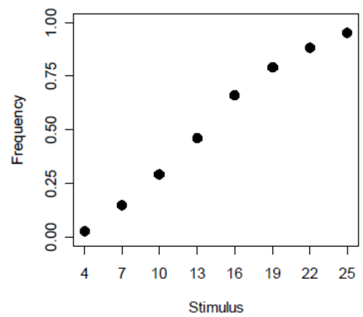


Figure 3.18: the value of each stimulus S and the associated frequencies of detection

In case we want to compute the differential limen (DL) the experimental paradigm would be rather similar. Each stimulus in the series would be compared to a standard, and the frequencies of the answer S>ST would be computed for each stimulus among M repetitions.

However, once obtained a situation as illustrated in Figure 19, there are many ways to compute the AL or DL.

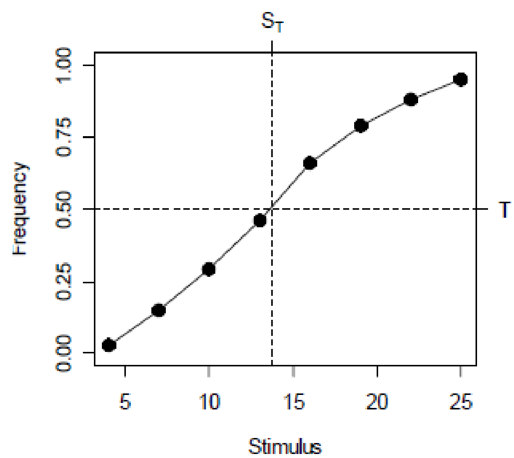


Figure 3.19: The linear interpolation method for the AL definition

Linear interpolation: In this modality, the threshold T corresponding to a probability of the answer "detected" P_T is the result of the equation:

$$T = S_l + \frac{(P_T - P_l)}{(P_u - P_l)}(S_u - S_l) \qquad (3.15)$$

Where P_T corresponds to the probability settled by the definition of the AL (in this case 0.5), P_u is the proportion of answer "detected" right above P_T, P_l is P_u is the proportion of answer “detected” right below P_T, S_u is the value of the physical stimulus corresponding to P_u, and S_l is the value of the physical stimulus corresponding to P_l . To compute the DL by mean of linear interpolation, it is sufficient to compute (Q_3-Q_1 / 2), where Q_3 and Q_1 are the values of the stimuli corresponding not to the 0.5 of probability (as it would be the PSE in case of comparison) but to, respectively, the 0.25 and the 0.75 I the frequency axis.

Another way to compute the AL is based on the shape of the psychometric function. In fact the shape of the psychometric function is the shape of a *cumulate probability distribution.* It is therefore possible to compute the original probability function starting from the differences observed among consecutive frequencies. In this way, it is possible to obtain a bell shaped function which mean represent the absolute limen of the participant. In particular:

$$AL = \frac{1}{N}\sum n_i c_i = \sum \frac{n_i}{N} c_i = \sum f_i c_i \qquad (3.16)$$

Where $c_i = (S_i + S_{i-1})/2$ represents the mean value between two stimuli.

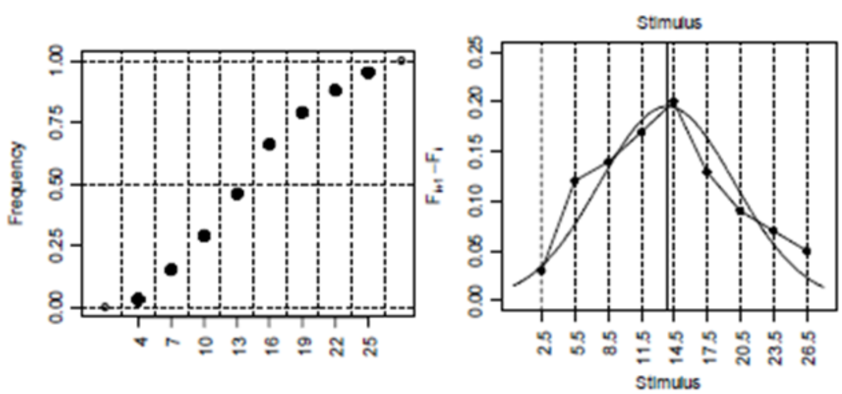


Figure 3.20: The method of cumulate frequencies for the definition of AL

The computation of DL in this modality is conceptually similar to the DL computed with the interpolation method. The only remarkable difference is that in this case, the experimenter will look on the table the value of the upper threshold and lower threshold. From that, it will be able to compute without any problem the PSE as (UT+LT)/2, the DL as (UT-LT)/2, and finally the CE as PSE- ST.

A further way to compute the absolute limen in the constant stimuli method is the interpolation with the *least squares linear regression*. The first step in this computation is to convert all the observed frequencies to Z points. At this point, it is important to note that, by definition, the relationship between the s stimuli and the Z point is linear, as expressed below:

$$z = \frac{S - AL}{\sigma_{AL}} = -\frac{AL}{\sigma_{AL}} + \frac{1}{\sigma_{AL}} S = a + bS \qquad (3.17)$$

It straightforward follow that it is possible to compute the *a* and the *b* by men of least square method (linear regression). From this relationship is then easy to compute the AL as:

$$b = \frac{1}{\sigma_{AL}} \Rightarrow \sigma_{AL} = \frac{1}{b}$$
$$a = -\frac{AL}{\sigma_{AL}} \Rightarrow AL = -a\sigma_{AL} = \frac{-a}{b} \qquad (3.18)$$

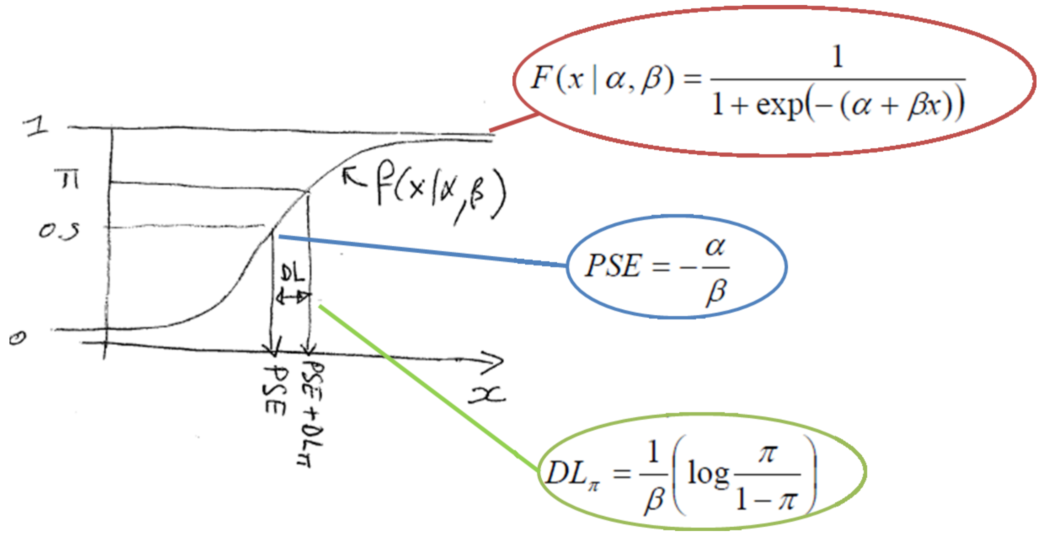
Again, the computation of DL by means of least square regression, is conceptually similar to the other modality. Again, as first UT and LT can be found. This is possible applying straightforward the formulas to compute a and b of the linear regression, this time transforming in the z point the frequencies relative to the threshold T of 0.25(LT) and for the threshold T of 0.75 (UT). The PSE can be computed setting the frequencies as relative to T=0.5, and therefore the UL can be computed as: DL = U_Z S_{PSE} where S_{PSE} is equal to 1/b.

FITTING PSYCHOMETRIC FUNCTIONS

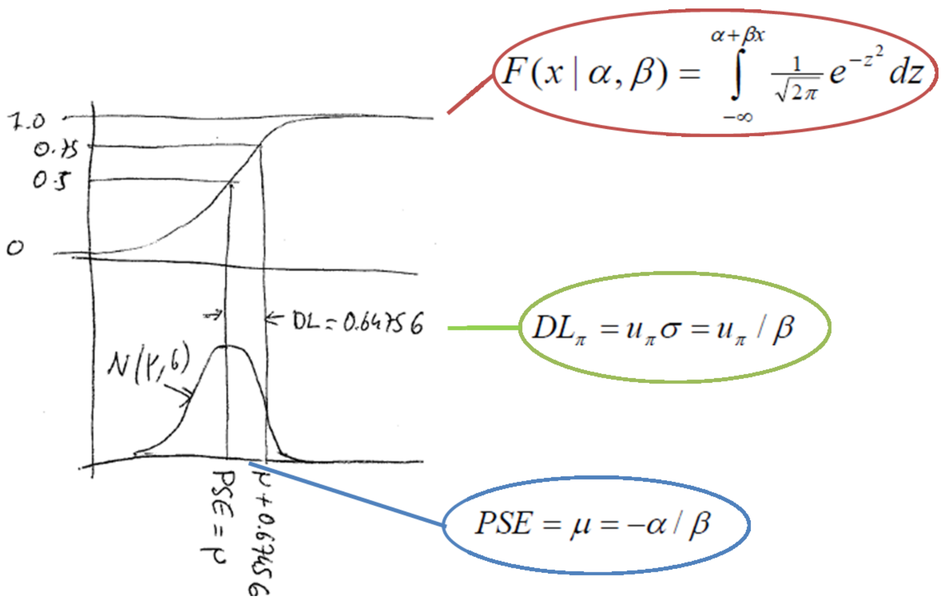
Despite different methods to find the DL and the AL have been reported, the one typically used in psychophysics consists of the fitting of psychometric functions to proportions of correct answers or even positive /negative answers (as "detected"/ "not detected"). By definition, the psychometric function F(x|θ) models the probability π of a positive response:

$$\pi = \Pr(Y = 1 | x) = F(x | \theta) \qquad (3.19)$$

where θ represents the parameters of the psychometric function. Among years, various functions F(x|θ) have been used to model the probability of positive response (e.g., the logistic, the probit or the Weibull function). Although the analytical form of these functions differ, they have as common properties that they are all S-shaped (sigmoidal) and they all increase monotonically from 0 to 1. Moreover, they have some parameters θ that need to be fitted to the data (the fitting problem). Most theoretical psychometric functions have two parameters α and β that are related to the location (AL or PSE) and slope (DL) of the curve. The precise meaning of these parameters, and their relation to the AL, PSE or DL, depends on the variant of the psychometric function used. In the following sections we will give a brief hint of the properties of two of the main psychometric functions (logit and probit) introducing the methods to estimate the parameters of each psychometric function itself. However, the manual computation of the parameters in these cases could result rather complex. Therefore computer programs can be used to automatically achieve the parameters of the functions. Here some brief description of the two functions. The logisitic function is defined as:



While the probit is defined as:



What usually happens when fitting psychometric functions as the logit and the probit is that the researcher uses an algorithm implemented in a computer program to fit (usually by mean of the maximum likehood) the function to the frequencies, and subsequently to extract the function's parameter.

