An analysis of the notion of illusion and illusory phenomena. Illusions in haptic, dynamic, kinesthetic touch

Elena Pasquinelli

ECOLE DES HAUTES ETUDES EN SCIENCES SOCIALES

THESE
pour obtenir le grade de
DOCTEUR DE L'EHESS
Discipline : Philosophie
présentée et soutenue publiquement
par
Mme Elena PASQUINELLI
le
10 Mars 2006

Titre :
AN ANALYSIS OF ILLUSION AND ILLUSORY PHENOMENA.
ILLUSIONS IN HAPTIC, DYNAMIC, KINESTHETIC TOUCH

(ANALYSE DE LA NOTION D'ILLUSION ET DES PHENOMENES D'ILLUSION.
INNLUSIONS DE TOUCHER HAPTIQUE, DYNAMIQUE ET KINESTHETIQUE)

Directeur de thèse :
M. Roberto Casati

JURY
M. Benoît Bardy
M. Massimo Bergamasco
M. Jerome Dokic
M. Guglielmo Tamburrini

An analysis of the notion of illusion and illusory phenomena.

Illusions in haptic, dynamic, kinesthetic touch.

Table of Contents

Preface

Motivations

The present work was begun during my stay in a laboratory specialized in perceptual robotics viz. in creating robotic systems for the haptic interaction with real, distant and virtual environments and in intersensory devices for virtual and mixed reality (PERCRO Laboratory – Scuola Superiore Sant'Anna, in Pontedera, Pisa). The collaboration was very rich and fruitful, the idea being that I would learn from the know-how embedded in the construction of the machines in use at PERCRO and I would contribute to theoretical knowledge about perception, in particular haptic and intersensory perception. In a triangulation of opinions between me, the director of PERCRO Massimo Bergamasco and Guglielmo Tamburrini, the co-director of the present thesis from the Dipartimento di Filosofia of Pisa, it was decided to begin research on different forms of illusion that concern the touch modality; in particular those aspects of the touch modality that could be of interest for haptic and intersensory devices, that is, illusions of touch in dynamic and/or intersensory conditions rather than tactile or cutaneous illusions.

The haptic and intersensory devices developed at PERCRO are in fact complex systems that allow the user to actively interact with virtual or distant objects. The haptic interaction is based on a force-feedback system: in response to the muscular effort deployed in order to tactually explore the object, the user receives back a certain resistance, a force which is related to the desired shape, elasticity or rigidity and texture of the object. The response is exerted at different points of the body of the user, depending on the particular structure of the force-feedback system: one or more fingers or even different points of the entire arm and hand system. The haptic sensation is normally coordinated with a visual stimulation which can be more or less immersive (from the traditional video monitor to cave systems where the user is totally immersed).

The simple contact with such devices raises some questions about the functioning of perception. The correct development of the amazing hardware and software devices I have seen in action at PERCRO requires, in addition to vast knowledge in robotics and computer science, a detailed knowledge about the functioning of perception. This knowledge about perception exists in part in the specialized literature on the psychology, psychophysiology, neurophysiology and physiology of touch and of the sensory organ; in part new knowledge can be gained by the use of these same machines by proving the perceptual capacities and the perceptual responses of the users in different stimulation contexts.

Some of the most important questions about the functioning of perception raised by haptic and multisensory devices concern the stimuli the tactile sense is sensitive to, the way a tactile object is constructed starting from force-feedback stimuli, the way the stimuli from different fingers are combined into a unitary, coherent percept, the way the stimuli from different sensory modalities such as haptic touch, vision and audition are combined into a multisensory coherent percept, the role of the action of the user in perception.

But other fundamental questions were posed to me by the researchers at PERCRO at each time we discussed perceptual issues and my work on illusions: what are illusions, what they do reveal about perception, is there a unified vision of perception? These questions became more and more impelling when a larger collaboration started which gave rise to a European Network of Excellence dedicated to the development of special interfaces based on the action and perception of the user (these are called ‘enactive interfaces’ and the network has been named *Enactive Network*). The network is comprised of researchers from widely varying disciplines, from robotics to psychology to philosophy (with the participation of the Institut Nicod). The idea is to combine the knowledge about the psychology and psychophysiology of perception with the technological competences that are necessary in order to create a new class of human-computer interfaces based on the principles of action and perception. In particular, different schools the domain of Psychology are represented, such as the ecological approach, the sensorimotor approach and the mainstream indirect, inferential perception approaches. According to the differences in the approaches to perception different opinions have been expressed about the different questions I have named before, including the nature of illusions and their role in the context of a psychological theory of perception.

Regarding the pragmatic needs expressed by the experts in the technological domain (the need for indications about the best way for designing interfaces based on action and perception) new difficulties arose from the differences in the approaches to perception. In some way, the experts in technology asked for some accord in order to proceed successfully.

A difficulty arose, for instance, in connection with the notion of illusion: the representatives of the ecological approach strongly objected to the notion of illusion, the sensorimotor theorists insisted on the redundancy of taking recourse to internal representations and other concepts that were used by the mainstream approach in order to characterize illusions.

Methodology

The aim of the present work is not to describe the nature and causes of illusions, but to provide a neutral characterization of the notion of illusion based on the structural features of illusory phenomena.

The methodology that I have adopted can be characterized as bottom up one: I start with the description of the controversy centering on with the most widely studied haptic illusion, the Size-Weight Illusion. The analysis of the terms of the controversy helps show that illusory phenomena are widely exploited in order to investigate the functioning of perception; disaccord arises when the causes of illusions and the nature of illusory phenomena are sought to be explained.

The text proceeds by the extraction of the common characteristics of illusory phenomena, so as to provide a neutral characterization of the notion of illusion based on the external and behavioral characteristics of illusory phenomena.

Through the description of other illusions (proprioceptive illusions provoked by muscle vibration, Aristotle's illusion, Viviani's illusions, some intersensory illusions and conflicts) I have introduced some other considerations about illusions; these considerations concern the heuristic role of the study of illusions for the understanding of perception and cognition and the role that illusions might play in human cognitive functioning, both at the adaptive and epistemological level.

The illusions I have chosen to describe issue from the haptic, dynamic and kinesthetic touch modality.

My research at the PERCRO laboratory and the the collaborations and discussions with the people there working on haptic interfaces have certainly constituted a guide for my researches in this sense.

My choice of the touch modality in dynamic conditions is motivated by the fact that the illusions illustrated are particularly relevant in the context of the controversy between indirect and direct (ecological and sensorimotor) approaches to perception about the notion illusion.

Ecological and sensorimotor approaches reproach the indirect approaches for focusing their attention on static phenomena that do not represent the natural, ecological conditions in which perception happens, that is, of hiding the dynamic reality of perception in their experimental settings. All the illusions I have illustrated present this dynamic character, in that they involve the issue of perception determined by movement and the issue of the perception of movement. Thus I have not introduced all the illusions related to the touch modality that are described in the psychological and technical (robotics, for instance) literature.

Another objection frequently raised by sensorimotor theorists and ecologists against the mainstream view is that in the mainstream approach perception is studied in isolation from the sensory modalities, while perception in normal conditions (outside the experimental settings of laboratories) is largely multisensory. I have thus chosen to illustrate the case of intersensory illusions where the haptic modality is involved.

Results

This is the background of the present thesis.

On the basis of the existing literature, both on the side of the mainstream and on the side of the ecological studies about haptic perception, I was inclined to consider illusory phenomena as powerful instruments for investigating the processes of perception. I noticed in fact that in the ecological approach to perception (the approach which is most critical toward the notion of illusion) illusory phenomena are employed in order to set up suitable experiments for investigating the specific quantities to which the haptic system is sensitive. The Size-Weight Illusion is an illustration of this fact. Nevertheless, ecologists refuse to call 'illusions' the phenomena they employ for their experiments and they discard the notion of illusion.

It could be suggested that the controversy about illusions can be reduced to a purely terminological debate to the extent that the ecological approach makes use of illusions without calling them by that name.

However, I do not subscribe to such a description of the controversy. The ecologists' rejection concerns the very notion of error and is not the simple avoidance of a term.

What is unacceptable with the notion of error and illusion, both for the ecological and the sensorimotor approach, is the idea of a failure during an inferential process based on internal representations and symbolic knowledge (an idea introduced by the indirect inferential approach to perception).

What I propose to do is to consider illusions from a pragmatic point of view and to provide a characterization of illusory phenomena which is immanent to the structure of the illusory experience, with no recourse to the notion of inferential process or other notions that are connected to specific theoretical approaches. This operation is possible because illusory phenomena do present some specific features which are not all together present in other perceptual phenomena, such as normal, non-illusory perception or even other types of errors in perception.

The first of the specific characteristics of illusory experiences is represented by the fact that an illusory experience can always be recognized as being non-veridical by the subject who experiences it, or at least by the fact that the illusory phenomena make the subject alert to the possibility of there being some error in his actual experience or in his past beliefs. The awareness of the presence of an error is an epistemic state which is made possible for the subject by the recognition of the presence of a violation of coherence between two or more of his experiences. There is no necessity for the subject to step out from the experiential course. The notion of error is thus assumed as a primitive notion and it is not defined but only characterized in terms of coherence and violation of coherence, since it is the presence of a violation of coherence (of a discrepancy) that indicates the presence of an error. The notion of error is not characterized in terms of the causes of the error or of the nature of the error: it is not committed with the indirect inferential approach to perception, and so it is not the notion of illusion.

A second characteristic of illusory phenomena which is widely recognized is represented by the robustness of illusions, both in the sense that illusions resist knowledge and in the sense that illusions are experienced systematically by the same subject in the same conditions and by different subjects. These are important characteristics that are not present in all types of errors that can be committed in perception.

As a third characteristic I have individuated the reaction of surprise which is provoked by the discovery that an error has been committed. Even if this characteristic is common to the discovery of many errors, it is a specificity of illusory phenomena that the subject can be surprised each time he experiences and re-experiences the same illusion; this specificity is connected with the resilience to knowledge and the systematic nature of illusory phenomena.

I suggest that on the basis of these three characteristics of the structure of illusory phenomena it is possible to provide a characterization of illusions which is neutral toward any theoretical approach to perception, because the characterization does not depend on the inner nature of illusions, on their causes or in the perceptual processes involved. This characterization can thus be used in the pragmatic context of the programming of experiments about perception and in the applications that are related to the study of perception, such as the development of human-computer interfaces based on action and perception.

In other words, my presentation of a neutral characterization of the notion of illusion is dedicated to disentangle the notion of illusion from the commitment to the notion of inferential process. What I want to show is that, once the disentanglement is done, illusory phenomena still stand out as a special class of perceptual phenomena which cannot be confounded with other perceptual phenomena. As in the case of pathology, the specific features presented by illusory phenomena allow the experimenter and the researcher in perception to isolate a specific class of experiences and specific conditions for the appearance of such experiences. This fact represents an important pragmatic value for the notion of illusion in the context of the research on perception and in the context of the indications for the applications described.

It could be suggested that the notion of error could simply be omitted in the characterization of illusory phenomena, since it is this notion that creates for the most part the problems with the notion of illusion.

However, there are some illusions, such as the proprioceptive illusions of impossible movement provoked by muscle vibration, that are accompanied by a sense of something being wrong, bizarre and even impossible. This sense of impossibility is connected with the perception of a discrepancy between two or more experiences of the perceiver or between actual experiences and held beliefs; the sense of impossibility alerts the perceiver that there is some error in his experience, that something in what he is perceiving is mistaken or some of his beliefs are false. The main interest of a situation like this is in the fact that the perceiver gains an immediate insight into the epistemological value of his experience, that is, the epistemological judgment does not require the perceiver to step out from his experience, but is internal to the experience itself. The notion of error is thus useful for an analysis of perception and illusions. This is, according to me, an important reason for maintaining the notion of error in connection with the notion of illusion, even if the characterization of the notion of error must be revised in terms of coherence and its violation.

Introduced concepts

In the context of the discussion about proprioceptive illusions produced by movement, the distinction between illusions we are immediately aware of and illusions we are not immediately aware of is introduced.

In both cases coherence is violated and the subject becomes aware of the possibility of committing an error by becoming aware of the existence of some discrepancy between his experiences. Illusions we are immediately aware of present a special interest because the awareness of the error (the recognition of the existence of a discrepancy between experiences) is immediate and does not require a further process of exploration of the comparison of the perceptual experience with external information. Illusions we are immediately aware of are thus particularly suitable for showing that illusions (the awareness of being victim of an illusion) present an epistemic value for the subject: the subject gains an immediate insight in the truth value of his experiences.

Another concept which is introduced is the distinction between synchronic and diachronic violations of coherence. In the case of synchronic violations of coherence the discrepancy exists between two or more stimuli that are simultaneously experienced. In the case of diachronic violations of coherence the discrepancy stands between actual experiences and past experiences or beliefs or knowledge.

This distinction is not to be taken as coinciding with the distinction drawn between illusions we are immediately aware of and illusions we are not immediately aware of; in fact, illusions we are immediately aware of can both involve a diachronic and a synchronic violation of coherence.

Intersensory illusions and conflicts reveal to be especially suitable for investigating the role of coherence in perception. Their characteristics indicate that coherence might represent an adaptive value for cognitive functioning. Coherence is in fact actively re-established every time it is possible to do so, even in presence of discrepant stimuli. It is when the re-establishment of coherence is impossible that the subject experiences an explicit conflict and becomes immediately aware of something going wrong.

As in the case of experienced conflicts, in the case of illusions we are immediately aware of the coherence between two or more experiences cannot be re-established. On the contrary, in the case of illusions we are not immediately aware of, the subject needs a surplus of information (a second round of exploration or the recourse to his own knowledge or the knowledge of a second person) in order to be surprised about his own error; this is also the case for the conflicts that are not explicitly experienced, when coherence is re-established in spite of the existence of discrepant stimuli.

The study of illusions thus presents a heuristic value for the study of different aspects of perception and cognition.

This value includes the investigation of the role of motor knowledge and motor skills in perception (which is a characteristic claim of direct approaches to perception such as the ecological and the sensorimotor view). I have introduced this topic in relation to the examples of two studies: the experiments conducted by Benedetti on Aristotle's illusion and the experiments created by Viviani on the perception of dynamic events.

The idea of the existence of an implicit form of expectations based on motor knowledge and motor skills in perception is not completely original: the sensorimotor approach to perception insists on the existence of sensorimotor connections (the concept of sensorimotor contingency), the ecological approach on the role of action on the contents of perception (the concept of affordance), and motor theories of perception in general insist on the role of movement and action in perception. I have introduced the idea that these different forms of motor knowledge and skills imply the existence of relative expectations, as it is the case for the expectations produced by explicit, symbolic knowledge. I suggest that implicit expectations based on motor skills and knowledge might play a role in the occurrence and appearance of some illusions.

Nevertheless, I do not advance a general thesis about the origin of illusions and about the role of implicit vs. explicit expectations in perception. I simply suggest that certain illusions are suitable for exploring this issue, and not that every illusion is caused by the interactions between action and perception.

Applications

In the present work I insist on the pragmatic value of the notion of illusion for gaining a better knowledge about perception. This knowledge reveals to be useful in the case of those technological applications that are based on the understanding of perceptual and cognitive processes.

The study of illusions, for instance, provides relevant indications for responding to some of the questions raised by the recent developments in the domain of human-computer interfaces and virtual reality.

The studies on the Size-Weight Illusion conducted by the ecological researchers indicate that the haptic system (the muscles of the arm) might be sensitive to the resistance opposed by a hand-held object to the fact of being moved, and specifically to the rotations imposed by movement.

The studies on a variation of the Size-Weight Illusion, the golf-ball illusion, indicate that the perception of weight can nevertheless be influenced by previously acquired knowledge about perceived objects. Special training with acquisition of knowledge could thus influence the perceptual result, at least in case of perception of weight.

Knowledge relevant for perception (in the sense of knowledge that influences the content of the perceptual outcome) need not to be of a symbolic form, as indicated for instance by the study of Aristotle's illusion. In the case of Aristotle's illusion, in fact, the illusion seems to be produced by the fact that when the subject assumes a position with crossed fingers he trespasses the normal range of action of the fingers; beyond this range no difference in the stimuli is perceived. The subject knows very well the position of his fingers and he cannot be fooled about that as he is fooled about the position of the objects which are sensed with the crossed fingers. The relevant knowledge for the illusion to appear and disappear seems to be of a practical and motor nature: it is based on the motor habits of the subject. In fact, a long training with crossed fingers has the effect of modifying the normal range of action of the fingers and of making the illusion disappear. In this case too, it seems that training could have important effects on the perceptual result. This can be an interesting indication for producing a desired perceptual experience, especially a new experience that is not possible in normal conditions or in the case where the stimuli provided by the interface are not sufficient. Additionally, the results of the experiments on Aristotle's illusion indicate that the combination of the partial percepts issued from separated fingers into one coherent unit (a problem which interests the designers of multi-finger haptic devices) depends on the existence of motor habits and proper ranges of action.

Both the studies on Aristotle's illusion and on Viviani's illusions show the importance of the role of movement for shaping the perceptual content. Viviani's illusions in particular show that subjects have a tendency to project a law which is specific of biologic motion in all the perception of dynamic event, and it is this law which connects the perceived trajectory and velocity of the dynamic object. It seems that the application of this law could make artificial creatures look more natural in their actions. It also seems that the shape of a perceived object can be modified by the pattern of velocity of its movement.

Studies on intersensory conflicts and discrepancies represent a great interest for the understanding of multisensory perception and for the development of mutisensory devices. It seems that the perceptual system presents a strong tendency towards the preservation of the coherence of the perceptual outcome, even in presence of discrepant stimuli. This observation seems to be valid also for diachronic conditions, that is, for the existence of a discrepancy between present and past experiences. Some of the difficulties in coordinating different sources of information in the case of multisensory devices could thus be simply solved by the perceptual system itself. A detailed study of the effects of the presentation of discrepancies and of the different outcomes in connection with varying conditions would thus be suitable for the development of multisensory human-computer interfaces.

All the cited examples provide us with a better understanding about the way the brain and the body in interaction with the environment contribute to the shaping of the perceived reality. The knowledge that is thus acquired presents a theoretical value for the theories of perception and cognition and a pragmatic value, for instance, for designing more and more believable interactions with virtual realities and artificial worlds.

Introduction

The *Introduction* presents the dichotomy between two kinds of approaches to perception: the traditional approach based on the role of internal representations and a new vague of approaches based on the role of movement. This distinction also involves a different attention toward perceptual phenomena that are preferentially investigated and a different approach toward the notion of illusion. The traditional approach has mainly focused on the visual modality and has assigned an important place to illusions in general and visual illusions in particular. The new vague insists on the importance of studying perception in a more ecological frame-work, as a multisensory and dynamic activity; the notion of illusion tends to be discarded because of its presumed entanglement with traditional approaches. The reasons of the new vague are presented and some difficulties of the traditional approach in explaining illusions are described. In particular the reasons of the new vague are related to the interest of focusing the attention on intersensory conflicts and haptic illusory phenomena, in which the role of movement and of intersensory connections is made explicit.

Illusions are controversial concepts

The aim of this thesis is to show that a theory of perception cannot easily renounce the concept of illusion without losing a part of its explanatory power. In fact, the description of a special group of illusory perceptual phenomena that are characterized by violations of coherence, robustness and a reaction of surprise provides the theory with an instrument for acquiring an insight into perceptual mechanisms. These mechanisms include the ones such as those involved in the reactions of the perceptual system to the violation of coherence (both in the case of synchronic inconsistency between actual stimulations and in the case of diachronic inconsistency between past experience or knowledge and present stimulations) and on the nature of expectations in perception.

These considerations are of an epistemological nature. The notion of illusion and the concepts that are involved in its characterization within the psychological literature are conceptually analyzed and the characteristics and behavioral consequences of illusory phenomena are investigated in order to provide a characterization of illusory phenomena which is not necessarily coincident with the common use of the term 'illusion' but which can be of use to psychological theories of perception.

The adopted approach goes bottom-up: in *Chapter 1* it will be shown how the notion of illusion is employed within the psychological literature (in particular by illustrating the case of the Size-Weight Illusion and the argumentation between direct and indirect approaches to perception which arises in connection with the explanation of illusory phenomena and the notion of illusion itself).

This will be followed by a philosophical analysis of the notion of illusion and of the related concepts that is intended to show how philosophical analysis can contribute to the debate about illusory phenomena by providing a characterization of the notion of illusion (*Chapter 2*).

Chapter 3 will defend the heuristic value of the notion of illusion within the framework of a psychological theory of perception and *Chapter 4* will conduct the discussion at the level of the functioning of the mind by suggesting a functional role for the awareness of being victims of illusions, as connected with the awareness of the presence of a violation of coherence. Two different roles will be analyzed: adaptive and epistemic.

The problem of the opportunity to take recourse to the concept of illusion arises in view of the strong criticism against the notion of perceptual illusions within the framework of certain direct theories of perception. Direct approaches to perception oppose the indirect, inferential approach (to which the classic definition of perceptual illusions is due) that perceptual phenomena described as illusions can be re-described with no recourse to cognitive inference and knowledge, just by well establishing the role played by movement and the connections between movement and perception in the perceptual outcome.

Nevertheless the concept of illusion is not necessarily entangled with indirect approaches to perception and a characterization of illusory phenomena will be provided in this thesis which is not based on the other concepts (such as the concept of cognitive inference) that are proper to indirect approaches. This thesis also aims at showing how the concept of illusion is compatible with the claim that movement can play a crucial role in perception and that the recourse to the concept of illusion allows a better insight in the way movement and motor possibilities can shape the perceptual outcome.

The traditional approach to perceptual illusions

In a sense, in the classic approach to the study of illusions, unimodal illusions -in particular visual illusions- are considered the paradigm for all illusory phenomena. R.

Gregory, for instance, has mostly dedicated his attention to visual illusions, even if, as he affirms:

> "Illusions can occur in any sensory modalities and they can cross the senses." [Gregory, 1968, p. 179]

However, the privilege accorded to visual illusions is not mandatory, and is more of an artefact in the historical development of research in perception, as vision has been studied first and more intensively than other senses or than integrated, multisensory perception. It is then important to keep in mind that there exist a wide variety of perceptual illusions. It turns out that a close look at illusions in other modalities, such as haptic touch, points out the difficulties in the explanation of classic geometric illusions which are proposed, for instance, by Gregory.

The so-called optic geometric illusions constitute a wide and largely studied class of visual illusions[1], which includes the Horizontal-Vertical Illusion or HVI (the length of a vertical line which forms a 90° angle with a horizontal line, thus forming an inverted-T or a L-shape, is perceived as longer than the horizontal line of the same physical length), the Mueller-Lyer illusion (a line with arrow shaped endings is perceived as shorter than a line of the same length with inverted arrow shaped endings), the Ponzo illusion (a horizontal line inserted in a wedge looks longer when it is close to the peak), Zoellner illusion (two vertical lines crossed by slanted lines, appear slanted) and Delboeuf illusion (when concentric circles are compared to an external circle, the internal circle looks bigger). According to Gregory, optic geometric illusions are products of the misapplication of

[1] See for instance [Coren, *et al.*, 1976]; [Watson & French, 1966]; [Fisher, 1966].

visual rules and knowledge[2]. The error is caused by perspective or other depth cues. It is suggested that size and shape constancy are the result of active scaling processes. In the case of 2-dimensional figures such as the crossed lines of the HVI, perspective or other depth cues are not connected to depth information. The result is an inappropriate constancy scaling, which causes a series of perceptual distortions. The hypothesis of the *Inappropriate Constancy Scaling* encounters some difficulties in the fact that some optic geometric illusions can be observed in the haptic modality. This is true for the HVI, the Mueller-Lyer, Ponzo, Zoellner and Delboeuf figures[3]. This fact suggests that a purely visual mechanism cannot be sufficient to explain the illusory effects provoked by the cited figures (which are reproduced in 3-D for the experiments with the haptic modality). It has been proposed by [Frisby, 1971], in order to save Gregory's explanation, that the haptic modality is mediated by visual representations, and that the presence of geometric illusions in the haptic modality is the effect of a cross-modal transfer of representations from the visual modality.