SIGNAL DETECTION THEORY (SDT)

Signal Detection Theory was developed in 1950s by engineers and mathematicians. Its use in Psychophysics is due to Tanner, Swets and colleagues. The starting point of detection theory is the analysis of the results of detection task, were the observer must decide whether some sensory event (sensation) was caused by an actual signal or by some random background process (noise). The main point in SDT theory is to assume the existences of a sensory and a decision process and find out the parameter characterizing that process, that are:

- The sensitivity for the sensory process
- The bias or response criterion for the decision process

Therefore, the notion of threshold is not central in the SDT. Different psychophysical procedures have been developed in the field of SDT theory, in order to find out sensitivity and criterion of subjects. For example, in the yes-no procedures, participants are asked to say whether the single stimulus on each trial was a signal or noise. In the Force-Choice Procedure (n-Alternative Force Choice Task), instead, the signal is presented in one of two or more intervals (usually temporal, but sometimes spatial) and the observer is instructed to select the interval that he (she) believes most likely to have contained the signal. Finally, in the Rating Procedure, The observer is presented with a single stimulus and is instructed to rate on an n-point scale the likelihood (confidence) that the observation was caused by the signal.

In a detection task, the observer is typically presented with one of two stimulus alternatives (present or absent stimulus). He (she) is asked to respond by selecting one of the two permissible responses (Yes or No). The results of an experiment conducted with the Yes-No procedure can be represented in a matrix of conditional probabilities as the one showed in Table 3.1:

Stimulus	Response	
	"Yes"	"No"
Present (SN) (Signal+Noise)	P("Yes" |SN) (Hit)	P("No"|SN) (Miss)
Absence (N) (Noise)	P("Yes"| N) (False alarm)	P(“No"|N) (Correct rejection)

Table 3.1: matrix of conditional probabilities for a yes-no experiment

Conditional probabilities express the observer's behavior independently of the number of times either alternative has been presented. By definition:

$$P(S|n) + P(N|n) = 1 \qquad (3.20)$$

$$P(S|s) + P(N|s) = 1 \qquad (3.21)$$

From a graphical point of view it is possible to represent all the information in a stimulus-response matrix as a point of a two dimensional graph where the horizontal axis corresponds to the false-alarm rate and the vertical axis to the hit rate.

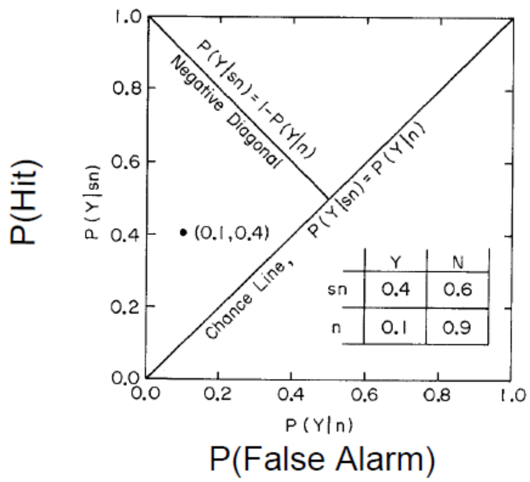


Figure 3.21:representation of a stimulus response matrix

In particular, the top left angle of the graph corresponds to the point of maximum discriminability: P(Hit)=1 and P(False Alarm)=0.

The diagonal corresponds to the case were P(Hit) = P(False Alarm). This is true if the two underlying probability distribution coincide (EN=ESN). In this case, it is impossible to make an informed decision and the observer must respond randomly. For this reason, the main diagonal is called the "chance line".

In SDT, sensory processing is assumed to have a continuous noise (N). When the signal (stimulus) is present, the signal is combined with noise (hence the notation SN). This idea is similar to Thurstone's concept of "discriminal dispersion" that the effects of stimulation can be represented by a random variable. The stimulus has a mean value on the relevant sensorial or psychological scale but its exact value fluctuates from moment to moment. Following Thurstone, it is often assumed that the noise and signal-plus noise distributions are Gaussian. Therefore, the representation as in Figure 23:

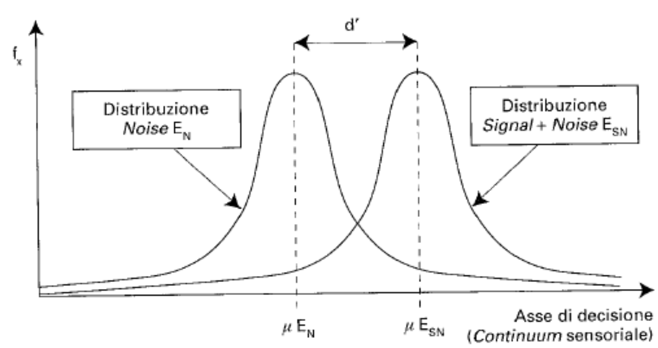
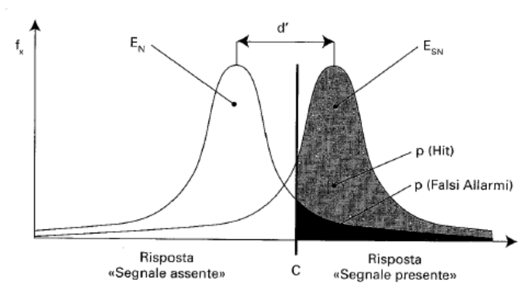


Figure 3.22: Distribution of noise and signal+ noise in the sensorial continuum

The difference between the mean of the distribution of the noise and the distribution signal plus noise represents the sensitivity of the participant to the signal (d'). In particular, the formula to compute the d' is (assuming the two distributions have the same variance):

$$d' = \frac{\mu_{SN} - \mu_N}{\sigma} \tag{3.22}$$

Another crucial concept in SDT is the criterion (c). In fact, The SDT assumes that the observer responds positively if the sensation (or state of excitation *e* of the sensory system) is above some value *c* and negatively otherwise. The value *c* is the decision criterion is under control of the subject who can adjust it to maximize, for example, the number of correct responses, or to maximize the number of hits, or to minimize the number of false alarm. Therefore, The optimal value of *c* depends on the context. This is one of the main differences between SDT and the classic psychophysics. In classical psychophysical theory, the value c corresponds indeed to the threshold and is thought as being a fixed property of the sensory system.



$$\text{Response} = \begin{cases} Yes & if \quad e \geq c \\ No & if \quad e < c \end{cases}$$

Figure 3.23: criterion c, sensitivity d', and distributions on the sensory continuum.

A further concept in SDT is the idea of bias. It corresponds to the ratio of the values of the Gaussian probability density functions that represent the signal and the noise at the point *c*.

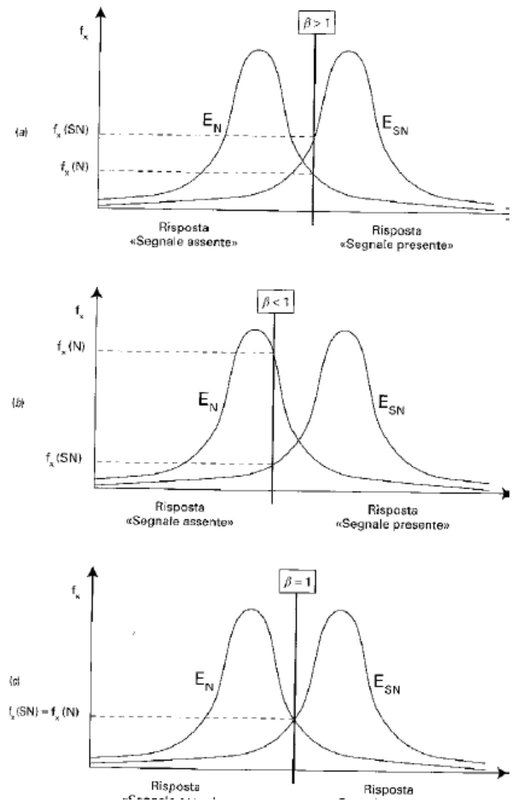


Figure 3.24: the different positions of beta. In the case beta is bigger than 1, the criterion is shifted toward the signal + noise distribution. If smaller than one, the criterion is shifted toward the noise distribution. If equal to 1 he criterion is perfectly between the two distributions

The bias can be computed as:

$$\beta = LR = \frac{f_{SN}(c)}{f_N(c)} \quad (3.23)$$

In the case the two distributions have the same variance then is also valid the following relation:

$$\log \beta = d'c \quad (3.24)$$

Now that we know the meaning of each element in the SDT, it is easy to compute the criterion and the sensitivity of a participant. The first step in doing that is to transform the response matrix in z points. As the transformation is done, it is easy to compute d' and c', starting from the concept we had expressed so far. For example, given the response matrix:

Stimulus-Response Matrix		Response	
		Yes	No
Signal	SN	0.4	0.6
	N	0.1	0.9

Its transformed will be:

z-transform		Response	
		Yes	No
Signal	SN	-0.253	0.253
	N	-1.282	1.282

And therefore, d', c, and beta will be equal to:

$$d' = -0.253 - (-1.282) = 1.029$$
$$c = -\frac{-0.253 - 1.282}{2} = 0.7675$$
$$\beta = \frac{0.386}{0.175} = 2.206$$
$$\log \beta = d'c = 0.79 \qquad (3.25)$$

Moreover, a graphical representation by means of a ROC curve will be possible as described above. The utility of ROC curves is that they show, assuming a fixed sensitivity of the sensory system (d'), how the proportions of hits and false alarms vary as a function of the criteria of responses.