However, this hypothesis is ruled out by the existence of haptic geometric illusions in congenitally blind subjects and by the results of the comparison of visual and haptic illusions for the same figures. In fact, not all the figures that generate visual geometric illusions generate corresponding haptic illusions (it is not the case for the Poggendorff illusion, for instance), and even in the cited cases of the existence of haptic counterpart of the visual illusions, the outcomes are not necessarily equivalent. In the haptic modality,

---

[2] [Gregory, 1963a, 1963b, 1964, 1965, 1966, 1967, 1968a, 1968b, 1973a, 1973b, 1978, 1983, 1997, 1998]; [Gregory & Harris, 1975]; [Humphrey, Morgan & Gregory 1965]; [Day & Gregory, 1965].

[3] [Suzuki & Arashida, 1992].

the direction of the lines of the Zoellner figure is opposite to the visual illusion[4]. And in the HVI the results of the comparison of the visual and haptic modality show a greater illusory effect for the haptic than for the visual perception of the crossed lines[5].

Different, autonomous explanations have emerged for the haptic HVI that take into account the role of exploratory movements and are based on purely haptic causes, with no reference to visual representations[6]. [Day, 1971]; [Wong, 1975a, 1975b, 1977], for instance, propose that the tactile version of the illusion could be explained in terms of the different effects of radial and tangential exploratory movements: radial movements towards and away from the body may be overestimated in comparison with tangential movements; radial motions are in fact executed more slowly than tangential movements; assuming that longer scan duration is equated to increased extent, the rate difference could account for the illusion. [Heller, *et al.,* 1997] show that the haptic HVI is strongly dependent upon exploratory strategies. In their experiments, the illusory effects appeared to be greater for bigger stimuli, thus hinting at a role for the scanning strategies one adopts. Movements of the entire arm seem to be involved, since the illusion disappears when the subjects are prevented from moving their arms.

---

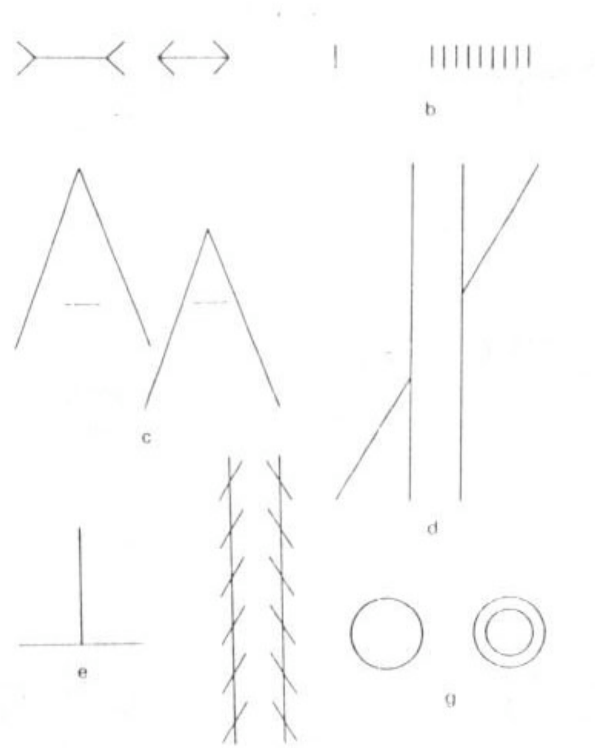
[4] [Suzuki & Arashida, 1992].

[5] [Taylor, 2001].

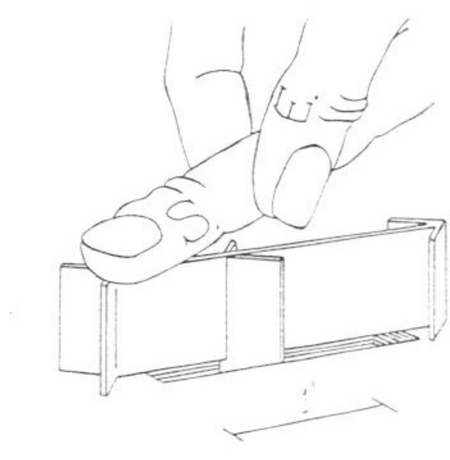
[6] [Day, 1971]; [Wong, 1975a, 1975b, 1977]; [Heller, Joyner & Dan Fodio 1993]; [Heller & Joyner, 1993]; [Heller, *et al.*, 1997]; [Millar & Al-Attar, 2000].

Figure 1. Geometric illusions

a. Mueller-Lyer pattern; b. Oppel-Kundt pattern; c. Ponzo pattern; d. Poggendorff pattern; e. Vertical-Horizontal pattern; f. Zoellner pattern; g. Delboeuf pattern [Suzuki & Arashida, 1992]



h. 3D Mueller-Lyer model [Watson & French, 1966]



Illusions and movement

The importance of the role of movement in perception seems to be strictly connected with the criticism to the concept of illusion. Direct approaches to perception, in fact, tend to discredit the weight of internal representations, cognitive inferences and symbolic knowledge in perception; at the same time, direct approaches affirm that the appearance of the perceptual experience can be explained with the help of two conditions: how the world is and what the perceiver does. Two theses exemplify this claim, even if they are not perfectly compatible with each other.

[Noë, 2003], for instance, proposes a two-dimensional theory of perception: how things appear not only depends on how they are, but it also depends on the relations of the perceiver to how things are. A causal theory of perception in fact affirms that how things appear in perception depends on how things are: one perceives that x is F if and only if one has the experience of x being F, x is F and the experience of x depends on x being F. But there are special properties of the perceptual content that do not depend on the object only, such as the property that a round object has of appearing elliptical when seen from a certain position. Furthermore, we keep track of the changes our movements provoke on the appearance of the objects, such as when we move our eyes, and this fact has a relevant place in the perceptual experience of the objects. Both these are perspectival aspects of the perceptual content that are only partly determined by how things are. It is possible for a perceptual experience to be veridical along one dimension, but not along the other. An example is presented involving the visual experience through a periscope: things are represented as they are, but our relation to them is not represented correctly, since we see them as if we were above sea level. This fact leads to the two-dimensional theory of perceptual content or representational content: the content can vary along a factual dimension (how things are) and a perspectival dimension (how things appear from the point of view of the perceiver).

> "Perception is a way of keeping track of how things are, but it is also a way of keeping track of our relation to how things are…" [Noë, 2003, p. 94]

Within this frame-work, the relation of the perceiver to how things are is also expressed in terms of sensorimotor contingencies, that is, in terms of how the perceptual outcome changes in contingency with how the perceiver moves. Sensorimotor contingencies are thus used within this frame-work as explanatory tools instead of internal representations, symbolic knowledge and cognitive inferences.

The second thesis, the ecological view of perception, differs from the sensorimotor approach because the assertion that perception is direct is equated with the assertion that perception is always correct,

> "without the addition of information beyond what is available in sensory stimulation." [Stoffregen & Bardy, 2001, p. 1]

This view is based on [Gibson 1979]'s concepts of ambient array.

> "Proponents of the ecological approach stress that ambient arrays are structured by the animal-environment interaction (that is, by the position and motion of the animal relative to its environment), and that this structuring is governed by physical laws (i. e., laws of the propagation, reflection, and absorption of energy) in such a way that any given physical reality gives rise to a unique structure or pattern in ambient energy. This leads to the hypothesis that potential sensory stimulation is sufficient for accurate perception because the animal-environment interaction is specified in the spatio-temporal structure of ambient arrays." [Stoffregen & Bardy, 2001, p. 1]

The energy patterns can be considered independently of the fact that they stimulate sensory systems. In fact, each animal-environment interaction gives rise to a specific pattern of ambient array, independently of the fact that the senses of the animal are stimulated and that a perceptual experience is produced. Nevertheless, patterns of ambient energy represent what is directly perceived and they are as they are in virtue of the interaction of the organism with the environment, of its movement and position. Thus, movement constitutes the condition for structuring the ambient information (under the form of ambient energy) in a non-ambiguous, correct way.

Movement versus internal processes

Movement represents, within the two presented views of perception, the condition for disambiguating information (ecological view) or the condition which modifies the appearance of the perceptual outcome (sensorimotor approach). In spite of the differences between the two views[7], in both cases movement structures the perceptual outcome and the relation between perception and movement is a lawful connection. In both cases, the connection between movement and perception makes the recourse to internal representations, cognitive inferences and symbolic knowledge obsolete.

---

[7] One difference is represented by the different importance which is attributed to experience. In the ecological view, experience has no role in the specification of the ambient array: the modification of the ambient energy produced by the animal-environment interaction is structured on the basis of physical laws such as the laws of reflection and propagation of energy and on the physical structure of the animal. In the sensorimotor version of the direct approach, sensorimotor patterns of contingency are also structured by experience which connects different movements with different perceptual experiences; thus experience and a form of knowledge play a role in the perceptual outcome.

The polemical target of the two cited direct approaches to perception is represented by the idea expressed by Helmholtz that perception is unconscious inference (see [Fodor, 1981], [Gregory, 1968, 1998]) and exemplified by the search for internal, constructive mechanisms for explaining the appearance of the perceptual outcome (see [Marr, 1982]). It seems in fact to the proponents of the indirect approach that the appearance of the perceptual experience cannot be explained in terms of the sensations that the stimulation by the environment produces. A classic example is the two-dimensional effect produced by light stimulation on the retinas as opposed to the three-dimensional effect of vision. Within this approach illusions can arise at different levels of the perceptual process, and in particular at the stage of the integration of the information captured by the senses with the knowledge, past experience and inferences that gives its meaning to the bare sensation.

I propose to consider illusory phenomena within a larger context than the one represented by the indirect approaches to perception, that is, than errors in an inferential process. For this reason I propose some criteria for the differentiation of illusory phenomena from other perceptual phenomena and errors on the basis of a neutral notion of error, the notion of robustness and of the reaction of surprise. Illusions are hence disentangled from the indirect perception approach.

I have chosen to study certain haptic, kinesthetic and intersensory illusions that involve the touch modality in order to defend the possibility of keeping the notion of illusion in the field of theories of perception.

This choice is motivated by the importance that movement plays in the touch modality, and in particular in the sub-divisions of the touch modality that are connected with the exertion of movement and with the involvement of the muscle receptors. As we have seen, in fact, movement is considered by the ecological and the sensorimotor approach as a promising substitute for internal representations and internal mechanisms in the explanation of the perceptual content.

Additionally, the ecological and the sensorimotor approach reproach the traditional, indirect accounts of perception for underestimating the characteristics of the perceptual activity in normal conditions. In normal conditions, perceptual activity is a dynamic process, intertwined with movement, constituted of exploratory actions and perceptual responses. In normal conditions, perception is multisensory and it is difficult to disentangle the different contributions to the final percept.

I have tried follow the direction of the objections that the ecological and the sensorimotor direct approaches raise against the methodological approach of the indirect approach to perception. I have thus chosen to focus my attention on dynamic and intersensory phenomena in order to eliminate one possible, preliminary objection that could be levied against my position from the ecological and sensorimotor direct approaches, viz. that the dynamic aspects of perception are not taken into due account.

Haptic, kinesthetic touch seems to me a good ground for confrontation with these approaches in virtue of the role movement plays in haptic phenomena.

Nevertheless I have not described all the haptic and kinesthetic illusions that can be found in the psychological literature but only those I have found particularly suitable for illustrating my arguments: the reasons of the controversy concerning illusions (Size-

Weight Illusion), the awareness of error as violation of coherence in illusory experiences (proprioceptive illusions produced by vibration), the possibility of invoking the role of movement and of implicit expectations based on motor skills for the explanation of the occurrence and appearance of certain illusions (Aristotle's illusion and Viviani's illusions), the role of coherence in perception and the functional role played by illusions in the cognitive process (intersensory illusions involving the touch modality).

Haptic touch well instantiates the integration of movement in perception

Within the frame-work of the direct approaches to perception described, the sense of touch assumes a special place.

> "On the enactive view, all perception is in these respects like touch. Mere sensation, mere stimulation, fails short of perceptual awareness. […] for perceptual sensation to constitute experience - that is, for it to have genuine representational content - the perceiver must possess and make use of *sensorimotor knowledge*. To imagine a truly inert perceiver is to imagine someone without the sensorimotor knowledge needed to enact perceptual content." [Noë, 2004, p. 17]

The characteristic of the sense of touch, which is invoked as a model for the understanding of the functioning of perception in general, is the intrinsic connection between perception and movement, and the fact that the ability to perceive depends much more on the mastery of sensorimotor skills rather than on one's own capacity for sensations[8].

---

[8] The necessity of assuming touch as a model for vision and perception in general had been affirmed by Merleau-Ponty [Merleau-Ponty, 1945, 1964] who sustained that all visual experience only exists in the context of the movement of the eyes and gaze, thus all visual experience makes reference to touch.

It is thus not by chance that the blind or blindfolded subjects represent a recurrent exemplification of perceptual experience within the sensorimotor or enactive view of perception. The blind make contact with the world by exploring it; the cane of the blind person in particular receives no sensation at its end, so that the responsibility for the perception of the world that arises when the world is sensed by a cane is individuated elsewhere, in particular in the mastery of the use of the cane [Noë, 2004][9].

In 1951-52 the cyberneticist D. Mackay had imagined an analogical intelligent machine capable of actively recognizing figures and objects without necessarily possessing an internal model of the world (the possession of an internal model being considered by Mackay as a passive form of perception or reception). The mechanism on which this intelligent artifact is based is explained by the aid of an example: the actions performed by a blindfolded person. When seeking to recognize a solid triangular figure a blindfolded subject is required to move his fingers around the outline in a specific sequence. Hence, to the blindfolded person,

> "the concept of triangularity is invariably related with and can be defined by the sequence of elementary responses necessary in the act of replicating the outline of the triangle." [MacKay, 1951-1952, p. 114].

When action is involved in the constitution of a percept or in the acquisition of a concept, touch is the model and tactile exploration is the exemplary case. On the contrary, vision represents the model for passive or merely receptive perception and concept acquisition.

---

[9] The use of a cane by a blind person is also exemplary of [Merleau-Ponty, 1945] approach to perception. In virtue of the use of the cane, the blind person acquires new motor and perceptual skills which are equated with new pragmatic knowledge. Both the world and the body schema are thus enlarged to encompass the cane as an extension of the body and the distant objects which are now at reach.

[MacKay, 1951-52] describes the template-fitting method of recognition introduced by [Wiener, 1948] and [McCulloch & Pitts, 1943] as a passive system in which a typical pattern of the sample to be recognized is stored in the artifact as a template, an ideal model to which real triangles must be re-conducted, and indicates in visual studies the reference for this model.

This example illustrates that even in the cybernetic context, touch has been indicated as a model for active perception (perception conceived as an exploratory activity) and contrasted with vision, assumed as a model of passive perception or recognition. The special role attributed to the touch modality depends on the evidence that exploratory movements constitute a fundamental condition for obtaining information about the tactile aspect of the objects.

The role of movement in the touch modality was affirmed early by [Katz, 1989. Original work published 1925]:

> "to study the sense of touch at rest is almost alike wanting to determine the capability of the leg musculature after the leg has been placed in a plaster cast." [Katz, 1989. Original work published 1925, p. 78].

According to Katz, movement plays a complex role in touch perception: it intensifies the action of static stimuli and prevents the habituation of the captors; movement also creates tactile phenomena in that it allows for the perception of qualities such as texture and elasticity that are not available to static touch:

> “Every ongoing tactual activity represents a production, a creation in the true sense of the word. When we touch, we move our sensory area voluntarily, we must move them, as we

> are constantly reminded, if the tactual properties of the objects are to remain available to us […] they remain mute until we make them speak." [Katz, 1989. Original work published 1925, p. 242]

Finally, movement constitutes the objective pole of touch: a stimulus can be perceived both as a subjective, proximal, local sensation or as the sensation of the external, distal object which causes the experience depending on the intervention of movement, of active touch. Touch, associated with movement, thus can be considered as the sense of reality.

More recently, Lederman, Klatzky and colleagues (see for instance [Klatzky, Lederman & Metzger, 1985]; [Lederman & Katsky, 1987, 1993]) have provided evidence for some specific connections between hand movements and the properties that are extracted by touch. The authors have described a set of exploratory procedures: stereotyped and recursive patterns of movement that perceivers perform with their hands when exploring different types of objects and surfaces, even if the perceivers are not necessarily aware of it. It seems that each of these patters of exploration is associated with the extraction of one particular property by touch; for instance, lateral motion seems to be associated with the extraction of texture, pressure with hardness, contour following with precise shape, etc. In fact, when freely exploring different properties of an object, the subjects of the experiments tend to perform the corresponding exploratory procedures and, also, the relative speed and accuracy in the recognition of a certain property are greater when the corresponding exploratory procedure is performed. These studies prove one aspect of the integration of perception and movement in the case of touch where there is an effect on the perceptual performance of the recognition of object properties[10].

Haptic touch and the problem of the classification of the touch sensory modality

Nevertheless, the term 'touch' is not unambiguous[11]. Different terms are correlated to the notion of touch, such as the term 'haptic' and 'dynamic' touch, and different classifications are proposed in the literature.

Neurophysiology, for instance, makes use of the term 'somatic sensory system' [Kandel, Schwartz & Hessel, 2000] comprising of 2 main components: a system for the

---

[10] In general, active or interactive perception approaches defend the idea that perception is not a pure and passive form of representation, in that the sensory systems are not simply hit by the external reality in its entirety, but actively contribute to the construction of its perception, and that this is done with the involvement of the motor systems. Active perception theories include a group of approaches named '*Active Vision*' and '*Interactive Vision*'.

[Blake & Yuille, 1992] *Active Vision* approach, for instance, insists on the fact that moving facilitates the interaction of the visual sensors with the environment. The active orientation of the sensors empowers the observer (which can be a human or a computer) to select the environmental information, thus to understand a visual environment more effectively and efficiently.

[Churchland, 1994] in the chapter "*A Critique of Pure Vision*" criticizes pure vision systems (those where the flow of information is only bottom up) and the assertions that we see a complete world; that is to say that the retina records a complete image which is further and at leisure analyzed; that information and representations follow a hierarchical organization; that information flows bottom up, with high-level and mid-level representations depending only on the low-level processes. The target of this description is the approach to vision that is contained in [Marr, 1982] and which constitutes the mainstream in computer vision research. In particular, of Marr's three hierarchical levels of visual representations: the lowest level of the primal sketch, where an image represents intensity over an array of points in space, the 2 1/2-D sketch and the higher level where the 2 1/2 –D sketch is converted into the 3-D view of the objects of the scene. Opposed to the idea of pure vision is the approach of interactive vision where information flows top-down. The main principles of the interactive vision approach state that perception evolved in order to satisfy distinct and variegated needs (and not only to provide a photorealistic image of reality). In fact, we see only a portion of the visible world, and movement redirects attention and then re-orients the visual system; motion and vision are then strictly connected: movement allows the system to see more of the world. The role of movement is well illustrated by the existence of saccadic eye movements: the viewer cannot clearly see the entire scene, but he gradually explores parts of it. Instead of being photorealistic, vision is interactive and predictive, since it builds models of the world and predicts what can be interesting for the system. The neurophysiological architecture finally is not hierarchical, and much information flows both ways; memory and vision for instance interact.

[11] The touch modality well instantiates the difficulty of providing unambiguous definitions of sensory modalities. For a discussion about the problem of touch and the classification of sensory modalities see [Casati, 1994]; [Pasquinelli, 2003].

detection of mechanic stimuli (light touch, vibration, pressure) and a system for the detection of pain stimuli and temperature [Purves, *et al*., 1997]. This classification is based on the physical energy of the stimuli to which the captors are sensitive. Mechanoreceptors are then sub-divided into tactile or cutaneous captors which are distributed at the surface (skin) of the body and proprioceptive captors which are located within the muscles, tendons and joints of the body (this classification is thus based on the localization of the captors). Different perceptual qualities are then associated with the two sub-systems: in a general fashion tactile captors are described as involved in the perception of the qualities of the objects of the external world (such as dimensions, shape, microstructure, movement relative to the skin) and the proprioceptive system as dedicated to the (more or less aware) perception of the position and movement of the body. Neurophysiology deals then with the ascription to the somesthetic system of 4 main functions: discriminative touch, proprioception, nociception, temperature perception. There is a difficulty in sharply separating the external and the internal mechanoreceptors and associating them separately with exteroceptive and proprioceptive functions respectively. Active exploration of the world's objects implies the utilization of internal, proprioceptive mechanoreceptors, but it provides information about the properties of the external world.

Active touch has been considered as a separate category of touch on the basis of the role that movements (and movement captors) play in the discrimination of the properties of objects. This category is labeled 'tactile-kinesthetic perception' or 'haptic perception'.

The term 'haptics' was first introduced by Revesz [Revesz, 1958] to incorporate cutaneous and kinesthetic information. [Loomis & Lederman, 1986] refer to the haptic sensory modality in terms of 'kinesthetic touch': kinesthetic touch is comprised of cutaneous and kinesthetic receptors, provides information about objects and surfaces that are in contact with the subject and guides the manipulation of objects. The modality of touch is then composed of three sub-modalities:

> "The modality of *touch* encompasses distinct cutaneous, *kinesthetic* and haptic systems that are distinguished on the basis of the underlying neural inputs. The cutaneous receptors are embedded in the skin; the *kinesthetic* receptors lie in muscles, tendons, and joints; and the haptic system uses combined inputs from both." [Loomis & Lederman, 1986, p. 1]

These classifications thus do not question the divisions accepted by neurophysiology and are based on the energy of the stimulus and the localization of the receptors.

[Katz, 1989. Original work published 1925], refused to accept what he considered an "*atomistic approach to perception*" by individuating and separating the activity of different sensory captors (thus multiplying the number of tactile sensations) and instead chose to adopt a system of classification based on the qualities perceived by touch. The world of touch possesses three main modifications or qualities: surface touch (the two-dimensional tactile structure that is identified when touching a continuous palpable area, localized at the surface of the object, and following the curvatures of the object), immersion touch (the tactile phenomenon without either definite shape or structure or spatial orienting, as when moving the hand in a fluid), volume touch (the perception of the shape, the spatial distribution of the object that we can have when the object is, for instance, covered by a textile or the hand is covered by a glove). The "*skin senses*" cannot then be separate since

> "in the living organism (whose expressions, after all, are what we wish to understand), large coalitions of sensory elements always work together." [Katz, 1989. Original work published 1925, p. 34]

The differentiation seen in the physiology of the senses is then an artifact, in that complex phenomena constitute the only real component of perception. Complex phenomena are not the result of logical operations conducted by the cognitive system upon atomic, simple elements. On the contrary, complex phenomena are the original components of perception, and no operation on the side of the cognitive system is requested for their production. Katz invites us to consider tactile perception as an immediately complex phenomenon which does not require the intervention of successive cognitive operations. Katz's suggestion does not solve the problem of differentiating touch from other sensory modalities, but is only limited to the internal classification of touch, since common qualities (such as the shape of an object) can be appreciated by more than one sensory modality (e.g. by vision and touch).