To draw the ROC curves is sufficient assume a given d' (let's say d'=1.029, as in the previous example). Let's assume then that that we want to compute the response for c varying from –2.0 to +2.0 (let's assume equal variance σN=σSN=1). The roc curves will then have the shape of Figure 25:

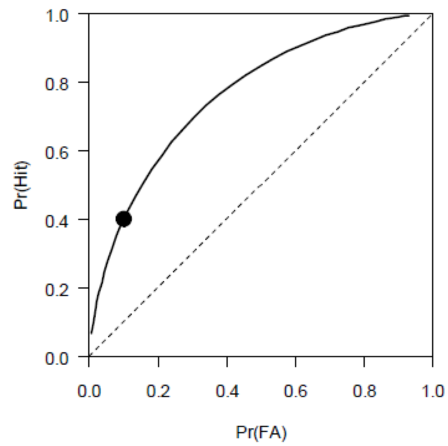


Figure 3.25: ROC curve for c varying between -2 and 2 of the example cited in the text.

Given that :

$$\begin{aligned}\Pr(\text{Hit}) &= \Pr(Yes \mid SN) = \Pr(E_{SN} > c) \\ &= \Pr\left(\frac{E_{SN} - d'/2}{\sigma_{SN}} > \frac{c - d'/2}{\sigma_{SN}}\right) \\ &\overset{\sigma_{SN}=1}{=} \Pr(Z > c - d'/2) \\ \Pr(\text{FA}) &= \Pr(Z > c + d'/2)\end{aligned} \tag{3.26}$$

For Pr (FA) meaning the probability of false alarms in the response matrix, PR (HIT) the probability of hits in the response matrix.

As a conclusive note, it is important to highlight another characteristic of the ROC curves in their ability to summarize the performance of a sensory system. In fact, it has been demonstrated that the sloop at each point of the ROC curve is equal to the bias beta for a given response criterion.

IMPORTANCE OF PSYCHOPHYSICS IN PRODUCT DESIGN:

In the recent years the development of technology in product design allowed designers and engineers to create a series of products allowing various kinds of interaction with users. In fact, products can communicate with users by means of visual, acoustic, or even haptic stimuli. In food science, the design of the flavour for snacks reached a high level of complexity, and formulae for new products can vary by very tiny amounts of different components. However, sometimes, lot of effort is put in the technical aspects of the product without paying attention to the effect that the technological enhancement will have on the user perception. In fact, technical improvement in many devices could not even being perceived by the user, resulting then in a waste of time and money. It is not surprising then that recently psychophysics acquired a major role in the prototyping and creation of new products (Tan, Srinivasan, Eberman, and Cheng, 1994).

Shinohara, Shimizu, and Mochizuk (1998) applied a psychophysical method to optimize a 3D display for visually impaired people. In particular, they created a tactile display device that can present tangible relief graphics for visually impaired persons. The tactile surface consisted of a 64 X 64 arrangement of tactorpins with 3 mm interspacing. The tactor-pins are aligned in a hexagonal, rather than a square formation, to assure smooth depiction. The matrix has a total area of 200 mm X 170 mm. Each pin can be raised in 0.1 mm steps to a maximum height of 10 mm. Users can get certain information by touching the pins raised at varying heights with fingers and/or palms. The vertical extension of the tactopins and their distribution was assessed with psychophysical methods in order to make them perceivable to the participants and, at the same time, not to waste efforts in making them over-performant.

An application of Psychophysical data in order to optimize an olfactory display was performed by Yanagida, Noma, and Tetsutan(2003), who based the design of their device on psychophysical data achieved by Murphy, Nordin, de Wijk, Cain, and Polich, 1994), which investigated the differences in psychophysical threshold between young and elderly. Back in the field of haptic, moreover, Ellis, Ismaeil, and Lipsett (1996), designed a haptic interface based on a planar mechanism for force rendering, validating their design choices by means of psychophysical experiments.

As it emerges from these evidences, psychophysics is used mainly for the pragmatical optimization of the products. In other words, it is used to tune the product, the device, or the interface to the user perceptive abilities, avoiding wasting effort in creating over-performant devices. At the same time, when it come to a device that is supposed to deliver sensory feedback of the user, psychophysics is generally used to make sure that the target population of the device will be able to perceive those feedback in any condition.

DEALING WITH MORE SENSES: CROSSMODAL CORRESPONDANCES

In human perception, we seldom have to deal with only one sense. Although in almost all the cases we can reduce our studies on only one dominant sensory channel (especially for what concerns the creation of devices designed appositely to elicit that sensor modality), our perception of the world happens to be multisensory. The study of how multisensory information is coded by our brain widely interested researchers in sensory science since many years. As a matter of fact, the majority of cognitive neuroscience research on the topic of multisensory perception has tended to focus on trying to understand, and increasingly to model (Alais & Burr, 2004; Ernst & Bülthoff, 2004; Roach, Heron, & McGraw, 2006), the spatial and temporal factors modulating multisensory integration (e.g., see Calvert, Spence, & Stein, 2004; Spence & Driver, 2004). Broadly speaking, it appears that multisensory integration is more likely to occur the closer that the stimuli in different modalities are presented in time (e.g., Jones & Jarick, 2006; Shore, Barnes, & Spence, 2006; van Wassenhove, Grant, & Poeppel, 2007). Spatial coincidence has also been shown to facilitate multisensory integration under some (Frens, Van Opstal, & Van der Willigen, 1995; Slutsky & Recanzone, 2001), but by no means all, conditions (see, e.g., Bertelson, Vroomen, Wiegeraad, & de Gelder, 1994; Innes-Brown & Crewther, 2009).

However, new trend of research focused, rather than on model for spatial and temporal integration between senses, on what are called crossmodal correspondences. The term crossmodal correspondences include a range of topic expressed in literature under different names (i.e., synaesthetic correspondence and synaesthetic association). In fact, crossmodal correspondences:

> *"...refer to a compatibility effect between attributes or dimensions of a stimulus (i.e., an object or event) in different sensory modalities (be they redundant or not). Such correspondences occur between polarized stimulus dimensions, such that a more-or-less extreme stimulus on a given dimension should be compatible with a more-or-less extreme value on the corresponding dimension. A key feature of (or assumption underlying) all such crossmodal correspondences is that they are shared by a large number of people (and some may, in fact, be universal)... (Charles Spence, 2009).*

Crossmodal correspondences refer then to a matching between stimuli among different sensory modality. Moreover, characteristic of these stimuli, is the fact that they do not straightforwardly express the same dimension of the object of the perception (for example the length of an object can be perceived actually by means of vision or touch), but instead it happens between stimuli not obviously related in different sensory modality (i.e., the pitch of a sound and the size of an object).

Crossmodal correspondences can work matching sensory stimuli in different ways. For example, at the most basic level, they may be related in terms of some common (amodal) stimulus feature shared by a number, if not necessarily all, of the modalities (Marks, Szczesiul, & Ohlott, 1986). A little bit more complex, they can also occur between different, apparently unrelated (and in some cases modal) characteristics of an object presented in two or more sensory modalities, as when people match high-pitched sounds with small and/ or bright objects. Crossmodal correspondences between stimuli may also occur at a more abstract level, matching items in terms of their pleasantness, cognitive meaning, or activity (see Bozzi & Flores D'Arcais, 1967; Crisinel & Spence, 2010a; Hartshorne, 1934; Janković, 2010; Lyman, 1979; Osgood, Suci, & Tannenbaum, 1957). Moreover, it has also been suggested that crossmodal correspondences can be established at the level of the effect that the stimuli have on the observer: For example, stimuli may be matched (or associated) if they both happen to increase an observer's level of alertness or arousal, or if they both happen to have the same effect on an observer's emotional state, mood, or affective state (see, e.g., Boernstein, 1936, 1970; Collier, 1996; Cowles, 1935; Poffenberger & Barrows, 1924; Simpson, Quinn, & Ausubel, 1956; see also Lewkowicz & Turkewitz, 1980).

It is important to note that crossmodal associations have now been documented between many different pairs of sensory modalities, such as vision and touch (e.g., Martino & Marks, 2000; Morgan, Goodson, & Jones, 1975; Simner & Ludwig, 2009; Walker, Francis, & Walker, 2010), audition and touch (e.g., P. Walker & Smith, 1985; Yau, Olenczak, Dammann, & Bensmaia, 2009), and tastes/flavours and sounds (see Bronner, 2011; Bronner, Bruhn, Hirt, & Piper, 2008; Crisinel & Spence, 2009, 2010a, 2010b; Holt-Hansen, 1968, 1976; Mesz, Trevisan, & Sigman, 2011). Researchers have also highlighted crossmodal associations between colours and odours (Gilbert et al., 1996; Kemp & Gilbert, 1997; Spence, 2010), tastes (O'Mahony, 1983), and flavours (see Spence et al., 2010, for a review). Elsewhere, crossmodal associations have been documented between auditory pitch and smell (Belkin, Martin, Kemp, & Gilbert, 1997; Piesse, 1891), smells and shapes (Seo et al., 2010), and even shapes and tastes/flavours (Gal, Wheeler, & Shiv, 2011; Spence & Gallace, 2011; see also Gallace, Boschin, & Spence, 2011). It therefore appears likely that crossmodal correspondences exist between all possible pairings of sensory modalities.

CROSSMODAL CORRESPONDENCES AND PRODUCT DESIGN

Crossmodal correspondences found a large application to product design among years. As it not difficult to imagine, it is a thrilling concept for a designer to suggest sensation, or ideas to the consumer by means of "mere" sensory stimulation. In some extent, crossmodal correspondence represents all what design is about, and what the design shares with art: to express your own aesthetic sense and elicit in the consumer by means of a sensorial experience concept and ideas. More recently, cross-modal correspondences have been applied to product design assessing their effect by mean of experiments (see Schifferstein & Spence, 2007, for a review), and the effect of the packaging on the perception of the product itself (Malnar, 2004; Pickton & Broderick, 2005, Chapter 29, pp. 599–612; Piqueras-Fiszman, Velasco, Salgado-Montejo, & Spence, 2013; see Spence & Piqueras-Fiszman, 2012, for a review).

For example, Piqueras-Fiszman and Spence (2012a) recently investigated the influence that the weight of food containers, cutlery, and packaging has on feelings of satiety (before and after tasting the food, in their case, a yogurt), and/or on the perception of density of the food itself. These researchers reported that increasing the weight (of the packaging/plate ware/cutlery) influenced the perceived density of the product contained within. These researchers also confirmed the weight-density illusion originally proposed by Piqueras-Fiszman, Harrar, Alcaide, and Spence (2011). The participants in this study also expected the contents of a heavier container to be more satiating than when exactly the same contents were presented in a visually-identical, but physically lighter, container. A number of other studies has focused on investigating the visual features of products and their containers. The appearance of the product and the colour of its packaging also exert a significant influence on consumer perception, behaviour, and preferences (e.g., Marshall, Stuart, & Bell 2006).

So, for example, Piqueras-Fiszman, Velasco, and Spence (2012) recently demonstrated that the taste of the food (crisps or potato chips) seems to depend, at least to a certain extent, on the colour of the packaging. Meanwhile, Ares and Deliza (2010) conducted a study to investigate the influence of the container on people’s perception of food, using word association and conjoint analysis techniques. These researchers evaluated how the sensory characteristics of the packaging (in their study, they varied both the colour and size of the packaging) altered their participants’ willingness to purchase the product (a milk dessert) and their liking for it.

Meanwhile, Parise and Spence (2012) have measured people’s performance in a modified version of the Implicit Association Test (see Greenwald, McGhee, & Schwartz, 1998) in order to assess the semantic attributes associated with the shape of different bottles of mouthwash. Their results revealed that the shape of the bottle in which the mouthwash was contained suggested certain specific characteristics and attributes to the consumer, expressed in terms of adjectives such as ‘‘gentle’’ or ‘‘powerful’’. The majority of the studies on the product perception that have been cited so far can be considered in terms of the notion of cross modal correspondences. Crossmodal correspondences’ refer to a series of dimensions of experience that are shared across sensory modalities (see Spence, 2011, 2012, for reviews). Crossmodal correspondences have often been studied by means of relatively simple mappings (or correspondences) between stimuli presented in the visual and auditory modalities (e.g., Marks, 1975, 2004), vision and olfaction (Demattè, Sanabria, & Spence, 2006a; Gilbert, Martin, & Kemp, 1996; Maric & Jacquot, 2013; Schifferstein & Tanudjaja, 2004), touch and olfaction (Demattè et al., 2007; Demattè, Sanabria, Sugarman, & Spence, 2006b), etc.

However, despite several studies have been carried out on design and crossmodal correspondences. In fact, studies in crossmodal correspondences, differently from the psychophysical studies, are versatile and applicable both to the pragmatic and hedonic characteristics of the product. However, among all the studies on crossmodal correspondences, some studies have been carried out basing on the intuition of designer and psychologist rather thans following a systematic methodology able to spot which aspect of the product enhances or optimize utilizing the sensory science. The aim of this thesis is to present the methodology described in Chapter 1, able to direct the studies on the sensory characteristic of the product to enhance both pragmatic and hedonic characteristic of the product.

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CASE STUDIES: FOUR

The aim of the methodology is the pragmatic and hedonic optimization of the product by means of a procedure articulated in three different phases. The first phase is the focus of the research question, where the aim of the optimization is settled. The second phase is focused on the study of the interaction, where the sensorial characteristics of the product are examined, and the important features and characteristic of the product are identified. This phase is crucial in order to find the variables to study in the third phase, the sensorial optimization. Part of the aim of this dissertation was to explain the methods and the experimental procedures so that a designer can carry out the experiments selecting the ones he (she) prefers according to the resources and the competences at disposal. In the third phase crossmodal correspondences and psychophysics are used to optimize the product basing on experimental data.

In this Chapter we will expose two of the case studies carried out during the three years of PhD. In the first one a tracking method is used to study the interaction with the product (a new technology device for virtual prototyping). Subsequently, SDT is used to compute the necessary sensitivity of the device.

In the second case study, a conjoint analysis experiment is applied to a set of bottles of liquid soap. Subsequently, the attribute to optimize, clear from the design question, which is the efficacy of the soap, is boosted by mean of crossmodal correspondences.

The results of the first two case studies have been published in Gatti, Re, Ferrise, Bordegoni (2011), and Gatti, Bordegoni, and Spence (2014).

OPTIMIZATION OF A HAPTIC STRIP FOR VIRTUAL PROTOTYPING

In this case study we applied the methodology for the pragmatic optimization of a haptic strip able to replicate curvature of object designed by a CAD program. The strip consisted of a plastic stripe moved by small servo motors ling beneath the stripe and shifted in the space by two MOOG HapticMaster systems (Van der Linde, Lammertse, Frederiksen, and Ruiter, 2002,).. The operation of the motors and of the Haptic Master systems was controlled by a CAD program. In the virtual CAD environment a virtual stripe was posed on the shape of the object. The computer product computed the deformation of the virtual stripe on the CAD object and moved both motors and HapticMaster in order to replicate the shape of the virtual stripe in the real device (Bordegoni, Cugini, Covarrubias, and Antolini, 2010). The problem of the stripe was the difficulty the motors had in bending the stripe in case of curvature discontinuities. In particular, motors could not replicate discontinuities in the radius of curvature given by a variation of the curvature radius bigger than the 7-8%.

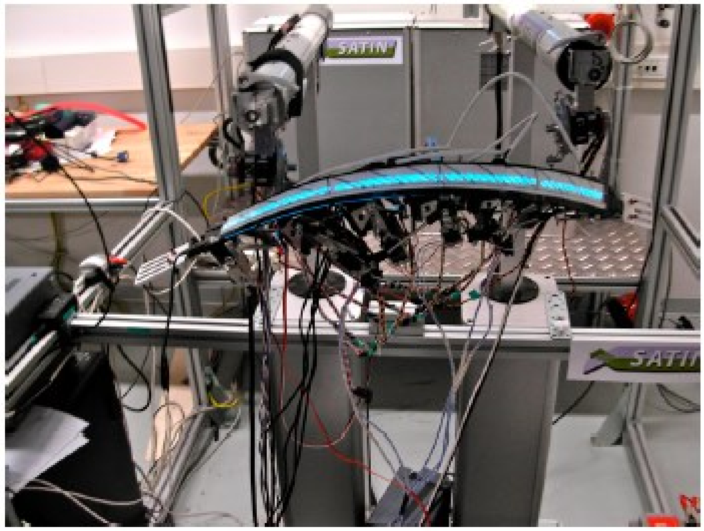


Figure 4.1: the haptic strip to optimize (Gatti, Re, Ferrise, Bordegoni, 2011)

After putting lot of effort in achieving a better performance of the device, the methodology has been applied in order to evaluate human ability to perceive a discontinuity in the curvature radius. First, a tracking study has been applied to study the path of participants when exploring curved surfaces. Results showed that no particular exploration path had an effect on the sensitivity of participants. Subsequently, an experiment was conducted in order to compute the minimum difference in the curvature radius perceivable by the users. Results showed that users could not perceive variation in the curvature radius smaller than the 12%, optimizing the product saving engineers for a waste of effort and time.

PHASE 1: THE DESIGN QUESTION

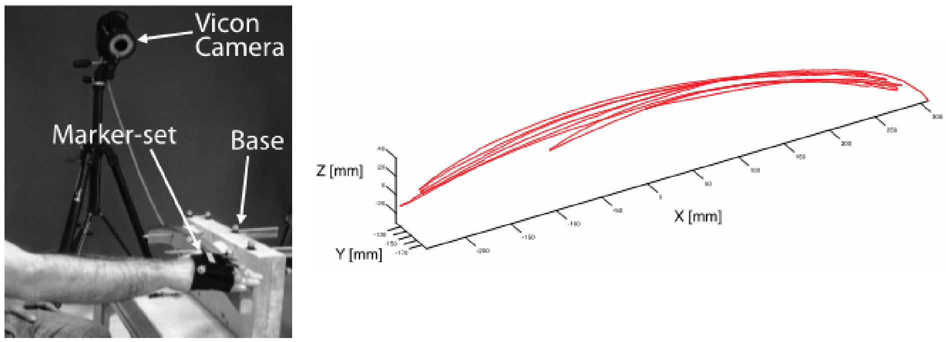
Even in case where the design question is utterly clear, it is important to go through this stage of the methodology. In particular, it is important a careful review of the literature, especially in the cases of pragmatic optimization, in order to see if anybody ever answered to the same question. To this purpose the human ability in perceiving curvatures has been reviewed.