A sort of mid-way position between the neurophysiological approach and the invitation to unity expressed by Katz is represented by Gibson's classification of haptic touch. In fact, Gibson's classification of the senses maintains the distinction between physical energies and types of receptors but also takes into account the object properties. [Gibson, 1962, 1966] suggested that there is a great difference in the resulting percept depending on the active or passive role of the perceiver: when the stimulation is passive, as when being touched by an object, even if the object is moving, the subject obtains sensations of skin modification; it is only when the subject plays an active role by actively touching the object that attention is directed to the sensed properties of the object. Active touch is then defined as an exploratory rather than a merely receptive sense: the variations in the skin stimulation are produced by variations in the motor activity. Thus the unitary perception of an object with multiple fingers doesn't require a central integration since the pressure of the fingers upon an object informs about the qualities (e.g. the hardness) of the object and does not give rise to separate, cutaneous sensations (on the contrary, in the case of passive touch, two separate pressures on the skin give rise to two different sensations). In the same way, in active touch, kinesthesia is neither to be separated nor to be simply combined with cutaneous sensations, since the patterns of change of the skin contact co-vary with the change in limb position giving rise to one and the same information about the object properties.

According to Gibson, touch is exemplary of the connection of perception and movement in perception, since in this case the equipment for feeling is anatomically the same as the equipment for doing. The non-separation of the skin senses from kinesthesia is labeled 'haptic system', and distinguished from haptic touch and dynamic touch:

> "The sensibility of the individual to the world adjacent to his body by the use of his body will here be called the haptic system. The word haptic comes from a Greek term meaning "able to lay hold of." It operates when a man or an animal feels things with his body or its extremities. It is not just the sense of skin pressure. It is not even the sense of pressure plus the sense of kinesthesis. […] The haptic system, then, is an apparatus by which the individual gets information about both the environment and his body. He feels an object relative to his body and the body relative to an object." [Gibson, 1966, p. 97]

The haptic system is successively sub-divided into: cutaneous touch (when the skin and deep tissues are stimulated without movement of muscles and joints); haptic touch (when the skin and deep tissues are stimulated by the movement at the joints, as in catching an object, palpating, squeezing, etc. in order to extract information about its geometry and microstructure); dynamic touch (when skin and joints are stimulated in association with muscular effort, as in the discrimination of weight, which is more accurate when the object is wielded, rigidity, viscosity, etc.); oriented touch (the combination of inputs from vestibular, joint and skin receptors); touch-temperature (the combination of skin stimuli with vasodilatation and vasoconstriction); painful touch; social touch (the affective components of touch, as in the new-born cares).

Dynamic touch presently represents a rich domain of studies in the ecological direction (see for instance [Turvey, 1996]. The perception of object properties by wielding is a prominent example of dynamic touch. Dynamic touch is thus active, but it is not concerned with, for instance, finger exploration. The haptic properties that are perceived by dynamic touch are those related to the macro-geometry and volume of the objects, as the extension, shape, orientation and weight; at the same time properties of the limb holding the object are discriminated. [Turvey, 1996] states as follows:

> "What sets kinesthetic touch apart from other forms of touch is the prominent contribution of muscular effort and its sensory consequences. As a grasped object is wielded, the receptors that interpenetrate muscular and tendinous tissues are mechanically stimulated. These mechanoreceptors, as they are called, respond to the stretching, twisting, and bending of muscles and tendons. Their collective response to the changing flux of mechanical energy is the primary (although not the exclusive) neural basis of dynamic touch." [Turvey, 1996, p. 1134]

Recently, another use of the term ‘haptics’ has appeared in the domain of computer interfaces. Computer haptics includes the technologies and processes for the generation of force-feedback stimuli to human users in virtual reality environments. The focus is on hand exploration and manipulation:

> “Haptics is concerned with information acquisition and object manipulation through touch. Haptics is used as an umbrella term covering all aspects of manual exploration and manipulation by humans and machines, as well as interactions between the two, performed in real, virtual or teleoperated environments. Haptic interfaces allow users to touch, feel and manipulate objects simulated by virtual environments (Ves) and teleoperator systems.” [Biggs & Srinivasan, 2001, p. 1]

Haptic devices allow the user to appreciate some haptic characteristics of virtual and distant objects, such as the shape, elasticity or rigidity and texture. Since the haptic devices’ functioning is based on force-feedback technology, the perception of haptic objects does not depend on a passive stimulation of the sensory organs of the user, but on the exploratory activity that the user accomplishes upon the haptic objects. The device generates forces in response to the forces that are exerted by the user (for instance with his fingers or arms, and possibly with the whole of his body). The feedback forces are applied in correspondence of the joints of the user and the kinesthetic system (joint and muscle receptors) is responsible for the relevant sensations that originate during the experience (other sensations are produced by the contact of the skin with the device). Haptic devices thus constitute an example of the connection between touch modality and movement and show the characteristics of the object that can be perceived in virtue of the movements and exerted forces.

The choice of exemplary haptic illusions

The choice of focusing this discussion on the illusions that concern the touch modality, and in particular the aspects of the touch modality that are more entangled with movement (such as the so called 'active touch', 'haptic touch' or 'dynamic touch' and kinesthesia), is hence motivated by the exemplary role played by this perceptual modality in the discussion regarding the integration of perception and movement and by the importance of this integration in the context of the criticism to the notion of illusion.

Four kinds of illusory phenomena will be discussed in detail.

First, the Size-Weight Illusion will start the discussion and introduce the argumentation between those who defend the notion of illusion and those who affirm that this notion is obsolete. The Size-Weight illusion will be thus presented as a case study; the different positions that have been expressed about its origin and nature will serve to illustrate how different the approaches to illusory phenomena can be and how illusory phenomena can play a different role in different theoretical settings.

Second, the case of proprioceptive illusions of movement and position produced by vibration will be successively analyzed in order to show a possible distinction within illusory phenomena between illusions we are immediately aware of and illusions we are not immediately aware of; this discussion will show the role of coherence and of ruptures of coherence in illusory phenomena. The contradiction of expectations and past knowledge does not necessarily represent the only explanation for illusory phenomena, since coherence can also be violated at a synchronic level, when two simultaneous experiences are inconsistent with each other.

Third, a detailed discussion of Aristotle's illusion is directed to show how implicit knowledge and sensorimotor expectations can be responsible for illusory phenomena. In fact, even when the violation of coherence is situated at a diachronic level, between actual experiences and past experiences or knowledge, violated expectations and knowledge are not necessarily of a symbolic kind, and the involved processes are not necessarily inferential.

Fourth, some phenomena related to the presence of discrepancies between multisensory stimuli (including haptic and kinesthetic stimuli) are presented. Their case illustrates the role of coherence in the production of illusions and the functional role of illusions in the cognitive processes.

The illustrated illusions help show that the indirect, inferential view of perception is not the only possible approach to illusions. A class of illusory phenomena can be described that present different characteristic from others normal, non-illusory phenomena. The study of illusory phenomena presents a heuristic value for different theories of perception, since it appears to be suitable for exploring the role of movement in perception and the existence of expectations that are grounded in the existence of motor skills rather than in the presence of symbolic knowledge and internal representations. Also, the presented illusions indicate that illusory phenomena are related to the presence of violations of coherence and that they can play a functional role in revealing the presence of discrepancies or in composing the discrepancies into coherent percepts.

Summary of the following chapters

Chapter 1 focuses on the issue that the concept of illusion is not above controversy, as the study of the case of the Size-Weight Illusion illustrates. The extreme positions are represented by the indirect, inferential approach to perception and the direct, ecological view; the first one indicating illusions as evidence for the role of inferential processes and internal representations in perception and the second one discarding the notion of illusion that goes along with the notions of inference and internal representation. Hence, the Size-Weight Illusion not only receives different explanations, depending on the specific view of perception adopted, but is also susceptible to not being an illusionary phenomenon at all. On the basis of their attitude towards the Size-Weight Illusion, ecologists deny the existence of illusions in general. Nevertheless, for ecologists too, the study of the phenomena that are analogous to the Size-Weight Illusion seems to be a precious instrument of research on the quantities the perceptual systems are sensitive to. This attitude motivates a deeper analysis about the notion of illusion and the characterization of illusory phenomena, which takes place in *Chapter 2*.

Chapter 2 aims at providing a conceptual analysis of the notion of illusion, starting from the description of the difficulties that arise in relation with its traditional characterization.

Chapter 2 thus analyzes the main theoretical difficulties with the notion of illusion. The hardest opposition to the notion of illusion arises, as the SWI reveals, from the refusal of the account of perception as an inferential process (the opposition is that between the indirect, inferential view of perception and the direct, non-inferential approach to perception).

The classic definition of illusion as systematic error in the inferential process of perception is in fact biased by the indirect approach to perception, and by the notion of cognitive inference. Along with the concept of cognitive inference, the concept of illusion is thus questioned by those who embrace a direct, non inferential approach to perception.

Moreover, the notion of error as departure from facts, which is adopted in psychology, is a common sense metaphor. The prevalent notions in the philosophical literature do not necessarily coincide with those of common sense; psychological theories too are not compelled to adopt common sense notions.

Hence it is interesting to propose a philosophical clarification of the notion of illusion and of the notions that are connected to the notion of illusion.

An investigation about the possibility of maintaining the notion of illusion independently of the acceptance of the two extreme views of perception (direct and indirect) is developed. The main reason for neutrality is that there are at least heuristic merits in the notion of illusion.

Not only does the notion of illusion proves to have pragmatic utility, but it seems to be possible to disentangle it from the issue of the opposition between direct and indirect approaches to perception owing to a philosophical analysis of the notion of error and of the individuation of some phenomenological characteristics and behavioral consequences of illusory phenomena. Accordingly, some characters that affect illusory phenomena are individuated, such as their robust nature and the relationship with the reaction of surprise, that are neutral toward the direct or indirect views of perception. These characters allow distinguishing illusory phenomena from other types of error in perception. The notion of error presents special difficulties. Nevertheless, illusory phenomena can be characterized on the basis of a notion of error which is neutral with respect to the argumentation between direct and indirect approaches and with respect to the notion of departure from facts.

The narrow notion of error as failure in an inferential process and as departure from facts is in fact contrasted with a broad notion of error which includes violations of coherence.

The notion of error is maintained because one can always be aware of his error in the case of illusions, both the ones we are immediately aware of and those we are not immediately aware of. The notion of error is hence developed in relationship with the awareness, on the side of the subject, that something is going wrong when an illusion is recognized.

The distinction between illusions we are immediately aware of and illusions we are not immediately aware of is developed with the help of an exemplary case: the proprioceptive illusions produced by vibration, both illusions of possible and impossible movement. Illusions are divided into the two cited classes depending on the more or less direct access they provide to the awareness that something is going wrong in perception, that is, to the awareness of committing a perceptual error.

Since illusions are a special type of errors and one can normally be aware of being victim of an illusion, the ascription of illusions seems to depend upon the theory which is accepted about the attribution of the capacity of being aware of committing errors. In *Chapter 2* it is proposed that illusions be considered as specific to the individual at his personal level because the capacity of being aware of committing an error (intended as related to the capacity of handling the concepts of truth, error and belief) arises at this level.

Robustness is subdivided into the characteristics of resilience to knowledge and systematicity, both intersubjective and intrasubjective. The robustness of illusory phenomena helps distinguish illusions from other types of errors such as local errors and hallucinations. Robustness also makes the connection between illusions we are immediately aware of and illusions we are not immediately aware of: in spite of their differences in fact, both phenomena can be repeated at will for the same subject and for different subjects: the result is always the same even if the subjects are informed about the nature of their experience. This is why the subjects can always be surprised when they experience an illusion they have previously experienced in the past or an illusory phenomena of which they have been informed. Other perceptual phenomena involving errors and presenting a reaction of surprise are not necessarily robust in the sense in which illusions are robust.

The association of illusions with surprise indicates the nature of illusory phenomena and the functional role they play in cognitive functioning by revealing the presence of violations of coherence.

The immediateness of the reaction of surprise allows distinguishing between illusions we are immediately aware of and illusions we are not immediately aware of. In both cases surprise arises when the possibility of an error is detected; only, in the former case the error is immediately detected and thus surprise is immediately related to the experience, while in the latter case the subject needs to undergo other experiences (or to be informed by another subject) in order to discover the error and consequently to be surprised about his error. In both cases nevertheless surprise arises from one and the same source: the presence of a violation of coherence.

Violation of coherence can thus be indicated as a fundamental perceptual condition which is associated with illusory phenomena; specifically, the violation of coherence can be considered as the source of the surprise reaction associated with illusions. In the case of illusions we are immediately aware of the presence of a violation of coherence is perspicuous: the subject is aware of his experience as being wrong because the experience presents some inconsistency. The inconsistency might be between two present experiences or it might exist between a presently experienced percept and a belief based upon past experience. In the first case, two or more synchronous perceptual experiences are in conflict with each other, but their robust character is such that they persist in spite of their inconsistency. In the second case, the present experience is considered as erroneous but it has a robust character and it persists in spite of the fact that it is considered as false on the basis of strong reasons (which is exactly the contrary of what normally happens when a past beliefs is revised due to the poignancy of the present perceptual experience). The two possible cases of discrepancy are described as ‘synchronic violations of coherence’ and ‘diachronic violations of coherence’.

The existence of a violation of coherence can be individuated also in the case of illusions we are not immediately aware of, even if it is less perspicuous than for illusions we are immediately aware of. As in the description of diachronic violations of coherence, inconsistency is present between the perceptual experience and the existence of strong reasons for considering the experience as false; in the case of illusions we are not immediately aware of, the strong reasons for considering the experience as false can be represented by information from a second subject (i.e. the experimenter, who can be trusted, or the writer of the book which includes illusory figures) or from successive explorations (which for some reasons are more trustworthy than the one considered as false). Even if the perceptual experience is not trusted, the subject cannot revise it and the experience stands in conflict with the others or with the information that indicate it as false.

Once the notion of illusion is characterized the role of illusory phenomena in the cognitive functioning in general can be better understood.

Also, illusions can be helpful for better understanding different aspects of the perceptual functioning such as the role played by coherence in the shaping of the perceptual content and the role played by movement. The study of certain illusions of movement seems to point out the existence of an indirect form of knowledge and expectations based on the direct connection between movement and perception.

The notion of illusion can thus present a heuristic value also for theories of perception where internal representations and inferences are criticized in favor of the direct connection of movement and perception.

An eliminativist view risks overlooking this aspect. This consideration further speaks in favor of preserving the notion of illusion in order to investigate the processes that are connected with the detection of errors in perception, as it is explained in *Chapter 3*.

Chapter 3 is in fact dedicated to the defense of the heuristic value of the study of illusions for gaining a better understanding of perception and cognition. This value is largely affirmed by the traditional studies of perception, but it is shown in *Chapter 3* that the study of illusions represents a valid instrument also for the investigation of issues that have an affinity with the new vague of studies on perception, such as the role of movement and of intersensory connections in the shaping of the perceptual content. Two studies on illusions in particular help show this point: certain experiments on Aristotle's illusion and other experiments on the perception of dynamic events. It s suggested that implicit expectations based on motor knowledge and motor skills might play a role in the occurrence and appearance of certain illusory phenomena and in normal (non-illusory) perception too.

Chapter 4 develops some considerations that have emerged in the course of the characterization of illusory phenomena, and in particular the notions of coherence and coherence violation. It is in relationship with these notions that illusory phenomena seem to play their functional role in the context of cognitive functioning. *Chapter 4* is thus dedicated to the understanding of the role of illusions in relationship to the role of violations of coherence in perception and to the mechanisms that operate for the maintenance of coherence or for the individuation of violations of coherence

One becomes aware of the violations of coherence when one discovers that he has been victim of an illusion. These violations of coherence have a negative adaptive value. This is confirmed both by studies on the violation of expectations based on past beliefs and by studies on intersensory discrepancies. The maintaining of coherence which is proper of certain intersensory illusions seems thus to present a positive adaptive value. In the mean time, the awareness of being victim of an illusion entails the awareness that something is wrong with the experience: the subject is thus alerted of the presence of an error.

In particular the effect of surprise related to illusions would present an epistemic value in that it reveals the presence of an error. This fact represents an epistemic value, especially for illusions we are immediately aware of because the discovery of there being some error is completely internal to the experience.

Since violations of coherence seem to have a negative effect on adaptive behaviors and the identification of violations of coherence seems to present a positive adaptive value, surprise raised by illusions we are immediately aware of has a positive adaptive value too, in that surprise associated with illusions alerts the subject about the presence of a violation of coherence.

Finally, in the *Conclusions* the opportunity of keeping the notion of illusion is reaffirmed in reason of the pragmatic, heuristic value of the study of illusions for the investigation of different processes in perception and cognition (such as the role of coherence, the role of movement, the role of implicit expectations) and in reason of the possibility of providing a characterization of the notion of illusion which is neutral with respect to the different approaches to perception and which permits us to assign to illusions a functional role in the cognitive functioning.

Chapter 1. A case study illustrates some theoretical problems about illusions

The present chapter adopts a bottom-up approach, in the sense that it illustrates the way the notion of illusion is employed in the psychological literature by describing the debate about the explanation and the nature of a well-known haptic phenomenon called the ‘Size-Weight Illusion’. The philosophical analysis of the notion of illusion and of related concepts starts from Chapter 2 with a proposal of characterization of illusions and continues in Chapters 3 and 4 with the discussion about the heuristic value of the notion of illusion which is so characterized and with the investigation of the role of illusions in cognitive functioning.

In this way I intend to show how the philosophical analysis can contribute to the debate about the nature of illusions and the present the opportunity of preserving the notion of illusion.

A concept, which by virtue of being a component of the characterization of illusion is closely related to it, is the concept of error. The study of the Size-Weight illusion and the analysis of the psychological literature show that the characterization of the notion of error which is adopted in this context (for instance as departure from facts) is a heritage from the common sensical use of the term ‘error’. An attempt at a philosophical clarification of these concepts might be useful for psychological theories of perception.

1.1 The size-weight illusion (SWI)

1.1.1 Description of the SWI: the smaller of two objects of equal weight is judged to be heavier when lifted

Haptic illusions have traditionally received less attention than visual illusions. One of the best known and more powerful haptic illusions is the so-called 'Size-Weight illusion' (SWI) or 'Charpentier's illusion', since this phenomenon was first described in 1891 by Charpentier as an effect of volume on the perception of weight[12]. Briefly, the SWI consists in the fact that the smaller of two objects of equal weight is judged to be heavier when lifted. It is a robust illusion that is resilient to the observer's prior knowledge of the actual relative weight of the objects.

Charpentier performed his experiment with two spheres of equal weight and of 40 and 100 mm of diameter respectively; the observers were allowed to look at the spheres and were asked to lift each sphere with the palm of their hand. The larger sphere was consistently reported as lighter [Charpentier, 1891]. The experiment demonstrates that the perceived weight of an object, its heaviness, does not depend only on its physical weight.

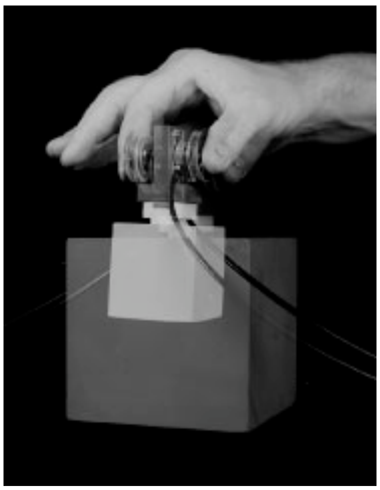
In 1894, Flournoy extended the experience to a large number of subjects and to different sorts of objects of equal mass that were to be ranked according to their perceived weight; he demonstrated that the SWI was resilient to the prior knowledge of the observer that the objects weighed the same [Flournoy, 1894]. Prior knowledge thus seemed not to influence the perception of weight, at least with active movement and

[12] Other weight illusions have been described, such as the shape-weight illusion [Dresslar, 1894], the material-weight illusion [Wolfe, 1898], the color-weight illusion [De Camp, 1917].

blindfolded subjects (the conditions explored by Flournoy). This resilience is considered a peculiarity of illusory phenomena and is often cited in order to demonstrate the non-permeability, hence the independence, of perception from cognition.

Figure 2. The Size-Weight Illusion

Device for testing the SWI when two objects of different dimension and same weight are lifted in alternation. This device also allows measuring the grip forces exerted in each case [Flanagan & Beltzner, 2003].



1.2 Explanations of the SWI

1.2.1 The expectation theory: the SWI is a cognitive illusion based on expected sensory feedback

A number of studies have since then followed aimed at investigating the role of mass, volume, density, gravitational cues in the perception of weight[13]. In particular, the role of movement in weight perception had been highlighted since the 19th century: [Weber, 1978. Original work published in 1934] had noticed that weight discrimination is more reliable when objects are wielded (thus, actively moved). The ability of discriminating weights of different masses by voluntary muscular exertion was termed "*sense of force*", a component of the "*muscular sense*"[14]. The problem was then posed of the respective role of touch and of the muscular sense (which is today indicated as *kinesthesis*) in the evaluation of weight. The improvement in weight evaluation with active lifting seems to indicate that receptors with sensitivity for dynamic events in the muscular apparatus are involved in weight perception[15].

Almost immediately following Charpentier's description, the SWI was mostly explained in terms of "*disappointed expectations*" [Murray, *et al.*, 1999]. *Expectation*

---

[13] For the interaction of mass and volume see [Anderson, 1970]; [Cross & Rotkin, 1975]; [Harper & Stevens, 1948]; [Koseleff, 1957]; [Ross, 1969]; [Ross & Di Lollo, 1970]; [Rule & Curtis, 1977]; [Stevens & Rubin, 1970]; for density [Harshfield & De Hardt, 1970]; [Huang, 1945]; for the variations of gravity [Ross & Reschke, 1982].

[14] [Bell, 1834].

[15] See also [Brodie & Ross, 1984]; [Holway & Hurvich, 1937]; [Raj, Ingty & Devanandan, 1985]; [Jones, 1986].

theories emphasize the role of previous experience in judgments of weight: cognitive expectations based on previously acquired knowledge about the relationship between weight and volume in normal conditions (the bigger object is normally heavier than the smaller one) affect the perception of the actual weight of the object.

In connection with the expectation theories different hypotheses about the role of *movement* and force in the SWI have been put forward[16]. This fact leads to the identification of at least three possible variations within the expectation theories.

In the first variation, the illusion originates from the consequences of the expectation upon the characteristics of the performed movement, such as the consequent lifting force and lifting rate of the object. The motor consequences of the cognitive expectation are thus responsible for the SWI.

Following the second variation of the expectations theories, it is possible that the information about the force exerted in muscular contraction, as in the lifting of the object, arises from at least two sources: an internal neural correlate or 'corollary discharge' of the motor signal sent to the motoneuron pool, which is then sent to the sensory centers; and afferent discharges originating peripherally in various sensory receptors of the muscles, tendons, spindles, joints. Hence, when proving the role of movement and of the exertion of force in weight discrimination, the respective roles of sensory information generated centrally and of sensory information generated peripherally in the production of the SWI should be determined. In fact, the mismatch between the two sources of sensory information could be individuated as the proper source of the illusion.