As seen in the paragraph about the haptic sense, the human ability to perceive the shapes of the objects interested the experts of perception since the first days of the psychophysics. In particular, the ability of recognizing different curved surfaces by touch is a relevant topic in those virtual reality systems that implements haptic feedback. Indeed, several different systems have been made to simulate curvature in the virtual world (Bordegoni et al., 2010, Frisoli et al., 2008) making the users able to touch a virtual curved surface as it was real. Thus, a series of studies have been performed in the engineering and psychophysical fields to better understand human ability to perceive curvature. For example in (Pont, Kappers, & Koenderink, 1997) it has been evaluated the subjects' capability to discriminate curvatures that are statically touched with different regions of the hand. Authors demonstrate that the cutaneous stimulation is an important factor in the human capability of discriminating surface, depending on the distribution of receptors on the hand skin and also on the contact length. In the same work they conclude that the effective stimulus for the discrimination of curved strips is the total difference in local surface attitude. In (Pont, 1997) the author replicates this finding also with an active dynamic touch paradigm, in accordance with the classical results obtained by Gordon and Morrison in (Gordon & Morison, 1982). In the works described in (Louw, Kappers, & Koenderink, 2000, 2002) participants were asked to detect or discriminate Gaussian profiles through dynamic exploration. It is demonstrated that the discrimination threshold increases with a power of 1.3 with the width of the shape. In van der Horst & Kappers (2007) it is examined the curvature discrimination aspects connected with the exploration procedure. In these studies it is found that the way of exploration has a remarkable effect on the discrimination performance of the subjects. In a following study (van der Horst & Kappers, 2008) it is also found the presence of a complete aftereffect transfer between the two hands. Finally Wijntjes et al. (2009) replicated the studies of Pont et al. with a dynamic exploration paradigm. Their results point out that the curvature of a given surface can be expressed by four different descriptors that are: changes in height, curvature, total orientation changes and the length of the path of exploration. It is demonstrated that for a given length of exploration path (from 12 to 780 mm) the total orientation changes are the dominant cues to understand the curvature of a given surface.

However, in this case study a different question needed an answer, which was the minimum discontinuity in a curved surface that can be detected by subjects through dynamic exploration.

PHASE 2: THE INTERACTION STUDY

In order to study the interaction of the user with the product we recorded the position of the user hand while exploring a curved discontinuous surface by means of an optical tracking system. The 20 participants (15 males, mean age 27) taking part to the experiment were asked to distinguish between a discontinuous surface and a continuous curved one, and their correct answers were recorded. For this purpose we used a Vicon System (www.vicon.com) equipped with 5 cameras (model M2) and two marker-set for the tracking of the hand and the base. The cameras sensor works only in the infrared spectrum. The system detects and tracks reflective spheres of 14 mm, which are illuminated by IR-sources with a frame rate of 120 Hz. We positioned the cameras in order to cover the entire working volume for the test (850 mm x 650 mm x 600 mm). The measurement error was under the millimeter. During the test the user wears a marker-set on the back of the hand and explores freely the surface, while the system detects the position of the hand relative to the base (Figure 4.2a).



(a) (b)

Figure 4.2: The recording of hand movement. In the left image (a) the whole tracking system for the experiment is shown. In the right image (b) an example of the recorded data during a test. (*Gatti, Re, Ferrise, Bordegoni, 2011)*

We processed the recorded data in order to obtain a compact representation by considering only one describing dimension. Actually, we discarded the movements in orthogonal direction to the curved template used to test the exploration, because limited by its thickness. Subsequently, we computed the curvilinear abscissa related to the curve. The hand position on the curvilinear abscissa has been exploited to estimate the kinematic features. We applied a low pass filter working at 4 Hz to the data and then speed, acceleration, and jerk of the movement have been computed by means of numerical differentiation. Finally, we computed point-biserial correlation index (r2pbis) to correlate the obtained dynamic features with the correct responses for trials.

The analysis of the path of the hand did not show any particular correlation between scan strategy of exploration and correct responses from the participants. This led us to conclude that no features were particularly important nor in the product nor in the participant behaviour in order to justify particular precautions during the third phase of the optimization process. Therefore we switched to the third phase of the methodology in order to compute the threshold.

PHASE 3: THE SENSORY STUDY

Twenty right-handed participants (5 females and 15 males) aged between 19 and 32 with no known neuromuscular disorders and naive to the task, participated in the experiment. All participants gave their consent prior to testing. The experimental setup consisted in a series of curved templates presenting discontinuity in curvatures, milled using a numerical controlled machine and mounted on a wooden plane having two metal rails in which the stimuli were inserted by means of two holes symmetric with respect to the middle plane (Figure 4.2a). All the templates have been geometrically defined by varying the value of a given radius of curvature subtracting a Δr (G2 discontinuity), while maintaining continuity in tangency (G1 continuity) in the middle point (as illustrated in Figure 4.2b). The standard stimulus (without discontinuities) was an arc of circumference of 540 mm long. The circumference had an 800 mm long radius. The variation of this base radius for the test stimuli was, for the first four subjects, a variation of 0%, 10%, 25%, 40% and 55% of the base radius. Given the high probability of correct response for the last two stimuli the set of possible variations has been changed in order to obtain a more precise threshold estimation. Thus, from the fifth subject to the twentieth, the variations of the base radius were equal to 0%, 5%, 10%, 25% and 40%. The null variation of 0% has been introduced to check for possible biases in the presentation order of templates.

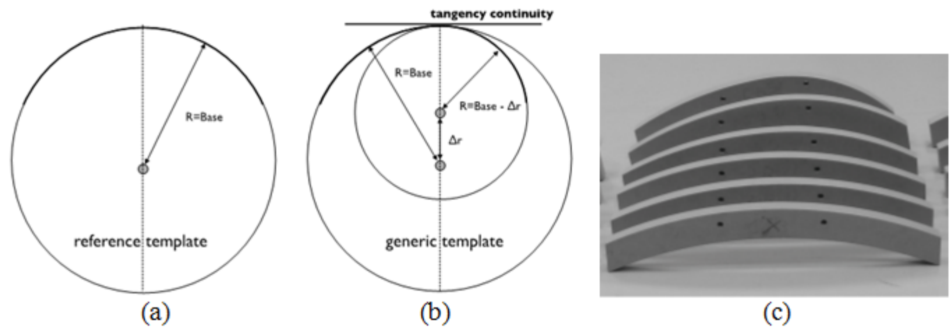


Figure 4.3. Two templates obtained varying the curvature radius keeping the tangency constant. In the left image (a) there is a continuity of the curvature radius. In order to obtain a discontinuity in curvature we only introduced a variation of the value of the radius while keeping the two tangents parallel (b). In the right image (c) some curved templates. (*Gatti, Re, Ferrise, Bordegoni, 2011)*

Participants at the experiments seated comfortably on a chair, in front of a table where the wooden plane was insured. The height and position of the chair were adjusted so as to align the right elbow with the center of the workspace. The order of the standard and the test stimuli on the plane (first vs. second) was balanced and randomized between trials. On each trial the subject started to explore the first template presented. When the subject was ready to start the exploration of the second template, the stimulus was changed by the experimenter. Subject task was to detect the template between the two presented on each trial that presented a variation in the curvature radius. A 2AFC paradigm has been adopted. A brief familiarization period was offered at the beginning of the experiment (26 trials, only using the two steepest stimuli as test stimuli). Experiment lasted one single session having 100 trials (5 test stimuli 2 presentation conditions X 10 repetitions). The evolution of the curvature (steeper side of the stimulus leftward or rightward) was changed every 10 trials.

For each participant, a stimulus response matrix for each Δr was constructed and the sensitivity index d' and response bias β were calculated (Macmillan & Creelman, 2004). In order to estimate the absolute thresholds in the curvature surface continuity we computed the slope of the best fitting line by averaging the slopes (α) of the d' corresponding to the four Δr%. α was computed as:

$$\alpha = \frac{(\frac{d_1^{'}}{\Delta r\%} + \frac{d_2^{'}}{\Delta r\%} + \frac{d_3^{'}}{\Delta r\%} + \frac{d_4^{'}}{\Delta r\%})}{n} \qquad (5.1)$$

Where n is the number of test stimuli and d_1^', the sensitivity index for the discrimination between standard and test stimuli, was divided by the respective Δr%. The threshold was then calculated as 1/α, which corresponded to the Δr% for d'= 1 (see (Pang, Tan, & Durlach, 1991)).

We computed the curvature discontinuity thresholds for all participants with respect to the base radius both fitting the best fit line to the averaged subjects d' and averaging the individual thresholds for each subject (results shown in Table 1). Results for the subjects 7, 9 and 16 has been omitted, since in these cases there was a too high rate of missing and false alarms that makes us unable to estimate the thresholds. However, for the remaining subjects the estimated variation of the radius of curvature necessary to feel a discontinuity on the surface and necessary to discriminate a discontinue surface from a continue one for a base radius of 800 mm was 24.8% of the radius itself (pooled d'). Moreover, the threshold from each single subject results (indicated as mean ± standard error of the mean) was 26.66% ±9.3%. The presence of response bias due to the order of presentation of the stimuli has been also tested, computing the frequency of responses in which the subject indicated the stimulus with discontinuity presented as first on the wooden plane when the two stimuli were identical and with a continuous curvature (Δr%= 0). The participants' frequencies of responses at 90 % binomial interval of confidence did not exhibit a response bias. We also examined whether the proportion of correct response (hit) varied together with the evolution of the curvature. A paired t-test at 95% confidence interval revealed no difference between the participants' proportion of correct response with respect to the side of the evolution. In order to perform this test only the response at stimuli with the Δr% near to the single subject's threshold has been used, excluding the Δr% with a proportion of correct responses > 80% or < 65%.

The threshold values are in line with the results exposed in the studies previously cited despite a quite large variability between subjects. In fact, it is possible to see the subjects' task as a comparison between two different tilted and adjacent 250mm long curvature, the first one with a 800 mm long radius, the second one with a smaller radius and symmetrically displayed. From this point of view, basing on the study of Wijntjes et al. (2009), the main cue for the curvature discrimination (and then for feel discontinuity in two surfaces with a constant tangency) for 250 mm long stimuli is the local surface orientation (attitude).

CONCLUSION

In the present case study we applied the methodology in order to optimize a new haptic technology. The technology to optimize was a haptic stripe able to deform following the shape of a CAD designed object. The design question related to the human ability in perceiving discontinuities the radius of curvatures, and in particular aimed to assess whether people are able to perceive a discontinuity lower that the 8% of the variation of the base radius. The interaction phase allows us to rule out any effect on the perceptive abilities of people given by exploratory procedures. The third phase of the experiment allow us to answer the design question, optimizing the product assessing a human ability in detecting discontinuity in the radius equal approximately to the 12-13% of variation of the radius.

OPTIMIZATION OF THE PACKAGING FOR A LIQUID BATH SOAP

In this second case study we used the concept of crossmodal correspondence for the pragmatical optimization of the product. The design question was to relate to the concept of efficacy, and in particular asked how to augment the perceived expected efficacy of the product at the moment of purchasing. It is important to note that the same case study could serve as example also for a hedonic optimization procedure. In fact, the procedure would not have changed with a different design question (i.e., how to augment the perceived pleasantness of the product). In the case study, we performed a conjoint analysis experiment in order to find out the sensory attributes related to the idea of efficacy in the product. We subsequently performed an experiment to boost the perceived efficacy of the soap by mean of crossmodal correspondences.

PHASE 1: THE DESIGN QUESTION

As in the previous experiment, the design question was utterly clear: How to augment the perceived expected efficacy of the product when the user has to choose it from the shelves of a supermarket? In order to answer to this question we first performed a screening of the literature on crossmodal correspondence applied to hygiene, body care, and bath product.

In particular, we focused specifically on soaps and body lotions finding, as reported in the literature (e.g., Churchill et al., 2009), that the role of olfaction in product evaluation was crucial. This kind of product offers users different kinds of sensory features (such as color, weight, texture, and fragrance) through vision, touch/haptics, and olfaction. According to Schroiff (1991), a product's fragrance can affect people's product purchasing decision in a number of different ways: Confirming the product's likely performance, determining the customer's likely overall satisfaction when using the product, impacting on the brand, and ultimately affecting their purchase behavior. Churchill et al. demonstrated that the fragrance exerted a significant effect on the perceived texture of the shampoo itself, and also on the perceived texture of a person's hair after washing. Finally, in older research, from Millward Brown (Millward-Brown, 2002) reported on a study of the evolution of soap packages and on the interaction between colour and smell. This report highlighted the importance of both fragrance and colour in driving the choice of consumers when it came to soap products. Interestingly, according to this report, colour assumes a greater importance when the fragrance is not available (e.g., when the consumer could not smell the fragrance through the product's packaging).

PHASE 2: THE INTERACTION STUDY

To study the perception of the user in terms of efficacy, a conjoint analysis experiment was performed. 20 healthy participants (12 male) aged between 19 and 34 years (mean of 26 years) took part in the experiment. A set of 12 identical soap bottles were painted in one of three different colours using coloured aerosol spray paint. The liquid soap contained in the bottles was not visible through the opaque packaging. The colours for the bottles were chosen to present different intensities of the colour red. It is important to note that there was little difference between the hues of the pink and red colours used to paint the bottles, while the hue of the white paint could be considered irrelevant given the very low level of saturation. The three colours also presented a similar level of brightness. The variable that differed most among the three colours was the saturation. We considered the white bottles as the null intensity for the attribute "colour", the red bottles as having the maximum intensity, and the pink bottles as having an intermediate level of colouring. Two different levels of perfume were added to the soaps contained in the bottles. The lower concentration consisted of three drops of a strong perfume essence ("Dragon's Blood1"), whereas the higher concentration consisted of the addition of 7 drops per bottle. The essence was thoroughly mixed with the soap in the bottle.

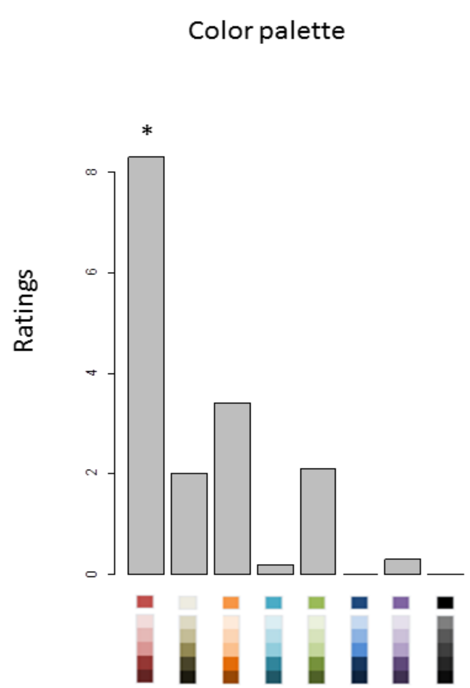


Figure 4.4: results on the preliminary study applied to choose the quality of colour of the bottles in the conjoint experiment.(Gatti, Bordegoni, Spence, 2014)

The colour was chosen basing on the results of a preliminary test. In this test, once the participants had recognized the bottles containing the scented soap, they then had to associate the fragrance with a specific colour range expressed by a chromatic scale. In particular, the participants rated the concordance between the odour and a series of colour palettes (see Figure 4.4), on a scale ranging from 0 to 10 (where a score of 0 indicated the absence of any match between the odour and the colour, and 10 was considered as a perfect match between the colour palette and the fragrance). The results of this preliminary study are shown in Figure 4.4. The participants exhibited a clear preference (average rating 7, Wilcoxon test, $p < .05$) for the red-coloured palette, providing an indication concerning the colour range that was best associated with the fragrance presented in the present study.

The weight of the heavier bottles (bottles 7 to 12, Figure 4.5) was increased by inserting 100 grams of lead weight into the soap container (thus resulting in these bottles being approximately 23% heavier than the lighter bottles). Prior to the start of the main experiment, a 500 grams weight was lifted by the participants as familiarization, in order to provide a common reference point for their subsequent weight judgments (see below). In fact, providing a baseline both for the smell and the weight stimuli, we expected to reduce the variability of responses amongst participants. Moreover, in the data analysis, participants have been included in the ANOVA and regression error terms, in order to further account for any inter-individual variability. Note here also that the differences between weight levels, and fragrance levels were selected in order to be clearly perceptible by the participants. This allowed us to obtain clear results about the main effects of each single sensory modality.

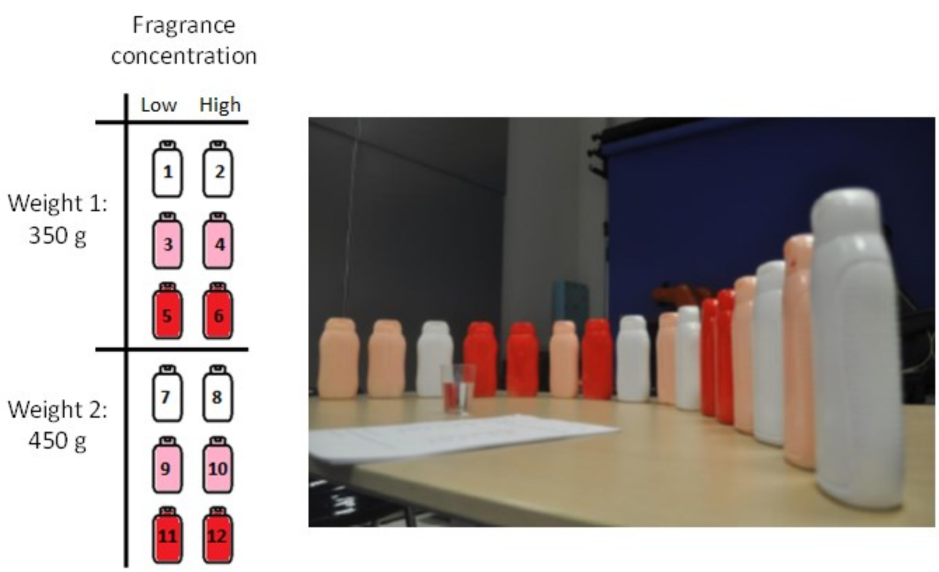


Figure 4.5: stimuli used in the experiment.(Gatti, Bordegoni, Spence, 2014)

The experimental set up had the participants seated at a table on which all 12 of the bottles were arranged in a randomized order. All of the participants took part in a brief familiarization phase, in order to instruct them about the fragrance that they would have to judge. Subsequently, the participants were given instructions concerning the task that they would have to perform. The participants started by lifting the first bottle placed on the far left of the display with their dominant hand. Subsequently, they had to open the bottle and sniff the fragrance of the liquid contained within. Finally, the participants were required to answer questions regarding the characteristics of the product. In particular, participant were asked to rate the expected efficacy of each bottle of soap using a Borg CR100 (Borg, 2007) response scale. The participants used a pencil to make a mark on the scale printed on a sheet of paper, in order to indicate the perceived intensity of the fragrance, paying particular attention to the verbal descriptors.

We were interested in participants' expectations concerning the expected efficacy of the liquid soap product. An ANOVA that included weight, fragrance, and colour as predictors was also applied to the data. According to this analysis, the soap contained in the heavier bottles was rated as having a higher expected efficacy ($p < .01$). Moreover, despite there was not a significant effect of bottle colour saturation or fragrance intensity on perceived efficacy, the mean expected efficacy for the bottles with the lower fragrance intensity was lower than that for the bottles with the higher fragrance intensity, and the p value concerning that factor was relatively low.