---

[16] For a detailed presentation see [Jones, 1986].

The hypothesis of the mismatch is strongly criticized in the formulation of the third variation of the expectation theories, which proposes to restore a purely cognitive explanation of the SWI, with no recourse to erroneous motor commands and eventual corollary discharges of the motor commands.

A constant for all the variations of the expectation theories proposed is represented by the cognitive nature of the expectation. In spite of the differences between the specific mechanisms that cause the illusion, the remote cause is individuated in the existence of an explicit knowledge about the relationship between the weight and volume of objects. This knowledge creates expectations about the perceptual consequences of certain movements, such as the lifting of an object.

The cognitive-motor variant of the expectation theory

The cognitive-motor variant of the expectation theory [Ross & Gregory, 1970] affirms that the SWI is alleged to the wrong application of knowledge about objects [Gregory, 1997]. In Gregory's view illusions are the product of a malfunctioning in perception. According to Gregory [see Gregory, 1968, 1973, 1997, 1998], two main categories of malfunctioning can be distinguished: those located at the mechanical or physical level of the sensory signals and sensory organs (optical or sensory illusions), and those that arise from the misinterpretation by the brain of sensory information (perceptual or cognitive illusions).

> "Perceptions are hypotheses: illusions are misplaced hypotheses. Further, perceptual hypotheses may be misplaced, either because the (physiological) mechanisms mediating the hypothesis-generating strategies are malfunctioning; or because the (cognitive) hypothesis-generating strategies are inappropriate." [Gregory, 1973, p. 69]

In the case of the SWI the mechanical and physical processes are not significant, but the assumptions regarding the relation of size to weight, and the inferences which are based on these assumptions, are misleading. This is why the SWI is considered by Gregory as a perceptual or cognitive illusion.

> "Small objects feel heavier than larger objects of the same scale weight; muscles are set by knowledge-based expectation that the larger will be heavier, which is generally, though not always true." [Gregory, 1997, p. 1124]

As for the mechanism which is specifically responsible for the SWI, [Ross, 1969] suggests that the illusion might be alleged to the characteristics of the lifting movement, and in particular to the force applied during the lifting of the object. As we have seen, prior experience of objects' shapes and weights leads the observers to expect a larger object to be heavier than a smaller object. The learnt correlation between large volumes and heavy weights and the consequent expectation would hence affect the force that the observer applies when lifting the object, a bigger motor command being transmitted to the muscles involved in lifting a larger object. [Ross, 1969] used a matching procedure to investigate the SWI: subjects were asked to match via the haptic modality the weight of a visible object to that of an unseen object whose weight remained constant. As the volume of the viewed object increased its weight too had to be increased ini order to keep the heaviness of the two objects the same.

Support for the expectation hypothesis and for the role of the characteristics of the lifting movement comes for instance from a study of [Davis & Roberts, 1976] in which subjects were asked to lift in turn a large can and a small can placed on their palm, and then to report which felt heavier. The authors examined the movement profiles as the observers lifted the objects. In individuals who undergo the illusion, initial acceleration and height are reliably greater for the large object which is experienced to be lighter. Reliable differences in peak lifting acceleration or height are not observed in those few individuals who do not experience the illusion. Since it is assumed that subjects would attempt to lift all objects at the same rate, the greater velocity, acceleration and deceleration found by [Davis & Roberts, 1976] during the lift phase probably reflects the fact that observers expected the larger objects to weigh more, and therefore applied a greater lifting force, thus producing a faster lifting movement. As a consequence of the unexpected speed, the rapid adjustment in the force exerted by the muscles leads to the perception that the object weighs less than a smaller object of identical mass[17]. Lifting rate and lifting force would thus be related and could be placed at the origin of the illusion.

Analogously, [Gordon, *et al.*, 1991] have found that the grip forces employed by the subjects to lift large objects are greater than those used to lift smaller objects of the same weight. The forces employed can be considered as a measure of the expectations of the observers, since they are prior to any feedback.

The cognitive-sensorimotor variant of the expectation theory

Some of the authors who have proposed the cognitive-motor variation have developed their explanation and have hypothesized that the SWI originates from the discrepancy between the peripheral sensory input (a decrease in the discharge rate of the

[17] See also [Davis & Brickett, 1977]; [Davis, Taylor & Brickett, 1977].

spindles receptors, due to the unexpected rapidity of the shortening of the muscles) and the expected sensory inflow[18]. The SWI may result from the interaction between central discharges and peripheral afferent signals, which are normally matched for the weight of an object.

In sensorimotor terms the process of generation of the SWI can thus be described as follows: during the lifting task, the central nervous system generates a prediction of sensory feedback based on an internal forward model of the object to be grasped and a copy of the motor commands (efferent copy). The predicted sensory feedback has the form of a corollary discharge: a copy of the elaborated centrally motor commands that are esteemed to be necessary and adequate for the lifting of the object is sent to the sensory areas. In the sensory areas the corollary discharge and the actual sensory feedback that originates from the lifting of the object can be compared. Expected weight and actually perceived weight are thus compared. In case of discrepancy between the two magnitudes, the error signal from this comparison would then feed into neural circuits responsible for producing weight judgments. In the case of the SWI, hence, the comparison produces an error signal, since a mismatch occurs between expected and actual sensory feedback. The mismatch originates in the erroneous forward model of the object because of misleading knowledge and misleading visual cues. The remote cause of the illusion is thus still alleged to the erroneous application of knowledge and to the existence of cognitive expectations about objects based on past experience.

---

[18] [Davis & Roberts, 1976]; [Ross, 1969].

The cognitive variant of the expectation theory

It is admitted by [Flanagan & Beltzner, 2000] that expectations about object weight are observable in the motor output during the initial load phase of the lifting movement (the sensorimotor component of the expectation theory). Before lift-off the vertical load force is increased (if the object is lifted with the index finger and thumb tips the horizontal grip force is increased to prevent slip). The rates of change of grip and load force are scaled to the expected weight of the object; they increase to a maximum and then decrease in anticipation of lift-off, as an effect of feed-forward control processes. This is why they can be considered indexes of the predictions of object weight. If predictions of object weight are faulty there would be perturbations in the lift-off phase.

Nevertheless, according to [Flanagan & Beltzner, 2000], the motor system reacts rapidly to these perturbations and changes in the force output soon follow. According to the authors, this fact leads to the rejection of the hypothesis that the SWI originates in a *mismatch* between the expected sensory feedback and the actual sensory feedback about the weight of the object and also that the illusion originates in erroneous motor commands about the characteristics of the lifting movement.

[Flanagan & Beltzner, 2000] have conducted the following experiment: subjects were asked to repeatedly lift objects (20 lifting trials) of equal weight and different sizes in alternation; subjects were also asked to visually examine the object before lifting and to express a prediction about the weight. Subjects unanimously expressed the expectation that the larger object would be heavier. After the set of trials, all participants still underwent the SWI (they reported the sensation that the smaller object was heavier). The comparison with a control experiment indicated that even the strength of the SWI was as high at the end of the trials as it had been at the beginning. The analysis of the forces deployed during the trials shows adaptation: the force and force rate functions for the smaller and the bigger object become very similar. Then, the subjects still undergo the SWI even if they make correct predictions about the fingertip forces that are required for lifting the objects. Following the authors, it is possible that the forward models are updated on the basis of the errors in sensory predictions. Anyway, once adapted, the forward models make correct sensory predictions in that they correctly estimate the forces that are necessary to lift the objects. The fact that the illusion has the same strength at the beginning and at the end of the trials confirms that the SWI is independent of the errors in sensory prediction and consequent motor commands.

After having discarded the mismatch model, [Flanagan & Beltzner, 2000] propose an entirely cognitive explanation of the SWI. Even if the sensorimotor component of the expectation theory is invalidated by the results of their experiments, in fact, the same cannot be claimed for the cognitive component of the theory. Therefore, the authors argue for the separation of sensorimotor (motor programs and corollary discharges) and perceptual or cognitive expectations of object weight. Expectations are relevant for the SWI to occur, but not under the form of sensorimotor expectations, erroneous motor commands and consequent mismatch between corollary discharges and actual perception.

The SWI would then originate in a mismatch or discrepancy, but in this case the discrepancy does not concern sensorimotor predictions and actual sensory feedback, but only perceptual predictions and actual sensory feedback.

In other words, since the motor component involved in the lifting of the object can be correct without annihilating the illusion, the illusion must be alleged to the sensory and cognitive components of the task (actual perception of the object weight and cognitive expectations about the object weight), with no involvement of the motor components (characteristics of the lifting movement, existence of corollary discharges of the motor commands).

The role of knowledge or top-down processes at the origin of the SWI seems in fact to be confirmed by a particular instance of the illusion: the so-called 'golf-ball illusion'. In an experiment conducted by [Ellis & Lederman, 1998, 2000], two types of subjects are presented with special golf balls: half of the subjects are expert golf-players, who have used both real and practice balls; the other half have no knowledge of golf, nor of practice balls. Real golf balls weigh 45 g, while practice balls are 7 g.; golf and practice balls are very nearly identical in their features, but expert players can distinguish them by small differences. Golfers should have developed expectations relative to the weight of real and practice balls depending on their features. Materials of the experiment included a set of real golf balls and a set of practice golf balls, with their normal external aspect. Nevertheless, the weight of the golf and practice balls is modified due to the insertion of different fillings in the balls: all the balls were made to weigh the same. Subjects are asked to provide magnitude estimates of the balls' weight, presented one after the other. As a result, experienced golfers report real balls (which they expect to weigh more than practice balls) to weigh less than practice balls of the same weight. Non-golfers (who don't expect the balls to weigh differently) report no weight differences between them, and they experience no illusion. It seems clear that top-down processes cannot be discarded in the explanation of this illusion: previous experience with the object and the related knowledge which is acquired play a crucial role in determining whether the illusion is experienced or not.

The occurrence of the golf-ball illusion suggests that cognitive components have the possibility of influencing the occurrence of weight estimates. Nonetheless, the role of previous knowledge in the golf-ball illusion does not *per se* demonstrate that the SWI is a cognitive illusion. Factors other than expectations (both in their cognitive and sensorimotor formulations) have in fact been enumerated for explaining the SWI of purely sensory nature.

1.2.2 Perceptual theories: the SWI is not a cognitive illusion, and not even an illusion at all (criticism of the cognitive component of the expectation theory)

[Ellis & Lederman, 1998] consider the imperviousness of the SWI to knowledge as a good reason for questioning the cognitive model, even if the golf-ball illusion provides evidence against purely sensory hypothesis.

Attempts at giving purely sensory explanations of the SWI (with no role for cognition) date back to the *density model* by [Thouless, 1931], who suggested that it is the object's density which is directly perceived rather than its weight.

More recently, [Masin & Crestoni, 1988] have argued against the role of cognitive expectations in the SWI by suggesting that only actual sensory information is relevant for the SWI to occur.

In their experiment an object was shown to the observers and then hidden from view; while still hidden, the object was lifted by the observer. The authors consider that, when a subject lifts an object after the object has been hidden, a motor set or a cognitive or perceptual expectancy still persist during lifting. The results of the experiment show no SWI illusion. In another experiment the subjects lifted the object before seeing it, but they rated its heaviness only after the object was exposed to view. In the control experiments, subjects lifted weights without being able to see the objects lifted or they lifted a weight while seeing it. The SWI illusion occurred in the situation of the simultaneous exposition (vision and lifting) only.

The authors have used these results to refute the notion of cognitive expectation as the mechanism underlying the SWI, and they have proposed that the SWI has direct *sensory origins*.

The hypothesis of [Masin & Crestoni, 1988] is based on the "*information-integration*" model proposed by [Anderson, 1970, 1972], and [Cross & Rotkin, 1975]. Following the information-integration model, heaviness should be considered as a function of both weight and size or volume. That is, in normal weight perception, the estimation of heaviness is a complex perceptual judgment which is based upon information regarding weight and information regarding size. Hence, the interaction between size and weight that is characteristic of the SWI is not an illusion at all. The so-called SWI is just a dramatic demonstration that perceived heaviness is a function of both weight and size or volume. The interaction between (visually perceived) size and (haptically perceived) weight does no require higher level processes, such as knowledge or expectations, but it only reflects a characteristic of the haptic system. The case of weight perception by the haptic system is analogous to the perception of loudness in audition, which is influenced both by frequency and sound pressure, and to the perception of hue in vision, which is a product of both spectral wavelength and intensity. In the same manner, size is to be considered as a property of the object that contributes to its perceived heaviness.

In the frame-work of the information-integration model the SWI is dealt with locally, on the basis of the specific characteristics of the haptic system when it comes to weight perception. However, one may question the notion of illusion in general terms. This is what the ecological theories – at least on some readings- do.

1.2.3 The ecological view: illusions do not exist

The perceptual model and the cognitive (non-sensorimotor) model point out the role of vision in the SWI : either visual cues are at the origin of the erroneous evaluation, or they accompany haptic cues and provoke the illusion.

In the cited work by [Masin & Crestoni, 1988] one of the experiments is performed by eliminating haptic cues obtained by grasping the object: the object, in fact, is lifted by pulling down a string which is attached to it. As we have seen, the SWI occurred when vision was allowed. This result indicates that vision is sufficient for provoking the SWI.

[Lederman & Klatsky, 1987] provide evidence that the haptic system is suitable for volume judgments and that information about object volume is extracted by exploratory procedures called "*enclosure*" and "*unsupported holding*". Both procedures involve lifting movements of the object, the traditional method for extracting weight information about objects. Hence, the observers of the experiment on the SWI obtained volume information about the objects both visually and haptically, when lifting the objects.

[Ellis & Lederman, 1993]'s investigation of the relative contribution of haptic and visual cues in the SWI demonstrates that a significant SWI can be obtained also in the haptic-only condition. In the haptic-only condition, observers were blindfolded and asked to express weight estimations about the objects. The vision-only and haptic-only conditions were plotted against vision+haptic conditions in which the observers were allowed to see the object while simultaneously lifting it. The illusion produced in the vision-only is less substantial than the illusion produced in the haptic-only and in the haptic+vision conditions. This indicates that, even if visual cues are effective in originating the SWI, a full strength illusion rather depends on haptic cues.

The nature of dynamic touch is at the origin of the SWI

Once the haptic nature of the SWI is established, it is possible to put forward a purely perceptual explanatory model of the SWI based on the characteristics of the haptic system.

The model is based on an ecological description of the haptic system, and in particular of the so-called 'dynamic touch' [Gibson, 1962, 1966]; [Turvey, 1996]. This is the kind of touch that occurs when an object, such as a book, is grasped and lifted, turned, carried and so on. The perception of object properties by wielding is a prominent example of dynamic touch. The haptic properties that are thus perceived are those regarding the macro-geometry and volume of the objects, as the extension, shape, orientation, weight distribution; at the same time properties of the limb holding the object are distinguished. Dynamic touch is also involved in the manipulation of instruments, such as forks, hammers, etc.

In other words, dynamic touch is closely related to what [Bell, 1934] has called 'muscle sense'. The object which is held and manipulated affects the state of the muscles and tendons of the hand-arm system, and activates the corresponding receptors ([Fitzpatrick, Carello & Turvey, 1994]). Being related to wielding and lifting movements [Lederman & Klatsky, 1987], the SWI and the perception of object weight in general is a matter of dynamic touch and its properties.

Weight perception depends on the inertia tensor

The general strategy adopted by Turvey and colleagues in the analysis of dynamic touch consist in the identification of the invariances[19] (time-independent quantities) of the relevant dynamics of different tasks[20], such as exteroception[21] and expproprioception in general[22], the perception of object weight[23], extension[24], length[25], width[26], shape[27],

---

[19] [Solomon, 1988].

[20] [Carello & Turvey, 2000]; [Turvey, *et al.*, 1981]; [Turvey, 1992, 1996, 1998]; [Turvey & Carello, 1995]; [Turvey, *et al.*, 1996].

[21] [Fitzpatrick, Carello & Turvey, 1994].

[22] [Pagano, Carello & Turvey, 1996].

orientation[28], distance[29], selective touch[30], position of grasping[31] and the perception of limb position[32] and orientation relatively to the object[33]. During wielding, lifting and so on, these invariances determine the deformation of muscles and tendons and the activation of the corresponding receptors in a time-invariant manner.

An object which is held and wielded in the hand has a motion pattern which can be suitably described as a rotation in three-dimensional space about a fixed center of rotation which is located in the joint of the wrist ([Fitzpatrick, Carello & Turvey, 1994]). The distance between the point of rotation and the center of mass of the object held in the hand remains constant, while the distance between the joints at the elbow and shoulder and the center of mass varies during wielding movements. The relevant quantities are then included in the quantities of the rotational motion about a fixed point.

---

[23] [Burton & Turvey, 1990b].

[24] [Pagano, Fitzpatrick & Turvey 1993]; [Solomon, Turvey & Burton, 1989a, 1989b].

[25] [Burton & Turvey, 1990a]; [Carello, Fitzpatrick & Turvey, 1992]; [Chan, 1994, 1995].

[26] [Chan, Carello & Turvey, 1990]; [Turvey, *et al.*, 1998].

[27] [Burton, Turvey & Solomon, 1990].

[28] [Pagano & Turvey, 1992]; [Turvey, *et al.*, 1992].

[29] [Chan & Turvey, 1991]; [Pagano & Turvey, 1993]; [Solomon & Turvey, 1988].

[30] [Carello, Santana & Burton, 1996].

[31] [Pagano, *et al.*,1994].

[32] [Pagano & Turvey, 1996].

[33] [Pagano & Turvey, 1995].

The hypothesis put forward by [Amazeen & Turvey, 1996] is that in the course of the rotation movement, the object presents a resistance to being moved. The pattern of resistances to rotational acceleration in different directions is expressed by the inertia tensor[34].

An object's rotational inertia is in fact represented by a quantity constituted of many numbers (in other terms, it is quantified by a hypernumber), since the object offers different resistances to rotational acceleration in different directions. The different resistances are function of the object's constituent masses and of the distribution of the mass of the object, that is, how far they are from the axis of rotation. The further the object's masses are distributed from the axis, the greater becomes its resistance to rotational acceleration about the axis.

The turning force about each of the three axis of the three space factors into two forces: a force which is radial to the rotational motion and a force which is normal to the rotational motion; therefore, there are inertial forces opposing both. For an arbitrary coordinate system *Oxyz*, the hypernumber representing the inertia to rotational acceleration about *O* is a tensor consisting of 9 numbers: three quantifying the moments of inertia (the forces opposing the tangential components for each axis) and 6 quantifying the products of inertia (the forces opposing the radial components, thus the centrifugal moments). It is possible to individuate a non-arbitrary system of coordinates at *O*. The axes of the non-arbitrary system of coordinates are the principal axes or eigenvectors. In this configuration, there are no products of inertia, but only principal moments of inertia or eigenvalues, the largest, intermediate and smallest respectively, referred to as I_1, I_2, I_3.

[34] In mathematics tensors are quantities or geometric entities represented by multi-dimensional arrays of components and defined independently of any frame of reference.

For any wielding of an object in three space the resultant deformation of the muscles is constrained in a time-independent way by all three eigenvalues [Fitzpatrick, *et al.*, 1994]).

Some experiments have highlighted the role of the eigenvalues of the inertia tensor in weight perception[35]. In a first experiment, the mass and volume of the object are maintained as constant, while the rotational inertia of the object is manipulated by modifying the distribution of the masses of the object. In a second experiment the rotational inertia is suitably manipulated in order to simulate variations in the volume, while the volume and mass are maintained as constant. In a third experiment rotational inertia is suitably manipulated in order to simulate mass variations, while the volume and mass are maintained as constant. The results indicate that weight perception varies with variations in the distribution of the masses, independently of the mass and volume of the object.

Special objects are designed in order to manipulate the eigenvalues of the inertia tensor without modifying the mass or the volume of the objects ('tensor objects'): the objects are constituted of two rods connected in the center forming an angle of 90° between them and with a third rod which is used as handle. Metal rings can be placed in different positions along the three rods in order to modify the distribution of the masses of the objects without modifying its overall volume and mass. The rings' position is occluded from sight.

---

[35] [Amazeen, 1995, 1997a, 1997b, 1999]; [Amazeen & Turvey, 1996]; [Amazeen & Woodrow, 2003]; [Burke & Amazeen, 1997].

The results indicate that, independently of the mass and volume of the objects, perceived weight varies with I_3, that is, with the smallest of the eigenvalues of the inertia tensor represented by the object: perceived weight decreases with the decreasing of I_3. Since variations in the mass and volume provoke variations of the eigenvalues, even the dependency of the perceived weight on the volume and mass of the object can be explained in terms of the variations of the eigenvalues of the inertia tensor. For instance, for an increase in object mass, the three eigenvalues uniformly increase; another experiment shows that increasing all the three eigenvalues results in an increase in the perceived weight.

Box 1. The inertia tensor

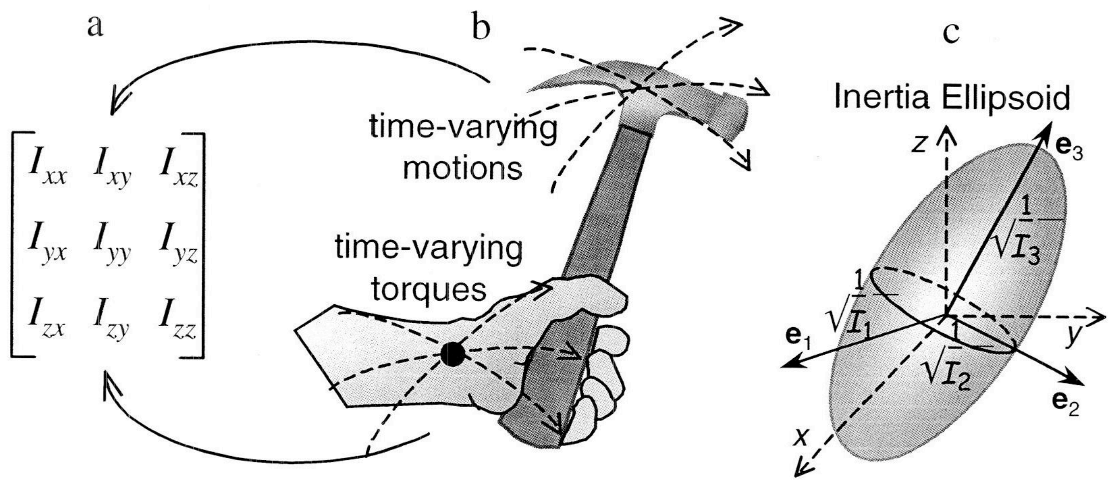
The inertia tensor quantifies different resistances to rotation in different directions. It is constituted of a matrix with moments of inertia on the diagonal and products of the inertia out of the diagonal.

The axes of rotation can be oriented in such a way so as to eliminate the components outside the diagonal. This is the only non-arbitrary position of the axes. In this position, the axes are called eigenvectors or principal directions; their length is indicated as eigenvalues or the principal moments of the inertia. Eigenvalues and eigenvectors are sufficient to describe the magnitudes (such as length, width, weight, etc) and directions (orientation, etc.) of the wielded object. The magnitudes match into the eigenvalues and the directions into the eigenvectors.

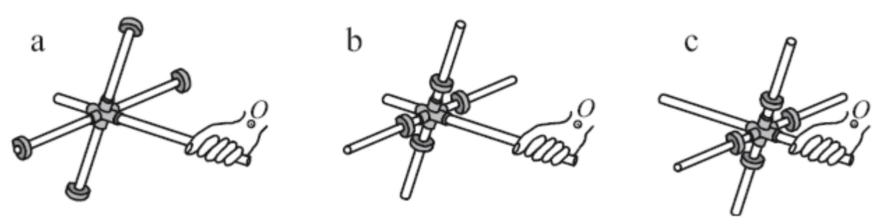
A geometric representation of the object can be drawn on the basis the eigenvalues and eigenvectors. The inertia ellipsoid constitutes a graphical description of the essence of the mass distribution of the object.

Figure 3. The inertia tensor

a. The matrix of the inertia tensor [Carello, 2004]
b. Hand-held object with relative axes of rotation [Carello, 2004]
c. Geometric representation of the mass distribution of the hand-held object (inertia ellipsoid) [Carello, 2004]



d. Tensor objects [Carello, 2004]



The SWI is an effect of the properties of the dynamic touch, and is not an illusion

> "…the possibility now exists for a theory in which the size-weight illusion is grounded in the same principles as normal weight perception." [Amazeen & Turvey, 1996, p. 222]

Within the model of the inertia tensor, the effects of size or volume on object weight perception are interpreted as consequences of the variations in the patterns of resistance of the object when the latter is being moved, that is, as effects of variations of the inertia tensor. Weight perception is truly dependent on the inertia tensor, and phenomena such as the SWI are normal consequences of the proper functioning of dynamic touch. Since perceived weight is not a function of the mass of the object but of the inertia tensor, no cognitive hypothesis, no mismatch (neither sensorimotor non perceptual or cognitive), no sensory integration is to be invoked in order to explain the variations in weight perception for objects of the same mass. One and the same principle, the inertia tensor, and specifically its eigenvalues, is sufficient for accounting for both 'normal' weight perception (when perceived weight is in accord with the actual mass of the object) and 'illusory' weight perception (when weight is not in accord with the actual mass of the object).

For this reason, [Amazeen & Turvey, 1996] claim that the SWI cannot really be considered as an illusion. In the opinion of the authors, the situation only appears illusory when the phenomena are wrongly described by the experimenter; in the case of the SWI, describing object weight perception as dependent on the mass of the object is misleading, since the haptic system (dynamic touch) in fact is not assessing weight, but is sensitive to a different quantity: the inertia tensor.

Illusions do not exist

Following the ecological approach [Turvey, *et al*, 1981], the recognition of the proper quantities a perceptual system is sensitive to is interpreted as leading to the dissolution of the notion of illusion.

The approach claims that phenomena such as the SWI are useful in order to guide the search for the real quantities the perceptual systems are sensitive to. The SWI is then used as a model situation for investigating the perception of object length, width, shape, orientation with dynamic touch [Turvey, 1996]. For instance, in a series of experiments, the effects of the eigenvalues and eigenvectors of the inertia tensor on different perceived qualities of objects that are held and wielded by the hand are evaluated. *Apparently illusory* phenomena are produced, in that the manipulation of the eigenvalues or eigenvectors provokes variations in the perception of the object qualities that are not in accord with the actual, measured qualities of the object. [Solomon & Turvey, 1988] show that haptically perceived object length does not depend on the actual length of the object, but varies in correlation with variations of the eigenvalues: it increases at the increase of the largest eigenvalue and decreases at the decrease of the smallest eigenvalue. On the contrary, perceived object width increases with increased smallest eigenvalue and decreases with increased largest eigenvalue.

For all the cited cases, the perceptual experience is manipulated in such a way so as to produce phenomena that are analogous to the SWI for different perceptual qualities, such as length or width. Nevertheless, the results of such modifications are not considered as illusory effects in that the perceptual systems is not committing any error but it is simply sensitive to certain qualities (invariances) that the suitable modification of the experience helps to highlight.

Chapter 1. Summary and conclusions.

We have seen that the explanation of the SWI is controversial. The reasons of the controversy aren't limited to the empirical discovery of explanatory causes for the SWI, but are extended to the question of the proper nature of the SWI and to the nature of illusions: is the SWI an illusion? If not, is its treatment as an illusion an artefact of the description of the experimental setting? These are specific questions limited to the explanation of the SWI and eventually to the nature of the SWI. But more general questions arise from the discussion about the SWI relative to the nature of illusory phenomena.

The mismatch or discrepancy between cognitive expectations and actual perception in the SWI have been opposed to the integration of multiple, actual, sensory cues.

Advocates of the latter approach refuse to consider the SWI as an illusion. The argument suggests the necessity of a deeper analysis of the *relationship between illusions and conflicts or discrepancies* between multiple sensory cues.

Advocates of the former approach are divided in their opinions with regard to the nature of the expectations. On one side, the hypothesis is constructed that cognitive expectations have sensory consequences, or at least motor consequences on the motor planning and that the sensory and motor consequences of expectations have a direct role in the occurrence of the SWI. On the other side, cognitive expectations directly play their role in the origin of the SWI, and no sensory or motor medium is introduced. Merely cognitive, explicit expectations have been discussed up to now: even when their action upon perception is mediated by their sensory and motor consequences, the nature of expectations is always connected with some form of symbolic knowledge and with some form of internal representation regarding the objects' weight and size. The question arises about the *nature of expectations and their role in illusory phenomena*.

Finally, the abandoning of the notion of illusion for what regards the SWI has been extended to all perceptual phenomena that have been described as illusory. In particular, the concept of cognitive or perceptual error, based on knowledge and expectations, has been opposed to the concept of a direct picking-up of relevant ambient quantities. According to the advocates of the ecological approach, when information is directly picked-up from the ambient array, the notion of illusion itself is deflated. The discussion about the SWI thus raises a more general question about the real *nature of illusory phenomena and about the possibility of maintaining the notion of 'illusion'* within the frame-work of a psychological theory of perception. It is a fact that the cognitive approach expressed in the context of the expectation theory and the ecological approach related to the inertia tensor model constitute two opposite views about the SWI and about the notion of illusion itself and represent two theoretically antipodal positions about perception in general.

Hence, the examination of the literature regarding the SWI reveals the existence of a conceptual problem regarding the definition of illusory phenomena and the status of illusions in relationship with other perceptual phenomena: *normal perception*, *perceptual errors* and *discrepancies* or *conflicts* between multiple information; and also a problem regarding the role of *knowledge* and *expectations* in illusory phenomena.

The following chapters aim at analyzing these issues.

Table 1. The different positions about the SWI and illusions

General approach	***Different positions toward the SWI***	***Specific explanation of the SWI***	***Different positions toward the SWI and illusions in general***
Expectation theories		The occurrence of the SWI depends on the existence of expectations based on knowledge (general or specific)	The SWI is a cognitive illusion
	Cognitive-motor theory	Expectations generate erroneous lifting movements which provoke erroneous weight evaluation	The SWI is a cognitive illusion; knowledge influences motor actions
	Cognitive-sensorimotor theory	The expected weight generates motor actions and relative corollary discharges, that is previsions about the sensory inflow in response to the motor action. The SWI is generated by the discrepancy between the actual sensory inflow and the expected sensory feedback	The SWI is a cognitive illusion; knowledge influences motor actions and expected sensory feedback
	Purely cognitive theory	The discrepancy between the expected weight and the actual sensory inflow generates the illusion. No role for motor errors and corollary discharges	The SWI is a cognitive illusion
Perceptual theories	Information-integration model	Weight perception in general depends on multiple factors, including weight and volume or size; the SWI serves as an illustration of this fact, but is cannot be set apart from non-illusory weight perception	The SWI is not an illusion
	Ecological view	Weight perception in general depends on the resistance offered by the object to the fact of being moved; the resistance depends both on the mass and on the mass distribution of the object. The SWI serves as an illustration of this fact, but is cannot be set apart from non-illusory weight perception	The SWI is not an illusion and illusions in general do not exist: the only problem is to find the real quantities the perceptual systems are sensitive to (such as the rotational inertia for the haptic touch and weight perception)

Chapter 2. Characterization of illusory phenomena

This chapter aims at providing a characterization of illusory phenomena.
As shown by the case study of the SWI, there is no unanimity within the psychological and physiological approach to perception concerning the definition of what illusions are, and even as to whether the characterization of the class of illusory phenomena is useful and justified. In fact, in its 'technical' use, the notion of illusion is strongly dependent upon the theoretical approach adopted.

For this reason, before a characterization of illusory phenomena is provided, it is important to analyze how the notion of illusion is made operational by the different theoretical approaches to perception that make use of it and also what arguments are given when the notion of illusion is discarded by the theoretical approaches that avoid making use of it. In particular the so-called *direct approach* and *indirect approach to perception* present significant positions about the concept of illusion. For both approaches, the acceptance or refusal of the notion of illusion is strongly motivated by the general approach to perception and the arguments in favour or against illusions are representative of the justifications for adopting a direct rather than an indirect view of perception.

It will be shown that one of the main difficulties arises because of the characterization of illusions as errors. The *notion of error* will be hence discussed before approaching the other characteristics of illusory phenomena.

2.1 Theoretical difficulties with the notion of error affect the characterization of illusions

Illusions are characterized as departures from reality or as errors both by common sense and by the psychological literature.

Such a characterization of illusory phenomena as errors is not unproblematic.

First of all, as it is shown by the arguments of the direct approach, the notion of error which is employed for the characterization of illusory phenomena is theoretically entangled with the indirect vision of perception.

Secondly, some of the phenomena that even the indirect approach characterizes as illusions are not errors in the sense of departures from reality; they are rather discrepancies from physical facts or discrepancies between the reality as it appears to perception and reality as it appears when measured with precision instruments (this is the classic definition of illusions provided by Gregory which matches the common sense use of the term 'illusion').

These two considerations lead to the necessity of revising the characterization of the concept of illusion, or of revising the notion of error as it has been used in order to characterize the concept of illusion.

2.1.1 Uses of the term 'illusion' by common sense and psychological literature: illusions are errors in the sense of departures from facts

The term 'illusion' is commonly used in ordinary language to indicate a variety of situations, not necessarily bound to perceptual phenomena. The term 'illusion' in fact can be assigned different meanings and can be used in a variety of situations. The term 'illusion' is sometimes used as a synonym for 'hallucination', in addition to 'semblance', 'deception' (both in the sense of creating expectations that are then deceived and in the sense of a magician trick) and 'misconception'[36]. In any of these examples two components are placed in relation: something as it is (the facts) and some perception, conception, belief about the facts; the two components are, in a sense that must be properly qualified, at odds. In general it is assumed that the appearance, belief or conception is false with regard to the facts. That is, illusions are departures from facts. Here are some paradigmatic examples:

---

[36] As an example of existing classification of the variety of uses of the term "illusion" one can see the The WordNet lexical database.

"Sense1:
Illusion, semblance (an erroneous mental representation)=> appearance (a mental represe ntation; "I tried to describe his appearance to the police")
Sense 2:
illusion, fantasy, phantasy, fancy (something many people believe that is false; "they have the illusion that I am very wealthy)=> misconception (an incorrect conception)
Sense 3:
delusion, illusion, head game (the act of deluding; deception by creating illusory ideas) => deception, deceit, dissembling, dissimulation (the act of deceiving)
Sense 4:
magic trick, conjuring trick, trick, magic, legerdemain, conjuration, illusion, deception (a n illusory feat; considered magical by naive observers)
=> performance (the act of presenting a play or a piece of music or other entertainment; " we congratulated him on his performance at the rehearsal"; "an inspired performance of Mozart's C minor concerto")"
[Fellbaum, 1998; The WordNet lexical database developed by the Cognitive Science Laboratory at Princeton University under the direction of George A. Miller. http://wordnet.princeton.edu/].

- "*I've seen something that resembled, that had the aspect of a cat, but as a matter of fact it was a shadow: I had the illusion of seeing a cat*"
- "*My friends take me for someone rich, but in fact I'm not: they have the illusion I'm rich because I spend so much*"; "*You illude yourself about the future of your country: it is declining*"
- "*The magician gave us the illusion that the woman was split into two parts*"

The research on illusions in the psychological literature: illusions as errors

In addition to the common sense use, the term 'illusion' is in use in the psychological literature in order to isolate a specific class of perceptual phenomena as, for instance, the Size-Weight illusion, the Horizontal-Vertical illusion, Aristotle's illusion, etc., and also other illusions that are suitably created in laboratory conditions for investigating specific phenomena. Research on illusions has in fact become a fundamental component of psychological research about perception.

The common sense use of the term 'illusion' as departure from facts is reflected in the psychological literature by the characterization provided by Gregory:

> "*Errors are illusions*. Certain situations present special difficulty, giving rise to *systematic errors* […]" [Gregory, 1968, p. 179; my italic]

Gregory gives the term 'illusion' the meaning of a special type of error in perception: illusions are systematic errors, as related to especially difficult and typical problems during the process of information extraction and interpretation which is proper to perception. Gregory also recognizes the difficulty of considering illusions as departures from reality, in virtue of the difficulty of defining what reality is, or of the risk of turning all perception into a massive illusion. He thus limits his definition to the departure from facts as physically measured or physical facts.

> "It is extraordinarily hard to give a satisfactory definition of an "illusion". It may be the departure from reality, or from truth; but how are these to be defined? As science's accounts of reality ever more different from appearances, to say that this separation is "illusion" would have the absurd consequence of implying that almost all perceptions are illusory. It seems better to limit "illusion" to systematic visual and other sensed discrepancies from simple measurements with rulers, photometers, clocks and so on." [Gregory, 1997, p. 1122]

In addition to the notion of error the notion of systematicity is recalled to define illusions as

> "Systematic deviations from physical facts." [Gregory, 1973, p. 49]

Errors *per se* do not provide an interesting scientific category, as they are hostage to contingencies. Errors that are committed systematically, on the other hand, delineate an interesting category, amenable to scientific investigation.

Systematic errors can be of two sorts.

As we have seen, there are a number of perceptual phenomena that are explicitly labelled 'illusion', and that have received, in the course of time, standard description in the literature about perception (such as the SWI), in spite of the differences in the interpretation of the causes.

Otherwise, illusions can be provoked by manipulating the stimulus situation in the controlled environment of the laboratory. These illusions do not necessarily receive a name, or a standard description. They are used in order to highlight some specific mechanism; they can be reproduced at will by recreating the same situations with any subject at any moment, and this is a mark of their systematicity.

Both sorts of systematic errors or illusions will be illustrated during the discussion about the characterization of illusions. In fact, the indirect account of perception explicitly makes use of standard illusions, such as the SWI. On the contrary, as we have seen, the ecological, direct account of perception refuses to accord to these phenomena the condition of illusions; nevertheless, phenomena described in the classic literature as SWI are investigated in order to individuate specific perceptual invariances. Also, as we have seen, phenomena analogous to what the SWI represents for weight perception are provoked for the perception of other different qualities (such as the haptic extension, orientation and position of objects) by suitably manipulating the masses distribution of hand-held objects. These phenomena too are systematic and have the property of revealing the invariances associated with dynamic touch.

Box 2. Gregory's classification of illusory phenomena

In the use made for instance by [Gregory, 1997] 'illusion' is an umbrella-term which includes a great variety of phenomena. Illusory phenomena are classified as such:

- *ambiguities* (as the Necker cube, the visual effects provoked by mist or retinal rivalry)
- *distortions* (as the SWI or other classic geometric illusions, such as the Horizontal-Vertical illusion, but also mirages)
- *paradoxes* (as the impossible triangle of L. S. Penrose and R. Penrose of 1958, which cannot be seen as a sensible three-dimensional figure, the so-called impossible figures and impossible objects in general. The mirror represented in Magritte's "*La reproduction interdite*" is equally considered a visual paradox, since it reproduces an impossible situation)
- *fictions* (as the rainbow, the faces one can 'see' in the fire, galleons in the clouds and so on, the after-images and figures such as the Kanisza triangle).

The number of phenomena that are described as illusions has greatly grown during the last two centuries. If some perceptual illusions were just known to the ancient Greeks (for instance, the so-called Aristotle's illusion), it is in the XIX century that the first scientific description of illusions were given.

[Gregory, 1968] describes the following steps in the study of illusions.

In 1832 L. A. Necker illustrated how a rhomboid reverses in depth, sometimes one face appearing the nearer, sometimes the other (perceptual reversal or alternation); W. Wundt described the Horizontal-Vertical illusion: a vertical line looks longer than the horizontal line of equal length that it encounters (distortion illusion); interest in illusions grew higher suite to the publication of some figures showing distortions which could affect the use of optical instruments, thus producing errors: the Poggendorff figure of 1860 (a straight line crossing a rectangle appears displaced), the Hering illusion of 1861 and the Wundt of 1896 (straight parallel lines look bowed outwards or inwards), the Mueller-Lyer arrow figure of 1889 (the outward-going arrow heads produce expansion of the shaft, and the inward-going heads contraction).

Distortion phenomena were then explained with reference to the stimulus pattern, (for example, in the case of the Mueller-Lyer figure that the acute angles tend to be overestimated and the obtuse angles to be underestimated).

Box 3. Experimental research on dynamic touch

Research on dynamic touch conducted in the context of the ecological view of perception uses the modification of the distribution of masses of hand-held objects as a privileged instrument for the identification of the invariances the dynamic system is sensitive to. Invariances proper to dynamic touch are in fact identified with quantities that are related to the rotational inertia of the hand-held object, that is to the resistance the object offers to being moved (movements performed with the arms are rotation, in virtue of the anatomical structure of the joints). The relevance of rotational inertia for the haptic perception of object properties is demonstrated in several experiments using an experimental setting of this kind: one or more rods connected one with the others with attached masses. The masses can be displayed in different positions so as to change the masses distribution without modifying the shape or the weight of the so-composed object.

In experiments about length perception, for instance, it is shown that a rod with a mass attached near the hand which holds the rod feels shorter than the same rod with the mass attached at the end far from the hand. The described phenomenon is systematic and is used to reveal the functioning conditions of the haptic dynamic system. Nevertheless, the phenomena that are provoked in this way are not considered as illusions by the experimented they are performed by.

As we have seen, in addition to the investigation of weight and length perception, other experiments of this kind regard:

- width,
- shape,
- orientation,
- grasping position of hand-held objects (exteroceptive properties)
- position of the hand and limb relatively to the hand-held object (expproprioception, or proprioception via exteroception).

2.1.2 The opposition of indirect and direct approaches to perception relative to the notion of illusion as perceptual error

As we have seen during the discussion about the SWI, over and above local objections raised about the SWI being or not being an illusion, general theoretical objections are addressed by the ecological account of perception against the notion of illusion considered in itself.

The general objections are connected with the characterization of illusions as errors. The notion of error which is used to characterize illusory phenomena is in fact theoretically committed with the indirect, inferential approach. In the frame-work of the indirect, inferential approach errors are failures during an inferential process, eventually involving the intervention of representational knowledge.

A characterization of illusory phenomena which is based upon these arguments would thus be objected to by other direct approaches to perception than the ecological one, such as the sensorimotor approach. The sensorimotor approach does not necessarily discard the notion of illusion (as the ecological approach does) and suggests a possibility for disentangling the notion of illusion from the indirect approach to perception and for providing a characterization of illusory phenomena which can be accepted by a larger audience in the psychological research.

Finally, another difficulty about the characterization of illusions as errors is discussed which is related to the inclusion of ambiguities and paradoxes within the class of illusory phenomena. If errors are characterized as departures or deviations from facts, the problem arises concerning those illusory phenomena where there is no departure from facts, even physical, measured facts, but instead perceived facts are themselves ambiguous or paradoxical.

Box 4. Direct and indirect approaches to perception

The claim that perception is direct consists in the argument that perception is a form of non-inferential awareness of the things we normally take ourselves to be aware of when we perceive [Noë, In press]. Mental intermediaries such as sense data, impressions, appearances are thus refused to be the things we are directly aware of in perception. The perceiver is instead directly aware of the world itself, and the world is accordingly very similar to what it seems like in perception (naïve or direct realism is connected to the direct approach to perception). There are a certain number of direct approaches to perception, including views propounded by psychologists and philosophers.

Among philosophers, [Austin, 1962] adopts a direct approach in that he refuses the notion of sense data and of a general object of perception which would be common to illusory and non-illusory experiences. The same line of argument is adopted by [Snowdon, 1980-81] and [McDowell, 1982, 1986]; in particular Snowdon and McDowell adopt an externalist view of perception according to which perceptual experiences are constituted by the relation between the perceiver and an external object. [Sellars, 1956] and [Strawson, 1979] too refuse the idea that perception might regard our sensory impressions: perception consists in the intentional experience of the world as being in this way or that.

In the domain of psychology, two main approaches to perception represent the direct view: the ecological approach introduced by [Gibson, 1966] and [Turvey, *et al.,* 1981] and the sensorimotor approach of [O'Regan & Noë, 2001].

One of the arguments against the direct approach to perception is the so-called 'argument from illusion' [Ayer, 1955]. Following the argument, the experience of seeing a really existing object and the experience of seeing an object that does not exist but is merely hallucinated are indistinguishable. Thus, a common entity must exist which is the object of perception in both cases: a sense datum. The real object enters the perceptual experience only as a more or less far cause of the perceptual process.

In the same vein, indirect perception approaches assert that when a round form is perceived form a generic viewpoint, an elliptical scheme is directly accessed by the visual system, so that the round shape of the object must be inferred as a result of conjecture and speculation.

In general, the problem of perceptual science committed with the indirect view is to explain how do we perceive what we do (i.e. a three-dimensional world) given the patterns of stimulation of the sensory organs (see for instance [Marr, 1982]).

[Fodor, 1981] asserts that the brain actively constructs the perceptual experience through the intervention of inferential processes, thus reaffirming the paradigm proposed by Helmholtz of perception as unconscious inference.

Box 5. Indirect approaches to perception: the inferential approach

The position expressed by Gregory can be traced back to H. von Helmholtz's notion of perception as a process involving unconscious inferences: perception is only indirectly related to objects in the world; data signalled by the senses are fragmentary and often hardly relevant, so that perception requires inferences from knowledge to make sense of the sensory data. Indirect approaches to perception affirm that it is not directly the objects that we perceive, but intermediates. The inferential approach is a variation of the indirect approach:

> "Following von Helmholtz's lead we may say that knowledge is necessary for vision because retinal images are inherently ambiguous (for example for size, shape and distance of objects), and because many properties that are vital for behaviour cannot be signalled by the eyes, such as hardness and weight, hot or cold, edible or poisonous. For von Helmholtz, ambiguities are usually resolved, and non-visual object properties inferred, from knowledge by unconscious inductive inference from what is signalled and from knowledge of the object world." [Gregory, 1997, p. 1121]

One of the most important applications of knowledge to perception regards the vision of scenes and object in a three-dimensional way. In the indirect perspective, in fact, three-dimensional vision is not straightforward, even if we normally perceive a three-dimensional world because the bottom-up information the visual system disposes of is just "*flat ghostly images in the eyes*" [Gregory, 1997, p. 1122]

To read reality from images is to solve a problem. And when the problem is quite difficult errors are to happen. Marr's researches about vision go into this same direction [Marr, 1982]

We can reconstruct the main argument for this position as follows:

1. stimuli are ambiguous (such as visual size) or insufficient for specifying object properties (such as for weight by sight)
2. nevertheless, the final percept is unambiguous and specified
3. some process must have taken place which has solved the ambiguity and allowed specification of object properties
4. in addition to present information, the subject disposes of previously acquired knowledge about objects of the world
5. knowledge can be used to disambiguate present stimuli and to specify incomplete information through a process of inference
6. inference is a mechanism that allows the use of past knowledge for producing new knowledge, thus the final percept is the result of an inference based on the content of actual experience and the content of past knowledge.