	Df.	**Sum. Sq.**	**Mean Sq.**	**F value**	**Pr (>F)**
Colour	2	838	838.0	1.79	p = .18
Weight	1	4811	4810.7	10.33	p < .01
Fragrance	1	1697	1696.8	3.64	p = .05

Table 4.1: results of the ANOVA applied to the results of the conjoint experiment

		Weight		
		350g	450g	
Fragrance	3 drops	29.9±4.4	42.3±4.6	36.1±4.6
	7 drops	38.6±4.5	44.3±4.9	41.4±4.7
		34.3±4.5	43.3±4.7	

Table 4.2: Mean and standard deviation of the ratings for the expected efficacy in the conjoint experiment

From this phase of the experiment we decided to consider relevant in the product interaction when the user had to judge the expected efficacy of a product the factors of fragrance intensity and weight. Therefore we proceeded to the third phase of the optimization procedure.

PHASE 3: THE SENSORY STUDY

In this have we applied a sensory experiment in order to exploit the phenomenon of crossmodal correspondences augmenting the perceived weight and the perceived fragrance in the bottle using sensory signals coming from different sensory channels. As important to note, we avoided to work on the senses of taste and hearing, since it is unlikely that these two senses were reliable in a super market-like environment.

For this study, the same stimuli and procedure of the conjoint analysis were used. However, participants were asked to rate with the same modality the Borg CR100 scale, but this time on the perceived intensity of the fragrance. Moreover, participants were also asked to give an estimation of the weight of each bottle.

To test for any effects of colour, fragrance intensity, and product weight on the perceived intensity of the liquid soap contained within the bottles, an analysis of variance (ANOVA; $\alpha = 0.05$) was performed on the data ($p < .001$). Post-hoc comparison (Bonferroni corrected: $\alpha = .05/3$) revealed statistically significant differences in the perceived intensity of the fragrance of the soap, as a function of the colour of the bottle (all ps < .001).

	Df.	Sum. Sq.	Mean Sq.	F value	Pr (>F)
Colour	2	10235	5117.4	14.81	p < .01
Weight	1	1553	1552.7	5.3	p < .05
Fragrance	1	7648	7648.2	23.4	p < .01

Table 4.3: results on the ANOVA for the perceived fragrance intensity.

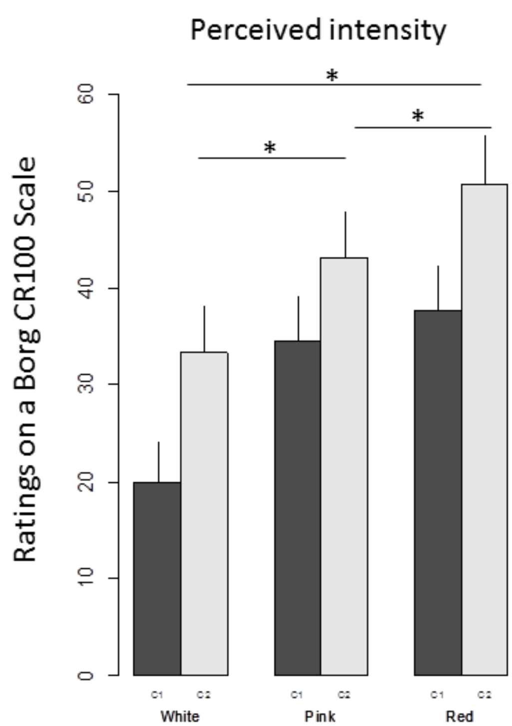


Figure 4.6: Results on the perceived fragrance of the liquid soap. .(Gatti, Bordegoni, Spence, 2014)

In particular, the liquid soap presented in the red bottles was perceived (on average) as having a fragrance that was significantly more intense than that seen in the other bottles (M = 46.6). That is, the participants rated the fragrance sniffed from red bottles as being 16% more intense than the fragrance sniffed from the pink bottles, and as being 44% more intense than the fragrance sniffed from the white bottles. Meanwhile, the fragrance of the soap contained in the pink bottles was rated as 30% more intense than the perfume of the soap contained in the white bottles. As expected, the bottles containing the more intense fragrance were rated as having a smell that was 30% stronger than the bottles containing the weaker fragrance ($p < .001$). Interestingly, the liquid soap contained in the heavier bottles was also rated, on average, as having a fragrance that was 15% more intense than the soap contained in the lighter bottles ($p < .05$). No statistically significant effects of the interactions between the considered factors were observed.

An ANOVA ($\alpha = 0.05$) was also performed in order to test for the effects of colour, fragrance intensity, and weight on the perceived weight of the bottles. No effect of the other sensory modalities was found on the estimated weight. Indeed, the only effect that was documented related to the weight inserted into the bottles. Indeed, as expected, the heavier bottles were indeed rated as significantly heavier ($p < .001$, average estimated weight ± standard deviation: 462g ± 175g) than the bottle without lead weight inserted (average estimated weight ± standard deviation: 271g ± 107g). Moreover, no interaction effects were found.

	Df.	**Sum. Sq.**	**Mean Sq.**	**F value**	**Pr (>F)**
Colour	2	4577	2288	0.29	$p = .74$
Weight	1	2316738	2316738	299.1931	$p < .001$
Fragrance	1	7362	7362	0.95	$p = .33$

Table 4.4: results of the ANOVA for the estimated weight of the bottles

CONCLUSION

In the present case study we optimized the ability of maximizes the expected efficacy of liquid bath soap. In the interaction phase we highlighted the characteristic of the product important when the user had to judge the expected efficacy of it. Subsequently, being these characteristics fragrance and weight, we performed a sensory study in order to boost these two characteristic of the product by mean of crossmodal correspondences. Results reported that changing the colour of the bottles and augmenting their weight would augment the perceived efficacy. This means that by only acting on the packaging, without modifying the content of the bottle, designer would be able to reach an optimized product.

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CONCLUSIONS AND FURTHER DEVELOPMENTS: FIVE

This thesis represents the final product of the three years of my PhD. It exposes a methodology aimed in optimizing products by mean of experimental methods. In particular the methodology is composed by a first phase in which the designer highlights and makes clear the design question expressed by the client. In a second stage, the interaction between user and product is assessed, in order to find the important characteristics of the product that are related with the design question. Finally, a sensory optimization experiment is performed in order to optimize the product by mean of cross modal correspondences or threshold measurements.

A further aim of this thesis was to understand, revise, and finally expose methods and theories connected with the two phases, in order to allow the designer to understand and apply the methods during the use of the methodology. In fact, this thesis can be also viewed as a review of methods to study the interaction with the product and its sensory characteristics.

As a matter of fact, this methodology links for the first time, in a systematic way, methods to study the user-product interaction (previously used in literature to reach an optimized design of products) and perception to sensory studies in order to optimize the product, proposing, in fact, a further step in the experimental optimization of the product. Indeed, although crossmodal correspondences has been largely used in the realm of product design, this is the first time that they are included in a structured methodology and explicitly treated as a tool to improve the design of product (for examples on design and crossmodal correspondences see chapter three). At the same time, this methodology give a prominent role to the psychophysics, which has been already widely used in order to "tune" new devices and technologies on the human perception, but that has also often been neglected in the product design field. It is also interesting to consider the outcome of the methodology speculating on its formalization based on trade-off analysis.

Trade-off analysis aims to answer to optimization questions involving a trade-off. In particular it answers to question like:

- "Are the solutions that are being suggested as good as possible, i.e., are they on the frontier?"
- "How much must I give up to get a little more of what I want most?"

Usually this trade-offs are expressed by means of Pareto diagrams. Pareto charts (diagrams, see De Corte, Sackett, and Lievens, 2011, cited in chapter 3) allow us to study the best solution by plotting all the possible solutions in a multidimensional space. Let us imagine, for example, that we have to optimize the product by augmenting the perceived quality of it, but keeping the price low. Let's then suppose, as it reasonable to think, that augmenting the quality will augment the price. Mathematically speaking, this is an optimization problem. Pareto charts allow us to compute the optimum for the two conjoint functions or, better, allow us to compute the Pareto front, which express all the infinite solutions coming from the optimization of a vector function. Graphically speaking, the Pareto front for our example is represented by the line in Figure 5.1.

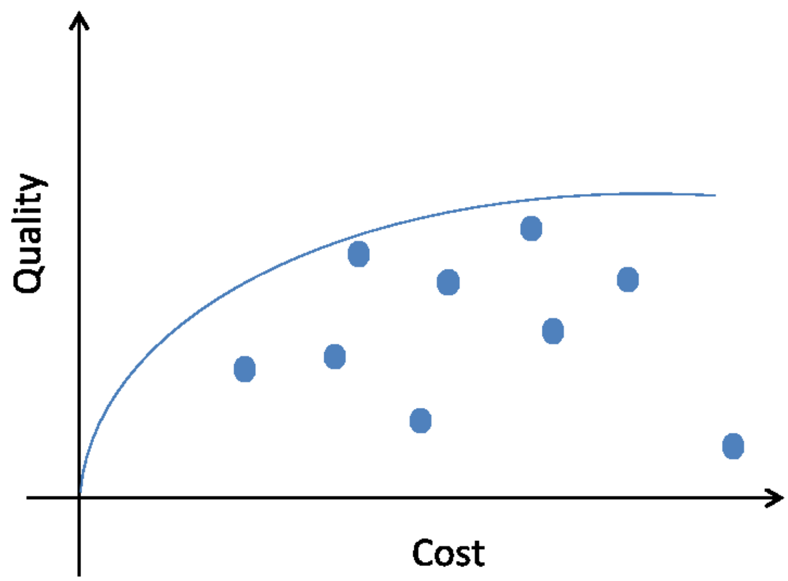

Figure 5.1: Pareto diagram for our example

The possible solutions are instead expressed by the blue dots. Let us imagine now to apply our methodology in order to change the sensory features of the product, for example the colour of the product, in order to augment the perceived quality of the product without influence the cost (assuming that the colour does not influence the cost of the product). The change in the Pareto problem would be as expressed in the figure 5.2, allowing a higher quality keeping the cost constant (or, as in the example of the soap bottles, allowing a higher perceived efficacy keeping the cost related to the augment of the fragrance in the bottle constant).