As a consequence, errors might arise at different moments in the course of the inferential process.

The argument of the inferential approach has been contested at different levels.

As we will better see in what follows, the type of direct perception approach represented by Gibson and others (ecological approach) contests the first point, that is, the assumption that information is ambiguous or insufficient. As a consequence there is no need for additional, cognitive processes as stated at point three in order to obtain a coherent, informative final percept.

Points two and three are discarded by [O'Regan & Noë, 2001], who endorses another type of direct approach to perception and sustains that there is no need for internal mechanisms because the final percept is not complete and the coherence of the final percept is simply warranted by the unity of the motor-perceptual experience.

Finally, point five of the argument can be contested because inference is not considered as the proper process at stake (as in the case of the application of Bayesian inference).

Box 6. Direct approaches to perception: the ecological approach

The ecological approach to perception and action originated in the work of J. J. Gibson (see [Gibson, 1966]), who claimed that the perceiving organism and its environment form a system, and that perception is an achievement of the system; thus, the input is defined by the overall system, notably including the motor activities through which the organism enters in contact with the surrounds. No intermediary steps or representations are necessary in order to achieve perception.

To this effect the theory introduces the notion of 'ambient array'. Ambient arrays are structured by specific animal-environment settings and constitute what is directly perceived. Ambient arrays are higher order properties, as the changing patterns of light that are typical of an animal approaching to an object or, vice-versa, of an object approaching to the animal: for instance, a global change in the pattern of light is specific of self-motion, local change against a stationary background is specific to object motion. The specific patterns of optic flow (the patterns of light structured by particular animal-environment settings, available to a point of observation) that are identified as relevant in guiding activity are called "invariants". Invariants are what organisms directly perceive.

There is no space for knowledge in the direct picking-up of invariants.

The invariants an organism is sensitive to are not necessarily the ones the experimenter is expecting, the ones that are named in the linguistic description of the task (as the measurable weight and length of an object). As such, they must be discovered empirically. The muscular system for instance is sensitive to variations in the resistance an object opposes to being moved, and the invariant quantities (the inertia tensor) that can be individuated for describing this resistance appear to be well suited to explain all the phenomena of the dynamic perception of object, included the so-called illusions.

Box 7. Direct approaches to perception: the sensorimotor approach

[O'Regan & Noë, 2001] and [Noë, 2001, 2003, Forthcoming, Commissioned] raise the problem of the recourse to internal mechanisms and representations as the problem of the consciousness of the perceptual object as a whole. As a matter of fact, the authors explain, when grasping an object or looking at it only a part of the object enters in direct contact with our sensors. Despite this limitation of the stimulus condition, we normally perceive (haptically or visually) the entire object and not an object with only its frontal part or its grasped part.

The problem of the presence or wholeness of the perceptual content also arises from the observation that the content of the perceptual experience is not given all at once. This is well shown by change blindness phenomena [O'Regan & Noë, 2001]: an observer is presented with a very detailed scene, say, a picture of Notre Dame de Paris; the vision is interrupted by a slight flicker and immediately reappears; even if a major change is made in the picture, the observer typically misses it, even if he can be looking directly to the change area. Thus, not all the components of a picture are directly and synchronously perceived. Nonetheless, the perceiver has a complete experience.

The authors refuse two main strategies for solving the problem of the consciousness of the perceptual experience as complete: on one side the suggestion that filling-in mechanisms are active in completing the partial experience with details that are added from the brain; on the other side, the suggestion that internal representations of the objects constitute the relevant knowledge which is recalled in order to complete partial impressions of the object and to experience the object as a whole. The second suggestion is strictly connected with the image of the perceptual system as based on inferential processes based on representational knowledge, that is, with the indirect inferential approach.

As an ability of exploration, perception does not happen instantaneously, but develops in time. This is the reason why, according to the authors, even if the perceiver does not see all the details of a scene simultaneously, they can be present for him (be part of his perceptual experience) as details that one has the possibility of discovering during the scan of the image. Touching a part of the object is making the experience of the object as a whole because a simple shift of the hand allows the perceiver to enter in contact with the other parts of the object. The other parts are thus present to the perceiver as the necessary consequences of possible exploratory actions, given a certain group of sensorimotor contingencies.

The perceptual sense of presence of an object as a whole arises because the parts that are presently unsensed are nevertheless within reach, in ways that are known by the perceiver [Noë, Forthcoming].

Box 8. Perception as Bayesian Inference

The Bayesian frame-work is a general formalism for specifying the information available to perceivers and for modeling perceptual inference [Knill & Richards, 1996]. The information about the world contained in a percept (for instance in an image) is characterized as a probability distribution. This approach is based on the Bayes formula for calculating the posterior probability:

$p(S|I) = p(I|S)\,p(S)/p(I)$

In the domain of visual perception, for instance,

- S represents the visual scene, such as the shape and location of the viewed objects;
- I represents the retinal image;
- p (I|S) represents the likelihood function for the scene: it specifies the probability of obtaining the image I given a scene S. The likelihood function incorporates a model of image formation and also of noise;
- p (S) is the prior distribution: it specifies the probability of different scenes occurring in the world, thus it formally expresses the prior assumptions about the scene structure;
- p (I) is a normalization constant derived from p (S) and p (I|S) and represents the probability of occurrence of an image.

The posterior distribution p (S|I) is thus the probability of the scene S given the image I expressed as the product of the probability of the image I given the scene S time the a priori probability p (S) of the scene, divided by the normalization constant p (I). The Bayesian frame-work thus suggests that the posterior probability distribution is determined in part by the image formation processes, that include the noise added to the image coding process and the statistical structure of the world. The likelihood function in fact reflects the noisiness of the data and distortions such as the optical distortion in the passage from 3D objects to 2D images. Noise has the effect of making the information provided by an image about a scene more unreliable and spreads the likelihood function over a wide range of possible scenes. The prior distribution expresses the prior distribution of different collections of scene properties actually occurring, thus it embodies previous knowledge of the structure of the environment that constrains the perceptual estimate of scene properties.

The notion of error as a failure during an inferential process

Gregory's view is that illusions can be generated in two main ways: through the malfunctioning of the physiological mechanisms for perception or through the inappropriateness of the strategies carried out by the mechanisms [Gregory, 1973]. These two causes give rise to two different types of errors: sensory illusions and cognitive or perceptual illusions. The first type of error has a physiological or physical character. It can be caused by disturbances between the sensory organs and the object (such as the presence of mist) or by perturbed neural sensory signals, as in the case of the effects of retinal rivalry (occurring when the two retinas are exposed to different stimuli). The second type of error is of cognitive character, in so far as it concerns the framing of hypotheses from the data that the perceptual system has extracted through the sensory organs. The second type of error is then related to the process of making sense of the sensory data and, following the indirect perception approach, is intertwined with knowledge. In this case too two types of causes can generate errors in the perceptual process: the misapplication to the actually perceived situation of general rules normally applied to all the objects and scenes and the misapplication to the actually perceived object of specific knowledge about specific objects. The SWI is an example of the misapplication of knowledge regarding the relationship between size and weight.

> "Small objects feel heavier than larger objects of the same scale weight; muscles are set by knowledge-based expectation that the larger will be heavier, which is generally, though not always true. [Gregory, 1997, p. 1124]

The definition of illusions as errors, and in particular the introduction of a cognitive or perceptual account of errors based on misapplication of general or specific knowledge, implies a general view of perception as an inferential process, which goes from the extraction of data to the attribution of meaning to the data on the basis of previous experiences and previously acquired knowledge. In this view, each stage of the inferential process can fail in some way and give rise to an inappropriate perception. The notion of error is strictly related to that of failure or malfunctioning in the course of an inferential process. In other words, according to Gregory, illusions depend on the organism's perceptual mechanisms and not on how the world is structured.

> "We carry in our heads predictive hypotheses of the external world of objects and of ourselves. These brain-based hypotheses of perception are our most immediate reality. But they entail many stages of physiological signalling and complicated cognitive computing, so experience is but indirectly related to external reality." [Gregory, 1998, p. 1693]

Illusions due to the disturbance of light between the objects and the eyes (as in the case of errors provoked by the presence of mist) and illusions due to disturbances in the sensory signals of the eyes (as in the case of retinal rivalry) involve the first part of the process, that of acquiring data, and are caused by *physical causes* [Gregory, 1997]. The other causes of error intervene in the process of making sense of the data, that is in the inferential process and for this reason are considered as *cognitive or perceptual causes* [Gregory, 1997].

The ecological approach rejects the notion of perceptual error as failed inference

The ecological approach to perception – a variety of direct perception approach - has strongly criticized the notion of perceptual hypothesis and the introduction of cognitive processing in perceptual tasks, and has hence refused to consider illusions as perceptual errors. Sensory stimulation is sufficient for accurate perception, or, perception based on sensory stimulation is always accurate without the addition of information beyond what is available to sensory stimulation [Stoffregen & Bardy, 2001]. In Turvey's words:

> "There is perhaps no topic more representative of the superficiality of established thinking about perception as the topic of error. The much-worked claim that "illusions" and "failures of perception" are instances of failed inference […] has about as much intellectual force as a cough in the night." [Turvey, *et al.,* 1981, p. 275]

For instance, if a straight stick partially immersed in water appears bent this is not because the nervous system has drawn the wrong inferences from the play of light in the eyes; even if the stick is really straight, the situation of straight-stick-immersed-in-water structures the light in a way that is different from the situation of a straight-stick-outside-the-water. Since the two situations structure the light in different manners, both the perceptions can be considered as veridical. When the stick is grasped and withdrawn from the water, held up and returned to the water, its appearance changes from bent to straight to bent, and the different appearances are linked by the transformation which consists in displacing the stick from one medium to the other.

> "States of affairs appear to organisms as they ought to appear, and it is because they do that successful acting and knowing are possible." [Turvey, *et al.*, 1981, p. 276]

The same principle (clarifying the physical grounds for the appearance of perceptual phenomena, instead of delving in inferential issues) is applied to the dissolution of classical geometric illusions: in the context of attached angles (the Mueller-Lyer figure) or T- and L-shaped lines, there are no reasons for the two lines to appear other than unequal in length, once the physical grounds for this appearance are explained.

> "The task reduces to the question: What physical principles are responsible for the different appearances of a straight stick (completely) in air and a straight stick (partially) in water? We assume, therefore, that the Mueller-Lyer figure is appearing to human and to fly as it ought to appear (That is, without the benefit of any epistemic intervention), and that the task is explaining why two lines should appear equal in some contexts and unequal in others. To assume that the figure is appearing as it ought to appear is to deny the assumptions that legalize the claim of perceptual error" [Turvey, *et al.*, 1981, p. 280]

The discrepancy (between the appearance of the figure to the bare sensory organs of the perceiver and the appearance of the figure when measured through a measurinig instrument, such as a ruler) is not an error, according to [Turvey, *et al.*, 1981]. In particular, the ecological approach refuses to conform to a conventional standard of measure as a reference for distinguishing between truth and perceptual error. The ecological theory of perception or direct perception approach has as a consequence an eliminativist attitude towards illusions, when illusions are considered as departures from facts, physical facts or even measurements.

Since there is no need for special epistemic interventions (cognitive inferences), the scope of the research on the so-called illusions is rethought as the need to explain the difference in appearance given the difference in the context, rather than the need to explain the failure that has given rise to the error in perception. Let us discuss this in some detail.

In the case of geometric illusions ecologists propose to individuate the bases upon which the measurement of extension for biological systems (such as the human perceiver) is grounded. The basis of measurement ought to be, according to the principles of the ecological approach, common to both the environment and the organism, since the synergy or mutuality of the organism and its environment is assumed. In the case of extension, the adoption of chord geometry (geometry based on the measurement of chords, of the differences in distance between two points in a figure) as opposed to point geometry allows us to explain the appearance of the Mueller-Lyer figure: in fact, angles that open outwardly have chord distributions with centers further out, approximately where the physical vertices are.

[Turvey, *et al.*, 1981] claim that, whenever biological systems basis for measuring are found in chord geometry rather than in conventional physics, then the appearance of the Mueller-Lyer figure is exactly as it ought to be and the perplexities of geometric illusions are solved. Two tenets summarize this view. First, a measurement by a biological system can sometimes be discrepant with a measurement by a non-biological system because the two do not share the same measurement basis; second, a structure embedded in a context (the Mueller-Lyer figure with the angles open outwardly, or T- and L-shaped lines) may appear to be different in extent from the same structure embedded in another context (the angles opened inwardly).

In the case of the Mueller-Lyer figure and of other phenomena that are described as geometric illusions, the strategy adopted by the ecological approach is slightly different from the strategies adopted in the case of the SWI or even of the stick which looks bent in water. In fact, in the case of the Mueller-Lyer figure no claim is advanced that a different property is perceived (as it is the case for the SWI) or that a property of the medium is perceived (as it is the case for the stick which looks bent in water); in the case of the Mueller-Lyer figure the main strategy consists in changing the system of measurement and in showing that when a different system of measurement is adopted the illusion vanishes and the perceptual result corresponds to the measured reality.

Whatever be the specific strategy adopted (a different property is perceived or the properties of the medium are perceived or no particular property is perceived but the perceived property is mis-measured), the general explanation of the impression that the subject undergoes an illusion is attributed to a linguistic mistake or a mistake in the description of the conditions of the perceptual experience on the side of the experimenter. When the conditions of perception are correctly described by the experimenter: the properties the perceptual system is sensitive to are individuated, the modifications imposed by the medium are taken into account and the perceived stimuli are evaluated on the basis of the ecological measurement systems of the subject of perception, no departure from facts can be individuated, since the perceptual systems exactly responds to the 'facts' (the ambient energies, modified or non modified by the presence of a medium) on the basis of the properties of the organism.

In cases such as the SWI, the fact that invariants used by the cognitive system are not those that are linguistically accessed by the experimenter or by common sensical language, creates the wrong impression (in the experimenter) that there is something wrong with perception, an illusion, conceived of as some error or inadequacy in the acquaintance to reality. It is in fact a linguistic error to describe weight perception as a matter of weight. For the perceptual system what is at stake is the evaluation of the masses and masses distribution of the hand-held object and not a matter of weight; the haptic system is not sensitive to the object's weight as the experimenter's and the common language are: the haptic system is sensitive to resistant forces that stimulate the kinesthetic receptors.

The sensorimotor approach rejects the recourse to internal representations

The inferential view of perception, and the consequent explanation of illusions, is also criticized by other approaches to perception which do not share the tenets of the ecological vision.

The sensorimotor approach, for instance, denies the necessity of taking recourse to internal mechanisms and internal representations in order to explain the aspect of the final percept. For this reason, the position expressed by the sensorimotor approach against the appeal to internal representations or representational knowledge can be considered as an objection against the notion of error which is expressed by the indirect, inferential view of perception, thus against the characterization of illusions which is based upon that notion of error.

Nevertheless, the notion of illusion is not necessarily discarded within this kind of direct approach.

A shift in the approach to perception is proposed by the sensorimotor approach: perception does not consist in the constitution of internal representations of the external world, but in an exploratory activity [O'Regan & Noë, 2001]. In fact, the world becomes available to the perceiver only through action and exploration of the environment [Noë, 2004]. Being a perceiver is thus an ability that consists in being able to keep track of the interdependence of perception and action; this ability comprises the capacity of keeping track of how what one does affects what one perceives. Hence, perception is based on skills that are both motor and perceptual and are called *sensorimotor contingencies* by the authors because perception is contingent to the exertion of motor explorations.

A special form of knowledge is introduced by the sensorimotor view which consists in the mastery of certain rules that connect movement and perception. The rules govern the sensory changes produced by various motor actions [O'Regan & Noë, 2001]. For this reason, they are rules of sensorimotor contingency.

Not only perceptual activity is in fact inextricably associated with patterns of movement. Blinking while looking at an object provokes an interruption of its sight; moving the head or the eyes a modification of its aspect and of the parts that are actually exposed to visual judgment; the movement of the object introduces variants in visual perception. All these modifications instantiate some rules of visuo-motor contingencies, that is, of interrelations between the motor and the sensory activity of the visual system. The knowledge involved in all the described tasks is an implicit, practical knowledge which is acquired through the experience of exploring and sensing objects.

Sensorimotor knowledge and the notion of sensorimotor contingency might play a role in the characterization of illusions in the context of a sensorimotor approach. In the opinion of [O'Regan & Noë, 2001] and [Noë, 2000, 2002], deviations from the laws of sensorimotor contingency extracted by the brain can cause modifications in the resulting percept.

> "Nevertheless, our brains have extracted such laws, and any deviation from the laws will cause the percept of the surface's shape to be modified. Thus, for example, our brains register the fact that the laws associated with normal seeing are not being obeyed when, for example, we put on a new pair of glasses with a different prescription: for a while, distortions are seen when the head moves (because eye movements provoke displacements of unusual amplitudes); or when we look into a fish tank (now moving the head produces unusual kinds of distortions), or dream or hallucinate (now blinking, for instance, has no effect). Our impression in such cases is that, then, something unusual is happening." [O'Regan & Noë, 2001, pp. 944-945]

Even if the term 'illusion' is not explicitly recalled, it seems that illusions can find their place within the sensorimotor approach at the level of the modifications of the perceptual aspect of the objects following some deviations from the laws of sensorimotor contingency and causing the impression that something unusual is happening in perception. Hence, illusions are not necessarily discarded by direct approaches, but their characterization on the basis of concepts that are proper of the indirect, inferential approach is questioned. In particular, the recourse to representational knowledge is not considered as necessary to explain illusory phenomena and a different kind of knowledge is introduced which is constituted of practical rules instead of representations.

Since the rules that are instantiated in sensorimotor knowledge are of a practical nature, perceivers do not have propositional or representational knowledge about sensorimotor rules. For instance, perceivers would not be able to describe the changes in perception produced by the hand moving upon a surface, but the brain has nevertheless extracted some regularity in sensorimotor experience that constitute laws of sensorimotor contingency and that, for this reason, allows the perceiver to nurture more or less implicit *expectations*.

> "To be a perceiver is to understand, implicitly, the effects of movement on sensory stimulation. Examples are ready to hand. An object looms larger in the visual field as we approach it, and its profile deforms as we move about it. A sound grows louder as we move nearer to its source. Movements of the hand over the surface of an object give rise to shifting sensations. As perceivers we are masters of this sort of pattern of sensorimotor dependence. This mastery shows itself in the thoughtless automaticity with which we move our eyes, head and body in taking in what is around us. We spontaneously crane our necks, peer, squint, reach for our glasses, or draw near to get a better look (or better to handle, sniff, lick or listen to what interests us)." [Noë, 2004]

Thus, even if the content of experience is not represented anyway the perceiver does bring into play a form of knowledge:

> "the content is given only thanks to the perceiver's exercise of knowledge of sensorimotor contingencies" [Noë, 2003, p. 6]

> "Consider, first, that our perceptual lives are structured by "sensorimotor contingencies". When you move toward an object, it looms in your visual field. When you move around it, it changes profile. In these and many other ways, sensory stimulation is affected by movement. These patterns of interdependence between sensory stimulation and movement are patterns of sensorimotor contingency. Perceivers are implicitly familiar with these sensorimotor contingencies." [Noë, 2003, p. 5]

Sensorimotor knowledge is thus defined as an implicit, practical form of knowledge, which is of the form of mastery or of practical grasp

> "of the way sensory stimulation varies as the perceiver moves." [Noë, 2004]

A skilled perceiver 'knows', in an implicit and practical manner, what will happen when he will turn his head while looking at an object.

In this sense, even if based on knowledge, the sensorimotor approach to perception is not indirect and does not need to fall back upon inference, because action and perception are directly connected within the mastery of the skill or ability.

The notion of illusion as failure during an inferential process cannot be accepted

The notion of illusions as error or failure during an inferential process is very partial, since it is strongly committed to a specific theoretical approach: the indirect, inferential vision of perception. In order to provide a characterization of illusions that can be accepted by a wider audience in the psychological research on perception, a revision of the notion of illusion is to be envisaged.

It does not seem to be necessary to abandon the notion of illusions as errors in general.

In fact, what the ecological vision objects in the adoption of the notion of illusion by a psychological theory is the characterization of error as an error in an inferential process.

But, as the sensorimotor approach indicates, distortions and deviations from normal perception that are considered as unusual by the perceiver can be explained without taking recourse to internal mechanisms, representational knowledge and cognitive inferences.

The notion of error can then be set free from the reference to failures during an inferential process and be connected to a more general class of *distortions and deviations from normal perception that strike the perceiver as unusual*.

A further reason for enlarging the notion of error is the existence of perceptual phenomena that are considered as illusions but are not deviations from facts, even from measured, physical facts.

2.1.3 Other difficulties with the notion of error as applied to the characterization of illusions: errors as 'departures from facts'

Another difficulty in the characterization of illusions as errors arises from the very core of the classic classification of illusory phenomena which is provided by [Gregory, 1997]. The class of illusory phenomena is in fact as wide as to include ambiguities and paradoxes, such as the ones provoked by the Necker cube, the Penrose impossible triangle and other impossible figures and impossible objects which do not present the subject with departures from facts.

It could be argued (and as a matter of fact it has been argued for instance by [Gregory, 1997]) that even the experience with paradoxes presents the subject with a form of departure from facts. Paradoxical figures, unlike normal figures, are impossible because they *cannot* be used to describe the facts, whatever they are. As in the other cases of illusion, hence, the facts are falsely described and the illusion is a departure from the facts of the world.

Nevertheless, the experience with paradoxical figures and objects cannot strictly be considered as departure from facts, at least not in the same sense in which this is affirmed for other illusory figures, such as the Mueller-Lyer pattern. In fact, when the Mueller-Lyer illusion is described in terms of departure from facts, the *facts* refer to the pattern of lines that constitute the Mueller-Lyer figure: the lines are perceived as being of different length while they can be measured to be of the same length. No reference is made to the facts of the world outside the figure, or of some physical fact that the figure could be supposed to represent.

On the other hand, in the case of the perception of paradoxical figures, the perception of the *figure* is correct: the pattern of lines that compose the figure, the perceived *facts*, are correctly described. Hence, when an ambiguous figure is perceived, the subject is not strictly speaking misperceiving the *facts that are the object of the perceived experience.* The use we made of some figures, their correspondence to physical facts (in terms of external representation or of resemblance) is not at stake.

Two possible options are present: considering that paradoxes such as impossible figures and ambiguous figures are not illusions, because there is no error in the sense of a departure from facts; or considering that paradoxes are illusions, but the notion of error that characterizes illusions must be revised in order to include other forms of error.

The second option is justified by the presence of many analogies between the experience of paradoxes and the experience of other illusions like the SWI or the Mueller-Lyer illusion, such as their systematic character, their resilience to knowledge and the reaction of surprise which accompanies the experience and which seems to be connected with its wrongness. Another analogy can in fact be put forward which makes direct reference to the notion of error. Both in the case of the experience with paradoxes and in the case of the experience with the Mueller-Lyer figure or the SWI, the subject experiences a violation of coherence, linked to the presence of a discrepancy.

In the case of the Mueller-Lyer illusion, the discrepancy stands between the experience of the subject who explores the pattern of lines with his eyes or his fingers and a further round of exploration in different conditions, for instance with the use of a ruler. The subject observes that the course of his experience is no more coherent and is disposed to consider one of the two experiences as false. His global experience and knowledge might tell him which one has to be held as true, but this is not necessarily so.

In the case of paradoxes and other illusions the subject is immediately aware that something is wrong because, even if the figure is correctly perceived, the experience of perceptual paradoxes is immediately detected as bizarre, and eventually as impossible. The perceiver does not really trust his experience, since it appears wrong in some way, and he reacts with surprise.

Two types of paradoxical experiences are described (the perception of ambiguous figures and the perception of impossible figures) that differently instantiate the possibility for a perceptual experience to feel bizarre, wrong and even impossible. Their discussion is introduced here in order to illustrate the possibility of enlarging the notion of error. .

The case of ambiguous figures in particular suggests that the sense of wrongness which is associated with these experiences is connected with the presence of discrepancies that constitute violations of coherence. The notion of error which is implicated in illusory phenomena should thus be *enlarged in order to include violations of coherence*.

If a broader notion of error is adopted, experiences with paradoxes and classical illusions can be considered as belonging to the same class of phenomena (even taking into account some differences related to the immediateness or non-immediateness of the awareness of the discrepancy) and in no case the notion of departure from facts seems to be required, since the notion of discrepancy or violation of coherence suffices to indicate the presence of an error.

Another argument against the reduction of illusions to departures from facts purports that the notion of error as departure from facts is not *sufficient* in order to distinguish veridical perception from illusions or hallucinations. This line of argument has been defended by D. Lewis in his discussion about veridical hallucinations.

The case of veridical hallucinations

[Lewis, 1980] proposes the following example: let us imagine that I am the victim of a wizard's spell; his spell causes me to hallucinate at random, but, for a lucky accident, the hallucination so caused happens to match the scene before my eyes.

The problem raised by Lewis is the one of distinguishing true cases of vision from veridical hallucinations. Veridical hallucinations are defined as a special class of hallucination that present the following particularity: they match the scene before the eyes of the perceiver, as it happens in cases of genuine seeing.

In virtue of the example presented by veridical hallucinations, the characterization of authentic seeing (of authentic perception) can neither be bound to the existence of a match between the scene which is in front of the perceiver and the experience of the perceiver, nor to the existence of conditions that cause the matching conditions (in the example of veridical hallucination reported, the wizard actually causes the matching experience). This line of reasoning induces Lewis to propose counterfactual dependence as the essential condition of seeing: one sees only when there are suitable conditions of counterfactual dependence of the visual experience on the scene before the eyes; the counterfactual dependence establishes that different scenes would have produced different visual experiences. In the case of veridical hallucinations, since the matching of the experience to the scene is just the effect of a lucky accident, if the scene had been different the visual experience wouldn't necessarily have been different in such a way so as to match the different scene.

In the context of the characterization of illusions, the example of veridical hallucinations illustrates the fact that the condition of adequacy or matching is not sufficient to pick genuine perception. The notion of departure from facts can be considered as synonymous with the notion of failure in the adequacy or matching of perceptual experience to the scene which is present in front of the perceiver or to the object with which he is in touch. Hence, the notion of departure from facts is not sufficient to define erroneous cases of perception, at least when they have the aspect of veridical hallucinations.

The case of impossible figures

In the same way, the perception of the Penrose two-pronged triangle (both in the two-dimensional and in the three-dimensional versions) immediately provokes a sense of wrongness, but no error can be attributed to the perception of the figure or of the object. The sense of wrongness is in this case associated with a sense of impossibility. Other examples of this kind of paradox are illustrated by the impossible staircase again described by Penrose and the impossible trident. In all these cases the perceptual experiences is immediately characterized as impossible.

According to Gregory [Gregory, 1973, 1997] impossible figures make use of pictorial rules in order to create the impression of the third dimension, but then some of these rules are broken by other cues in the figure, so as to make the object impossible to construct. The illusion of an impossible figure is thus explained as the application of opposite rules for one and the same depiction. The two-pronged triangle, for instance, is a possible drawing following the rules of two-dimensional depiction, but becomes an impossible object when the rules of three-dimensional depiction are applied. Gregory considers these examples as errors in the sense of departure from facts. The facts indicated by Gregory are the facts of the real world of which the impossible figures or objects should stand as representations.

If errors are conceived in this way, the class of illusory phenomena represented by paradoxes becomes too wide since it becomes to include all pictures of three-dimensional objects. According to [Gregory, 1968],

> "In a sense, all pictures are impossible: they have a double reality. They are seen both as patterns of lines, lying on a flat background and also as objects depicted in a quite different, three-dimensional space. All pictures depicting depth are paradoxical, for we both see them as flat (which they really are) and in a kind of suggested depth which is not quite right." [Gregory, 1968, p. 181]

But as a matter of fact, the directly perceived facts are the features of the figures, which are correctly perceived. For this reason we can affirm that there is no error in the perceptual experience of the observer in the sense of a departure from facts.

The case of ambiguous figures

In the case of the Necker cube, the observer is not able to judge the orientation of the cube, since the cube alternatively appears to have two different orientations. A similar phenomenon is instantiated by the figure of the Woman of Boring, the figure of the Vase of Rubin and the duck-rabbit figure, just for citing some well-known paradoxical figures. In all these cases, the perceptual experience is ambiguously double: for instance, the same figure can be interpreted as a duck and as a rabbit. The two interpretations cannot be synchronic: the visual system seems to have no choice but to access one aspect at a time. Even if the subject has experienced both the interpretations, and thus knows that two interpretations are possible, he cannot perceive them simultaneously.

We have in fact a special attitude through stimuli that can be ‘interpreted’ as being two different entities or figures at the same time: we separate their descriptions, saying that we see, now, the stimulus as one object, and, then, as another, and we call this act an “*interpretation*” and not a “*direct perception*” (this is in part the difference between “*seeing*” and “*seeing as*” as described by [Wittgenstein, 1958]).

Ambiguous figures can thus be defined as figures that support two or more different interpretations. In addition to ambiguous figures, ambiguous objects have also been produced.

In the case of the perception of ambiguous figures, there seems to be no error, in the sense of a departure from the reality of the pattern of lines which is perceived. In fact, the subject correctly perceives all the features of the figure. The fact that two possible interpretations are both present in the one and the same perceptual experience, and that they are not reciprocally compatible, provokes a reaction of surprise in the observer and the experience is described as bizarre. Even if one interpretation can be primed, the subject experiences indecision between the two interpretations. As when an error is committed, the subject cannot act properly, since perception cannot guide his action toward a non-ambiguous well identified target.

These examples indicate the possibility for a different interpretation of the notion of error that that of error as departure from facts. Errors can also be constituted by *the presence of discrepancies between some of the contents of the experience*.

The discrepancy between the contents of the experiences can be an *inconsistency* (technically, consistency is considered as the attribute of a logical system that is so constituted that none of the propositions deducible from the axioms contradict one another).

Hence, the situation which is produced by the presence of inconsistent contents is a *violation of coherence* (technically, coherence is defined as a consistent relation of members of a set of contents and a set is coherent if and only if each member of the set is consistent with the other members and each member is implied by the others; and violations of coherence are considered the inconsistencies between experiences that are part of one and the same set of experiences that are in some way bound together).

Illusions can be characterized as errors only if a wider notion of error is adopted

Some difficulties have been highlighted with the characterization of illusions as errors when errors are conceived as departures from facts.

The notion of error as departure from facts is in fact too wide to distinguish illusory phenomena and hallucinations from veridical perception and too narrow to give a satisfactory characterization of perceptual paradoxes. Additionally, if the facts to be taken into account are not the directly perceived facts, but the facts that are represented by the paradoxical figures and objects, normal pictures and the representation of three-dimensional objects as also fall in the category of illusions.

From the analysis of the experience with ambiguous figures it can be suggested that the notion of error also includes *violations of coherence* of the perceptual experience. When coherence is violated, in fact, the subject feels his experience to be bizarre and even impossible; he reacts with surprise and is stricken by the fact that something is going wrong with his perception.

The difficulties with the characterization of the notion of illusions and of the notion of error which is connected to illusions do not constitute a sufficient reason for abandoning the notion of illusion.

The criticism of illusions is in fact a criticism of two specific notions: that of inferential error and that of representational knowledge.

It seems plausible to revise the notion of error in order to enlarge this concept so as to embrace errors that are not failures in inferential processes and also situations where the coherence of the perceptual experience is violated, with no departure from facts. In other words, a *narrow notion of error*, linked to an inferential view of perception or defined as departure from facts, can be contrasted with a *broader notion of error* which includes *violations of coherence*.

Hence, it seems possible to provide a characterization of illusory phenomena as errors in perception without embracing a particular theoretical approach to perception such as the indirect, inferential view. As a matter of fact, some features have emerged during the discussion about the SWI and the analysis of the difficulties with the notion of error that are suitable to provide a more neutral characterization of illusory phenomena (without assuming that illusions are the result of erroneous inferences).

2.2 Some distinctive characteristics of illusory phenomena

In this section some characteristics distinctive of illusory phenomena will be analyzed.

In spite of the difficulties with the notion of error, I will maintain that, if the notion of error is suitably enlarged as I have suggested, the term '*error*' should be preserved in the characterization of illusory phenomena,

Although it could be argued that we should abandon the notion of error in the characterization of the notion of illusion (for instance in favor of a more general notion of coherence), rather than enlarging the notion of error so as to include violations of coherence, I will show that a typical characteristic of illusory phenomena is represented by the fact that the subject who is victim of an illusion can immediately or later become aware that something is wrong with his experience, in a broad sense (the two cases are distinguished as *illusions we are immediately aware of* and *illusions we are not immediately aware of*).

In the case in which the subject is immediately aware of the illusion, the experience seems or feels impossible to him, he considers some of the components of his experience as wrong.

This fact has a great importance for characterizing the role that illusions might play in the cognitive functioning. In fact, the awareness that something is wrong represents an epistemological judgment about one's own experience. In the case of illusions the judgment that something is wrong, that is, that there is an error, is internal to the experiences of the subject. Illusions could thus play an epistemological role in the cognitive functioning.

Nevertheless, the awareness that something is wrong depends on the detection of a discrepancy. The presence of the discrepancy constitutes a *violation of coherence* and consequently the subject who becomes aware of being victim of an illusion becomes aware of a violation of coherence. The judgment about the presence of an error is not directly a judgment about the existence of a specific departure from facts. When coherence is violated the subject is alerted that there must be an error somewhere in his experience but he is not necessarily in a condition of being able to individuate the error.

For this reason, the notion of error still seems to be useful in order to characterize illusions. As we have seen both in the case of the SWI and the perception of paradoxical pictures, in fact, when an illusion occurs, something is going wrong with perception.

The suggested, wider notion of error, is completely internal to the course of experiences of the subject, and can hence be placed at the opposite end of the notion of departure from facts which requires the subject to step out from his experience in order to compare perception with the facts.

Then other characteristics are introduced that are suitable for distinguishing illusions from other kinds of errors in perception. These characteristics have just emerged during the previous discussion.

Illusions are *systematic* phenomena, as the SWI well shows, because they present the same form for every subject and for the same subject at different times, so that they can be reproduced at will.

The SWI also shows that illusions are *resilient to knowledge*: one might know the real weight of the two balls of the SWI experiment without being able to resist the perception that the balls weigh differently. Systematicity and resilience to knowledge characterize illusions as *robust* phenomena and help distinguish them from hallucinations and local errors.

Finally, illusions provoke a reaction of *surprise*. The reaction of surprise helps distinguish illusions from typical errors that are not surprising. The reaction of surprise can be of two types, direct and indirect, in accordance with the subdivision of illusory phenomena into illusions we are immediately aware of and illusions we are not immediately aware of.

The notion of surprise is connected with the notion of error and with the notion of expectation. Surprise is in fact considered by different authors as a consequence of the frustration of an expectation. As some illusions show, expectations that provoke surprise are not necessarily linguistically expressed or even of a representational kind, but can originate, for instance, from motor habits.

The analysis of some illusions and paradoxes illustrates the possibility of illusions of occurring in the absence of the violation of expectations and in the presence of discrepancies between different sources of information at a synchronic level. The two cases are distinguished as *diachronic* and *synchronic violations of coherence*. The reaction of surprise could nevertheless be connected with the violation of some general expectations, such as the expectation that perceptual experience is correct, also in the presence of synchronic violations of coherence.

These considerations suggest the possibility of individuating illusions as phenomena where the awareness of the violation of coherence alerts the subject to the possibility of error and as phenomena that present a robust character and a typical reaction of surprise.

The present characterization is neutral in respect with the indirect inferential approach to perception and is addressed to a larger audience in psychological studies.

No reference to cognitive inferences and relative failures is made in order to characterize illusions. Illusions as errors are attributed to individuals at their personal levels, and the possibility of the perceptual system being wrong is excluded, in accordance with the ecological approach to perception and its criticism toward illusory phenomena.

Moreover, the characterization of illusions as violations of coherence, helps solve the problem represented by paradoxes in relationship to the notion of error as departure from facts: as the reaction of surprise, the sense of wrongness and impossibility provoked by paradoxes can in fact be alleged to the identification of a violation of coherence or to the violation of a general expectation of coherence of the perceptual experience.

Finally, the possibility is hinted at that in some cases the expectations involved in diachronic violations of coherence are of a special type, in that they are not necessarily based on representational knowledge but on motor skills and direct, specific connections between action and perception that recall the sensorimotor contingencies described by the sensorimotor approach to perception.

The present characterization of illusory phenomena also indicates the heuristic value represented by illusions for the understanding of the role of expectations, movement and coherence in perception. The robust character of illusions constitutes an added value for considering them as a suitable instrument for the investigation of the functioning of perception.

It could be objected that a characterization like the one presented, in which the notion of illusion is immanent to the characteristics of illusory phenomena, such as the presence of a discrepancy (with no recourse to a more essential definition, for instance in terms of departure from facts), might run the risk of losing the power of distinguishing illusions from true perception. For instance, it would make it impossible to distinguish between cases of illusion, where incoherence signals that one of the contents of perception must be wrong, and cases of false testimony, where perception is correct but discrepant with respect to false knowledge or false testimony.

Another, related objection runs as follows. Illusions with synchronic violations of coherence and illusions with diachronic violations of coherence present the following asymmetry: in the former case, two aspects of an experience are in conflict, but neither is dominant. The subject is just aware that something is wrong and he is merely alerted that there must be an error. This is a case of internal incoherence. In contrast, in the latter case, the experience is the culprit.

I would reply to these objections by recalling that the immanent characterization of illusions is not based on the notion of error only, but on robustness and surprise, too. Illusions we are aware of and illusions we are not aware of belong to the same class of illusory phenomena because, in spite of their differences, both phenomena present the same group of characteristics. Robustness in particular might help distinguish illusory phenomena from cases where there is no perceptual error but only false testimony, and the perceptual experience is correct. False knowledge in fact can be revised, at the other end of false perception in the case of illusions, which is robust. It is true that, as long as false knowledge or false testimony is not revised the presence of a discrepancy might induce one to think that there is a perceptual illusion. But the difference between false testimony and illusions cannot be obliterated, because false knowledge can be revised and illusory perception cannot be revised. One cannot but feel two balls of different size and equal dimension as weighting differently.

It is true that all that we have in cases of synchronic violations of coherence is a discrepancy, one experience does not necessarily dominate over the others. One can only be aware that *something* is going wrong. The case of diachronic violations of coherence seems to be very different because one tends to choose to consider the present experience as wrong and the knowledge or past experiences as correct. But, as the example of false testimony shows, knowledge might be incorrect. Even in the case of diachronic violations of coherence, as in the case of synchronic violations of coherence, all what we have is the presumption of the presence of an erro, presumption which is alerted by the presence of a discrepancy which can stand between synchronic experiences, between an experience and the result of a second round of exploration or between an experience and knowledge. The choice of generally considering a long run of experiences as true, or of trusting the experimenter's knowledge and in general relying more on specialized knowledge rather upon direct perception, is a characteristic of our perceptual functioning which is not directly related to the problem of illusions.

2.2.1 Illusions are errors as violations of coherence

When an illusion occurs the subject is not always immediately able to recognize his error.

In the case of the SWI, for instance, the subject becomes aware of having committed an error only when the illusion is revealed by another subject or by further exploration. Some other illusions, on the contrary, provoke a sense of wrongness, bizarreness or impossibility which immediately makes the subject recognize them as wrong. This is the case of proprioceptive illusions of impossible movement and position provoked by muscle vibration.

A specific terminology is introduced in order to distinguish the two cases: *illusions we are immediately aware of* and *illusions we are not immediately aware of*.

In illusions we are immediately aware of the subject is directly aware that something is going wrong with his experience even if he cannot necessarily indicate what is going wrong. The awareness of the bizarreness of the experience appears to be related to the presence of a discrepancy between the contents of two present experiences or between the content of the present experience and the content of some form of knowledge or belief. In the case of an illusion one is not immediately aware of, the subject is not aware that something is wrong in its experience until he is informed or until he starts another round of exploration. When he becomes aware of his error, the subject also becomes aware of the presence of a discrepancy, for instance between the content of the illusory experience and the content of the successively acquired information.

Both in the case of illusions we are immediately aware of and in the case of illusions we are not immediately aware of, illusions are errors one can be aware of.

For this reason, only the entities that can be aware of committing an error are suitable candidates for having illusions. This limitation suggests that illusions can be attributed only to individuals at their personal level, and not, for instance, to the perceptual system. As we have shown, the denial that the perceptual system can commit errors is part of the argument of the ecological approach to perception against the existence of illusions.

The case of proprioceptive illusions produced by vibration

Two kinds of illusions of movement and position can be produced by vibrating the muscles of the limbs: illusions of possible movement, of which the blindfolded subject can only be aware when allowed to look at his vibrated limb, and illusions of impossible movement and position, of which the subject can be directly aware with no sight[37]. The experimental settings are very similar.

In some experiments (for instance in [Goodwin, McCloskey & Matthews, 1972a]), the blindfolded subject sits at a table with the upper arms resting on it and the forearms free to move. Vibration is applied to the tendon of the biceps muscle, thus producing the reflex flexion of the arm. Only the muscles of the experimental arm are vibrated, while the subject is asked to maintain the tracking arm aligned with the experimental arm. A way for demonstrating that vibration produces the distortion of the position sense is in fact to use one arm or leg to indicate the illusory position of the other.

As a result of the vibration, a reflex movement is produced in the experimental arm. The initial part of the reflex movement is not perceived by the subjects, as demostrated by the fact that the tracking arm is kept still even if the experimental arm is moving. When the subject becomes aware of the movement of the experimental arm, he begins to move the tracking one. Meanwhile, an error of few degrees is produced, which is progressively increased by the fact that the tracking arm is moved more slowly than the other.

The subject is not aware of his error until he cannot see the difference in the position in which the two arms have reached in virtue of their respective movements.

> "If at any point during the movement the blindfold was removed the subject would invariably express surprise at the position in which he had put himself." [Goodwin, McCloskey & Matthews, 1972a, p. 711]

[37] [Eklund, 1969, 1971, 1972]; [Craske & Cranshaw, 1974]; [Craske, 1977]; [Craske, Kenny & Keith, 1984]; [Goodwin, McCloskey & Matthews, 1972a, 1972b, 1972c, 1972d].

Once vision is allowed, the subject expresses surprise at the discovery of his error.

A variation of this illusion of movement and position is produced by arresting the reflex movement without the subject's knowledge. The subjects develop the sensation that the arm is being moved in the direction opposite to that in which it was just moving, as if the movement was changing from flexion to extension. At the end of the period of vibration the difference between the positions of the two arms reaches about 40°. Nevertheless, most of the subjects of the experiment remain unaware of the error, and even the sensation of reversal of movement is not sufficient for awakening a doubt about what is actually happening (only a few of the subjects stopped moving the tracking arm after a little displacement, and declared they felt the experimental arm moving into extension, but knew that it could not really be doing so. Other subjects moved the tracking arm backwards and forwards saying they could not decide what was happening). It is only when the vibration is stopped that the subjects correctly align the two arms and become aware of their error. Still, the discovery of the error provokes surprise.

In other experiments (for instance in [Craske, 1977]), the subjects become aware of their error while experiencing the illusion and surprise immediately ensues. The immediate awareness of the error seems to depend on the sense of impossibility that the movement provoked by vibration creates when the experimental arm is stretched against contraction. In the experiment described by [Craske, 1977] the biceps and triceps tendons of the experimental arm are vibrated and the related muscles are stretched against contraction: for instance, during the vibration of the biceps tendon, the experimenter opposes the contraction by moving the forearm in extension. The subjects are asked to judge when they attain the position of maximum extension or flexion at the elbow. Some subjects report a strange sensation, as if the arm were heavy or the arm were bending. In other cases the sensation that the arm is in two places at one time is reported. Then, the subjects who have reported unambiguous sensations are newly vibrated and asked to move the limb beyond the point that they had previously reported as the limit of extension or flexion. As a result, all the subjects report the sensation that the arm is moving beyond the limits of flexion or extension, that is, they report various degrees of hyperextension and hyperflexion. This sensation is described as follows by the subjects: "*the arm is being broken*", "*it is being bent backwards, it cannot be where it feels*". The subjects also display the signs that normally accompany pain, such as writhing, sweating and gasping, even if no pain was actually involved.

The same results are obtained in the case of the vibration and reflexive movement of the hand, with the experimenter slowly moving it in a position previously defined as the comfortable maximum. All subjects feel the hand to be bent backwards towards the dorsal surface of the forearm, that is, in an impossible position.

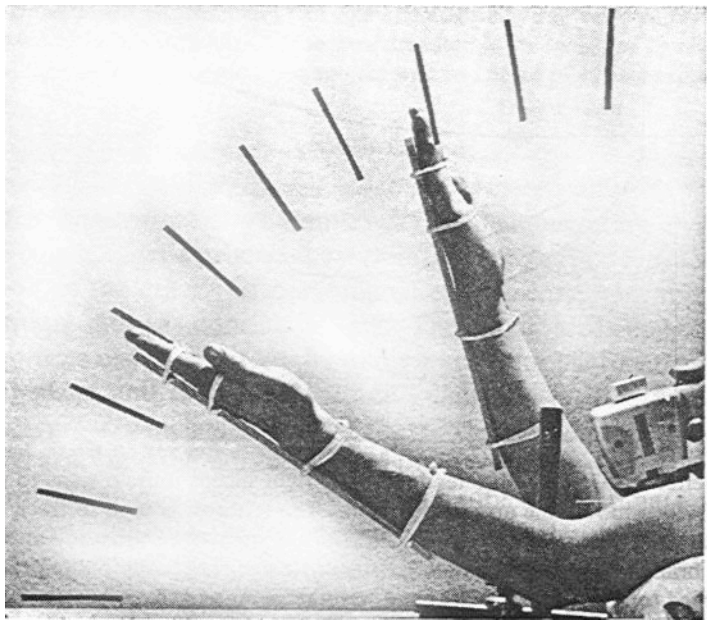
Sensations of impossible movement and position not only feel wrong to the subject, but impossible or at least bizarre.