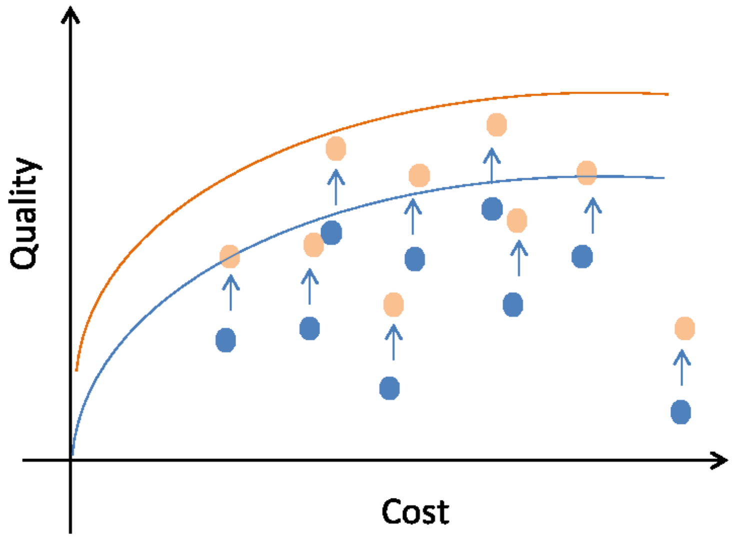

Figure 5.2: Effect on the Pareto representation of the application of the methodology

The formalization of the effects of the methodology by mean of Pareto diagrams and trade-off analysis is only speculative at his stage, and further studies are necessary to better go deeper in the formalization.

Other further developments of the work will include the representation of the methodology by mean of an interactive map. In particular, an online platform will be developed. The website will be designed as a toolkit aimed at guiding designers in structuring their experiments. The website will be free to access for everyone, although it will require a registration in order to contribute actively adding methods, comments and further case studies. A first computer based version of the methodology is already in development.

In the final version (a possible screenshot can be seen in Figure 5.3), the designer using the methodology will first name his (her) case study and choose whether to focus on a hedonic or on a pragmatic optimization. Once selected the desired option, the computer based program will guide the user through the first phase of the methodology: the formulation of the design question.

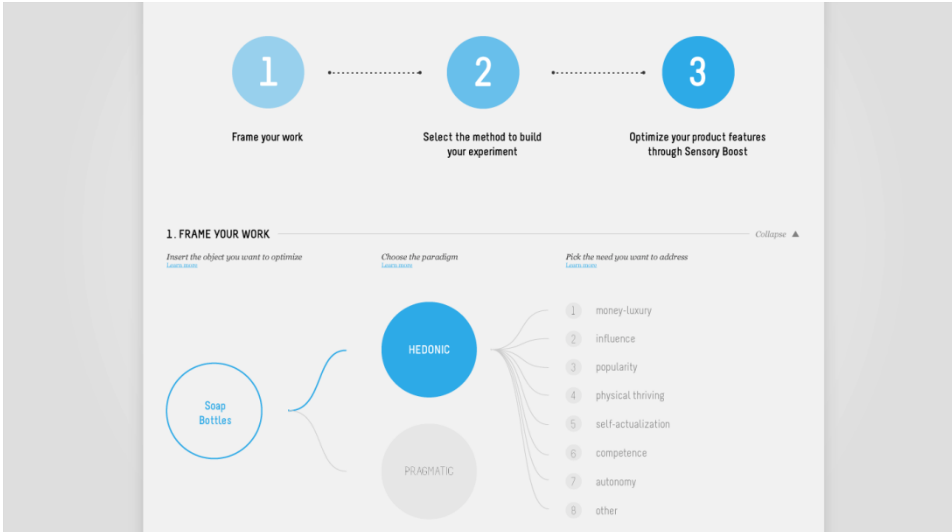

Figure 5.3: A screenshot from an embryonic version of the computer based methodology

Each choice of the user will be recorded and each phase of the methodology will be explained and offered to the designer on the computer screen. On figure 5.4, for example, a screenshot from the first computer based prototype shows the phase of selection of the methods to study the important features of the product (Phase two, interaction study).

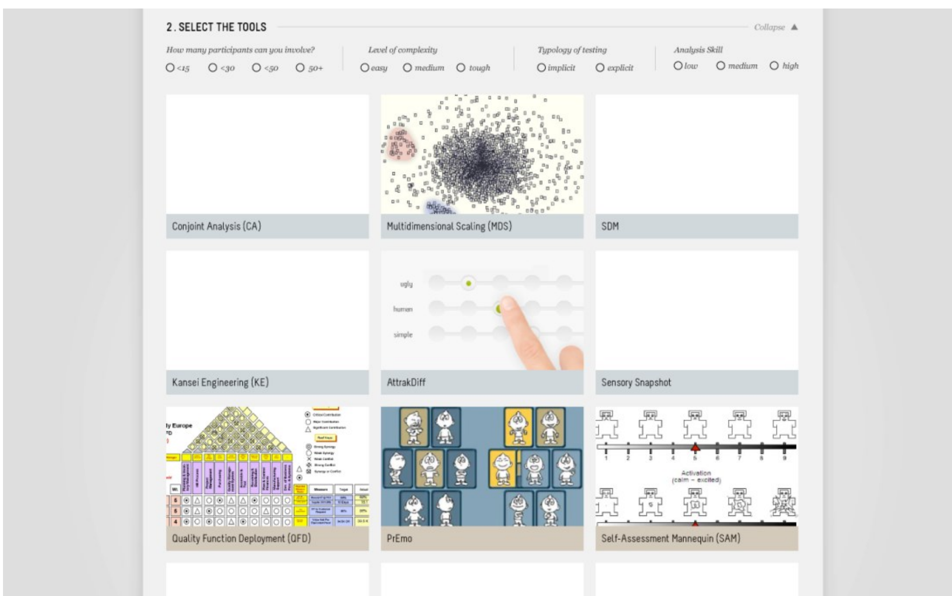

Figure 5.4: A screenshot from the second phase of the methodology, the choice of the experiment investigating what is important for the user during the product-user interaction

Noteworthy, further information will be associated with each method. It will be indeed possible for the user to apply filters to the methods, in order to be facilitated in choosing the method that better suites him (her). The filters considered so far are: the number of participants that can be involved by the user, the level of complexity of the experiment (which includes equipment, phases, set up, prototypes, etc.), the user's skills in analysing data (some of the tools may require medium-advanced statistical skills), the contribute the experiment bring in addressing a pragmatic question, the contribute the experiment bring in addressing a hedonic question, and a further categorization of the methods and tools, explicit or implicit. Moreover in the present version of the computer based methodology, all the windows representing the method are actually clickable and expandable: a quick preview on any of them can be visualized by the user, and a link to the page where a complete explanation of the method is available.

Finally, the "Sensory Boost" section of the computer based version stores all the information regarding the third phase of the methodology, and therefore includes tips on how to run experiments, plus the definition of psychophysics and crossmodal correspondences, some case and examples, and the methods to measure the thresholds in the psychophysical experiments (Figure 5.5).

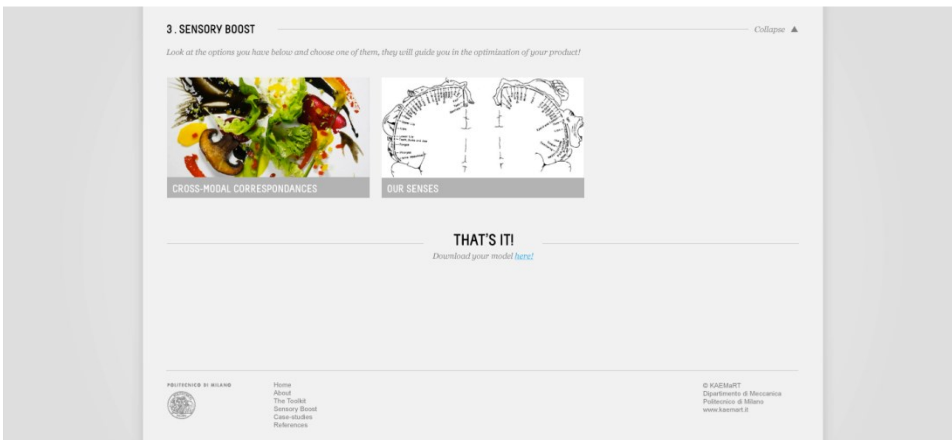

Figure 5.5: Screenshot f the computer based version of the methodology concerning the sensory boost.

Finally, a Case-studies section has been thought for the web version of the methodology, which will include a list of projects and researches that have been developed following the methodology here presented. This section is designed to be open-access and crowd-sourcing, since anyone will be able to contribute uploading his/her own application of this tool.

As final remark, from a personal point of view, this methodology is the product of three years spent working in a multidisciplinary environment. Collaborating for these years with the engineers in the mechanical engineering department, being involved in studies that included usability assessments and prototype evaluations, allowed me to develop the knowledge needed to learn the methods exposed in the phase two of the methodology. It also provided me with the mathematical and programming skills needed to apply the methods and to develop frameworks for the method application. The third phase is instead due to my collaboration of more than one year with the experimental psychology department in Oxford, which deserves the credits for the part of the methodology related to the optimization by mean of crossmodal correspondences. Finally, the first part of the methodology (chronologically the latest included), as well as the whole experience design framework represented in which the methodology is nestled, come from a constant effort of tuning the experimental methods to the design realm, following courses on the design thinking and culture, and actively discussing with designers inside and out the academia (on this particular regard, many thanks to Francesco Trabucco, Fabio di Liberto, Betina Piqueras-Fitzman, Jerome Linder, and Serena Camere).

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