It is worth noticing that the anatomy of the joints prevents the subjects from having experienced such positions in the past. These experiments are then interpreted in the light of the role of afferent sensation for the position sense: the position sense is affected by afferent sensations from the muscle receptors that can also contradict the explicit representation one has of one's own bodily possibilities and movements.

Proprioceptive illusions produced by vibration show that the subject of the illusion may or may not be immediately aware of his error. In both cases, the subject judges his experience as erroneous, in virtue of the visual appearance of his limbs or in virtue of the specificity of the proprioceptive sensation which immediately appears as impossible, with no need for further exploration through the visual modality.

Figure 4. Proprioceptive illusions provoked by muscle vibration

Difference in position of the vibrated and of the tracking arm [Goodwin, McCloskey & Matthews, 1972a].



Illusions we are immediately aware of

The example of proprioceptive illusions of impossible movements shows that in some cases the subject of the illusion can be immediately aware of being 'fooled' by his own experience. In particular, the victim of this kind of illusions reveals, by his reaction of surprise and by his comments, that he considers the perception he is experiencing as impossible, or at least bizarre, as it is the case for the perception of paradoxes. The experience immediately looks or feels wrong to the perceiver. In fact, he is surprised while undergoing the experience.

Illusions of impossible movements and positions and the experience of paradoxes can thus be considered as two forms of *illusions we are immediately aware of* in virtue of an immediate sense of impossibility, bizarreness, wrongness as manifested by an immediate reaction of surprise.

As in the case of paradoxes, the subject who experiences impossible movements and positions is faced with a discrepancy or inconsistency.

Illusions we are immediately aware of are suitable for showing that the awareness of the illusion and the occurrence of the illusion repose on the presence of a discrepancy or inconsistency which constitutes a violation of coherence.

In fact, two explanations can be put forward for the illusions of movement and position provoked by vibration ([Goodwin, McCloskey & Matthews, 1972a]).

As a first possibility, the actual perceptual experience of movement and position may be compared with stored knowledge about the motor possibilities of the limb or with expectations based upon this knowledge (for instance, that the joints of the arm or of the hand cannot go beyond a certain position without breaking or provoking pain).

As a second possibility, the awareness of the impossibility of the movement experienced during muscle vibration may be the result of a conflict between two sources of proprioceptive information: the one registered by the captors of the joints and the one registered by the captors of the muscles. The captors of the joints in fact signal to the perceptual system a different position of the arm relative to the angle at the joint.

In both cases, the awareness that something is wrong with the actual perception depends upon the presence of discrepant hints about one and the same object (the subject's own limb). Only, in the first case, the discrepancy refers to actually perceived information and the expectations that are based on previously acquired knowledge or experience. In the second case, the discrepancy involves two present sources of information. Thus, in both cases coherence is violated.

[Goodwin, McCloskey & Matthews, 1972a] suggest that the occurrence of proprioceptive illusions of impossible movement and perception provoked by vibration depends on the existence of a discrepancy within actually perceived information. The fact that the illusion is inhibited by the lack of afferent sensations seems in fact to reject the role of corollary discharges produced by expectations and to prove the role of the activity of the peripheral afferents at the origin of the described illusions.

Illusions we are not immediately aware of

The experience of a violation of coherence is not the only possibility in presence of inconsistencies within the stimulus situation. For instance, under certain conditions the discrepant contents can be modified in such a way that the perceptual outcome is perceived as coherent.

As we have seen for proprioceptive illusions provoked by vibration, if the illusory movement is not perceived as impossible the illusion persists unnoticed. Surprise only arises upon the revelation that one has been taken in.

Classic geometric illusions, the SWI, proprioceptive illusions of movement and position with no sense of impossibility are thus illusions we are not immediately aware of.

In the case of illusions we are not immediately aware of, it is only in virtue of the acquisition of new information from experience or from communication that the subject becomes aware of the presence of a discrepancy between the content of one experience and the content of another.

As we have seen in the case of illusions of possible movement and position produced by vibration, for instance, the error is revealed to the subject when he is allowed to open his eyes and he visually controls the position his limb has reached, or when he is informed by the experimenter of the movement he has really performed with his experimental limb. In the former case, the discrepancy stands between the content of the visual experience and the content of the kinesthetic experience. The subject of the illusion becomes aware of the error if he executes some additional perceptual actions. The two experiences do not occur in the mean time, but only successively. In the latter case, the discrepancy stands between the content of the kinesthetic experience of the subject and the content of the knowledge that the subject gains from the experimenter. The 'diagnosis' that there is an illusion is assessed due to the information gained from a second person, for instance the experimenter, who knows the conditions of the experiment. In this case too, the two discrepant contents are not gained simultaneously and the experience which is afterwards recognized as illusory comes first.

The difference between illusions we are immediately aware of and illusions we are not immediately aware of is not so clear-cut in practice, even if they can be easily distinguished in theory. Illusions we are not immediately aware of, such as the SWI, might in fact become illusions we are immediately aware of. It is sufficient that the subject has just been informed that the two objects are of equal weight. The subject will perceive a different weight, in virtue of the resilience of illusions to knowledge, but he will immediately be aware of the discrepancy between the information gained through knowledge and the information gained through perception. He will immediately be aware of the presence of an error.

Nevertheless, the case of illusions we are immediately aware of is different from the case of illusions we are not immediately aware of because we can only become aware of the former whereas the latter can remain unnoticed.

Illusions are true errors in the sense of errors one can be aware of

As we have seen, the subject who is victim of an illusion commits an error of which he can be directly or indirectly aware. Whether the awareness is immediate or not, the subject who is victim of an illusion can judge he has committed an error.

According to [Davidson, 2004] a mistake which is judged as an error from the point of view of the agent who makes it, and not only from the external point of view of the observer, is a true error. Illusions are thus *true errors* in the sense described by Davidson.

Davidson expresses the view that true errors can be traced only in organisms that have beliefs, wills, that form judgments, entertain propositions and manage the difference between true and false. In fact, according to Davidson, the subject must master the concepts of truth and falsity in order to recognize that a certain perception is wrong, that the world cannot be as the perception presents it to be (the world cannot be as such as if the perception were to be taken as true).

An animal or a merely reactive robot, a mechanical toy that is designed for survival in a hostile environment, that has the ability of moving about, manipulating objects and taking advantage of many energy sources is not necessarily supplied with thought and it is not able to make true mistakes.

> "If an earthworm eats poison, it has not in this sense made a mistake – it has not mistaken one thing for another: it has simply done what it was programmed to do. It did not mistakenly classify the poison as edible: the poison simply provided the stimulus that caused it to eat." [Davidson, 2004, p. 8]

> "Our mechanical toy could, of course, make mistakes – but these would be mistakes only from *our* point of view (since we designed it with a purpose – our purpose). But nothing I have described would justify our attributing to the robot the concept of error or mistake, and lacking such a concept, it could not have the idea of the difference between how something seems and how it is, the concept of truth or objectivity." [Davidson, 2004, p. 4]

So, in order to take into account the content of his perception and to consider it as an error, the subject must have certain characteristics, connected with the mastering of the distinction between true and false. Animals, artificial creatures or systems that are not able to master the concept of objective truth do not commit real errors.

The mastery of the concepts of truth and error is related, according to Davidson, to the mastery of the concept of belief, which consists in the understanding that a belief can be true or false. Beliefs, in fact, are such that their truth is not in general guaranteed by anything in us and truth is such as to be independent of our will and attitudes. If an organism entertains propositional contents or has beliefs (which are the more characteristic and basic propositional attitudes) then the same organism can commit true errors.

Individuals at their personal level can be aware of being victims of an illusion

Perception disposes the subject to form beliefs about how the world is. This is at least one of the functions of perception (other functions can be indicated in the guidance of action or in the simplification of cognitive tasks). The awareness of committing an error has thus an effect on the beliefs of a subject.

A subject who is aware of being the victim of an illusion does not come into possession of a corresponding true belief. For instance, when a subject knows that two balls weigh the same and, in virtue of the resistance of illusory phenomena to knowledge, he nevertheless experiences the SWI, he does not believe in his perception. In the light of his previous knowledge about the balls and also in virtue of his knowledge about the effects of illusions, the subject is inclined to reject his actual perception and to persist in his belief that the balls weigh the same. When a subject perceives an impossible movement or experiences a paradoxical content, the subject is not inclined to form a true belief about a state of the world which appears to him as wrong.

As the property of committing true errors, the property of forming beliefs pertains to individuals, that is, to human subjects that entertain propositional contents. As stated by Davidson, in fact, the concepts of truth, of error, objectivity, belief, and the awareness of the possibility of being wrong come in a bundle: : if an agent possesses any one of these attributes it has all of them. A thinking agent is then supplied with a wide set of true beliefs against which false belief can stand.

If we accept Davidson's characterization of non-conceptual organisms in respect to the notions of error and truth, we should also accept that sub-personal systems cannot experience illusions, because illusions are errors one can be aware of and because they are connected with the possession and formation of beliefs. We can turn the cited example of the earthworm from [Davidson, 2004], into a statement about sub-personal systems. A sub-personal system, such as the visuo-motor system, cannot make autentical mistakes, in the sense of misrepresenting the reality or of mistakenly classifying the perceived state of the world: *it has simply done what it was programmed to do*. That state of the world has simply provided the stimulus for the sub-personal system to have the reaction it had.

As I have asserted at the beginning of this paragraph, perceptual activity cannot be reduced to a single function, such as the function of disposing the subject to form beliefs.

Many studies account for other functions of perception, such as the simplification of cognitive spatial tasks (see for instance the studies of [Kirsh & Maglio, 1995] about the role of vision and action in the success of spatial cognitive tasks involved in the computer game *Tetris*) or as the guide of action in absence of visual consciousness of the object (see for instance the interpretation proposed by [Jacob & Jeannerod, 2003] about visual phenomena without perception such as the case of blindsight, in which the pathological subject is able to correctly react to visual stimuli about which he has no conscious perception). A neurohysiological matrix for the studies about the existence of a pragmatic and non-perceptual role for a part of the visual system is represented by [Milner & Goodale, 1995] relative to the existence at the neuro-anatomic level of two visual sub-systems: the *where* (dorsal stream) and the *what* system (ventral stream). It has also been suggested that there might be illusions for the visuo-motor level, that is, illusions involving the dorsal stream only [Jacob & Jeannerod, 2003].

If we adopt Davidson's approach for sub-personal systems, phenomena of a visuo-motor kind cannot be considered to incur misrepresentation, but only a reaction for which the stimulus has been provided. It is only when the content enters the possibility of being judged as true or false by an organism which entertains beliefs that it is possible to consider it a mistake. No matter how many functions perceptual systems can perform, illusory phenomena belong to the component of perception that encounters beliefs or disposes to beliefs.

Box 9. What and where in perception

According to [Merleau-Ponty, 1945], concrete movements are bound to the real, actual situation, while abstract movements allow the performer to act freely and in a creative manner. In abstract movements the action is not elicited by the present stimuli, but open to different possibilities. Abstract movements are then made possible by a projective function and they have a productive character. Concrete and abstract movements are related to two types of motor intentions: on one side the actions that are guided by the intention of knowing and on the other side the actions that are guided by the intention of reaching [Merleau-Ponty, 1945].

The dichotomy between the intention of knowing and the intention of reaching has been developed by [Milner & Goodale, 1995] in the case of visual perception.

It is asserted by [Milner & Goodale, 1995] that the function of vision is not bound to the perception of the world; vision also provides control over movement. The authors argue that two types of visual behaviour can be distinguished both on functional and on anatomophysiological basis. Hence it is possible to speak of two systems for vision: vision for action and vision for perception, as associated to different pathways in the brain. The two visual systems are anatomically associated with two broad groups of projections that have been identified in the macaque monkey brain by Ungerleider and Mishkin in 1982 as the ventral and dorsal streams.

The two groups of projections both originate in the primary visual area: the ventral stream eventually projects to the inferior temporal cortex, and the dorsal stream projecting to the posterior parietal cortex. It seems likely that the human brain may involve a separation into ventral and dorsal streams similar to that seen in the monkey.

Ungerleider and Mishkin argued that the two streams of visual processing play different but complementary roles in the perception of incoming visual information: the ventral stream plays a critical role in the identification and recognition of objects (*what*); the dorsal stream has a role in the localization of those same objects (*where*). Lesions of inferior temporal cortex of monkeys' brain produce in fact deficits in the ability to discriminate between objects on the basis of their visual features but did not affect their performance on a spatial localization task; lesions of the posterior parietal cortex produce on the contrary deficits in the spatial task but do not affect object discrimination.

According to [Milner & Goodale, 1995] the distinction stands between perception on the one hand and the guidance of action rather than between sub-domains of perception.

The perceptual systems do not experience illusions

The application of Davidson's view to illusions and sub-personal system presents the pragmatic advantage of reducing the disaccord with ecological theories of perception. Hence, it goes in the direction of a neutral, unified characterization of illusions.

If only individuals at their personal level can commit true errors and thus be aware of being victims of illusions (directly or indirectly), then the ecological approach to perception is right in rejecting the possibility that the perceptual system is wrong or that the perceptual system experiences illusions.

In fact, as we have seen in the discussion of the SWI, the direct perception approach invites us to consider perception as a sort of automatic response of the perceptual systems to certain environmental conditions: the perceiving organism is attuned and directly responds to some invariant characteristics of the ambient array that have been selected by the specific interaction of the organism with the environment. The possibility of error is excluded by the fact that the perceptual system is simply reacting to the stimuli the system is attuned to. There is no need for the organism to disambiguate or complete what has been directly perceived with knowledge and inferences. In the case of weight perception, for instance, the activity of the muscular system (the act of wielding) selects a specific invariance from the ambient array: the rotational inertia of the hand-held object. Additionally, the receptors of the muscular system are apt to respond to the rotational inertia of the object (that is, to the resistance that the object offers to the fact of being moved). The result is a direct picking up of the relevant information present in the environment. The relevant information the dynamic system directly picks up does not consist in the quantities we usually indicate as weight, or length, or width of the object. The relevant information which is directly picked up refers only to the quantities of the inertia, that is, for instance, the distribution of the masses.

According to the ecological approach, the perceptual quantities of the perceptual system do not fit with the linguistically described quantities because the sensed properties (for instance, the distribution of the masses) are different from the properties the subject and the experimenter assume to be sensed (the weight of the object) [Turvey, 1996]; [Turvey, *et al.*, 1981].

For this reason, the ecological approach insists that the only error is the one committed by the subject or the experimenter in the description of the perceptual task, not in the picking up of the information by the perceptual system: one is surprised of one's misjudgement because one ignores the fact that the perceptual system is picking up information about the distribution of the masses of the felt object, and not about the weight of the object; thus the judgment about the weight can be wrong without the perceptual system committing any error in its specific task [Turvey, 1996]. It is shown in fact that if the distribution of the masses is suitably modified in the course of a laboratory experiment, the dynamic system correctly registers this modification; nevertheless, the subject expresses a wrong judgment relative to the weight (or length, width, etc.) of the object. This error when discovered provokes surprise in the subject.

Even if the dynamic perceptual system correctly picks up the right quantity, the surprise that arises when the subject discovers his error in the judgment of the weight of the object is itself a datum which requires an explanation.

In order to explain the reaction of surprise which follows the discovery of the SWI, it can be proposed that the individual at his personal level, and not the dynamic perceptual system, is victim of the illusion. The subject is surprised because of the discrepancy between his judgment about the object's weight and the object's weight as it is measured by himself or by the experimenter. As it appears, the subject has no awareness of the quantities to which the dynamic system is sensitive. The subject instead possesses some beliefs regarding the perception of weight and eventually regarding the fact that normally an object should weight the same when weighed by the bare hands and when weighed by a precision instrument. If the measure with the bare senses and the measure with a precision instrument diverge, the discrepancy is considered by the subject as an error on his side, which eventually surprises him. Thus, the SWI and the others illusions do not affect the perceptual systems but the subject who entertains beliefs regarding what he is perceiving and the concepts of error and truth.

Errors in perception are connected to the problem of misrepresentation

The term 'true error' employed by Davidson suggests that true errors, where concepts are involved (both possessed and used) and first person access to the error is possible, must be distinguished from 'reactions'. A non-conceptual entity can only have reactions when faced with stimuli of the environment; it cannot commit errors, since the reactive behavior is something automatic. The reactions can be described as errors by an observer who is provided with concepts, but they are not errors at the first person level. It is only when the creature is provided with concepts (which in Davidson's opinion is coincident with the possession of language) that the agent can be mistaken because his behavior is not reduced to mere reactions, but depends on the conceptual representation of the world. The first person access or awareness of the error is thus equivalent to the possibility of committing errors, in the sense that some aspect of the world is misrepresented.

The position expressed by Davidson is open to the objection that the possibility of being aware or not aware of committing an error does not imply the existence of true errors and other kinds of errors.

[Dretske, 1995] cites the distinction by [Moore, 1922] between what we are aware of (what we experience) and our awareness of it (our experience of it) and claims that there is no difference between the experience of a creature provided with concepts and the experience of an animal, a child and a thermometer (or between conceptual experiences as thought and perceptual experiences). Each of these situations is based on representations, thus children, animals, thermometers and perceptual systems are open to the possibility of misrepresenting objects or object properties. It only changes the kind of access to the misrepresentation, since only those creatures that are provided with the capacity of meta-representation (the representation of one's own representational states) can be aware of misrepresenting. Thermometers, children and animals have representations and commit errors but they are not aware of it.

The objection by [Dretske, 1995] is based on a representational approach to sensory experience, and in particular on a teleological vision of representations.

Box 10. Representation and teleology: an attempt at naturalizing mental content

Teleological theories of mental content are motivated by the desire, which is common to contemporary philosophers of mind and cognitive scientists, of naturalizing the contents and the functioning of the mind.

One of the main problems addressed by teleological theories of mental content is the naturalization of intentionality, that is, the fact that mental states are about something or have meaning. A naturalistic treatment of intentionality must not make use of intentional concepts. As a first alternative, intentional descriptions can be excised from scientific or natural accounts of mind functioning, as the phlogiston has been excised from chemistry [Churchland, 1989]. As a second alternative, it is proposed that natural ontology and intentional account of the mind are compatible, but cannot be reduced to one another: the result is an anomalous monism where no nomological law bridges the two descriptions of mental functioning [Davidson, 1984]. A third alternative is represented by those who propose an informational treatment of mental content. Within this approach, intentional content is equivalent to the information which is carried by a system under certain conditions [Dretske, 1981].

The teleological interpretation of representations is thought to address an additional problem, which subsists for informational accounts of intentionality, which is the problem of misrepresentation [Millikan, 1984; Dretske, 1995]. The proper of teleological approaches is the introduction of the notion of function in the definition of representational content.

According to [Dretske, 1995], for instance, the system S represents F if and only if S has the function of indicating F, that is, of providing information about the F of some domain of objects. Two notions are thus employed to characterize representations: the notion of information and the notion of function; a system which carries some information without having the function of carrying it is not a representational system; any other system which associates information carrying and teleology is a representational system. Any representational system is open to misrepresentation, when it does not perform the function it is designed for.

Some consequences of considering perception as based on representations

[Dretske, 1995] proposes a representational account of perceptual experiences. The representations that are characteristic of perceptual experiences are natural, as all the others mental states, as opposed to conventional representations (conventional representations characterize for instance the functioning of artifacts as the thermometer which are designed by human beings and where the fact that the level of the mercury indicates the temperature of the environments depends on a convention).

Natural selection and other types of selection are invoked in order to account for the content of natural representations in the absence of conventions. Selection operates on functions and functions constrain the content of perceptual representations. When a system is not carrying the information it has been selected for the system malfunctions and then it misrepresents the world. Perceptual systems are described by [Dretske, 1995] as having the general function of representing the world with each perceptual system endowed with specific selected functions.

Perceptual representations are also non-conceptual, as opposed to the conceptual representations that are typical of thought and judgment. Two types of awareness of the mental states are distinguished by [Dretske, 1995]: phenomenal awareness, or the awareness of something as having some phenomenal quality, and conceptual awareness, which is possible only when the corresponding concept is possessed. This distinction corresponds to the distinction between simple seeing and epistemic seeing [Dretske, 1969]. Hence, one can have phenomenal awareness of something as blue or heavy (see it as blue or feel it as heavy) without being conceptually aware of something that is blue or heavy (see that it is blue or feel that it is heavy). A thermometer can have representations and in a certain sense it perceives the temperature, that is, in a conventional and not in a natural way. Children and animals perceive and represent the world at least phenomenally. Also, since in Dretske's approach the property of having representations only requires a function and the carrying of information, sub-personal systems of adult human beings (the perceptual systems) can have representations.

Also within the teleological approach proposed by Millikan, the content of the representations is determined by the function of the system which consumes the information. For this reason, even organs such as the stomach of the frog are described as having the function of representing [Millikan, 1984, 1993].

Within this account of perception, thus, errors can be assigned not only to non-conceptual creatures but also to the perceptual system and other components of the organism.

As we have seen before, the only difference is represented by the access to the error, not to the nature of the error in itself. If no additional restriction is added in the characterization of illusions as errors, illusions are thus to be attributed to the perceptual system and to non-conceptual creatures, which is at odds with the attribution of illusions to individuals at their personal level which I have presented before. Still, no commitment to indirect, inferential views of perception is made within this approach.

The teleological approach is nevertheless open to some objections on the basis of the considerations expressed before on the variety of perceptual activities and of other considerations relative to the attribution of representational content and connected with Davidson's argument.

First, it can be objected that in the informational teleological approach to errors and perception the perceptual system cannot be described as bound to the function of carrying information and representing the world. Some authors, such as the supporters of the sensorimotor approach to perception, consider internal representations as being at least unnecessary for explaining most of the tasks performed by the perceptual system.

Second, the problem persists of how to furnish the perceptions and representations of non conceptual creatures and systems with content.

What is the proper function of the frog (or the frog's stomach) in the presence of black moving spots or flies: is it to catch flies or black spots that the frog has been selected? Different representational contents fit with the behavior of the frog and with teleological selection: flies, black spots, etc. The fact of committing an error in catching a black moving spot which is not a fly depends in fact on the content of the representation which is attributed to the frog. According to Davidson, since the frog has no concept and no conceptual awareness of its representations, the presence of an error depend strongly on the interpretation that the observer gives of the physiology and behavior of frogs, that is, on the presence of concepts. If the interpreter attributes to the frog the representation of flies, then catching black spots seems to be an error. But in this case, if the frog actually catches a certain number of black spots one can simply change one's interpretation and consider that frogs are selected in order to respond to black spots. There is no error on the side of the frog, because the frog can only react in the way it has been selected for. If the frog reacts to black or even to red spots, this just means that something in the stimulus was suitable for appealing to the frog's reaction. It is not necessary to credit the frog with the possession of any representation in order to explain its behavior.

Concepts, errors and illusions

The perceptual system could thus be described as a reactive system, while perception and illusions could be specific of conceptually endowed individuals. Only individuals, and not perceptual systems, can experience the meaning or sense (seeing a duck-rabbit figure as a rabbit or as a duck [Wittgenstein, 1958]) and be victim of illusions.

The idea that concepts are necessary in order to misrepresent, and that without concepts one can only speak of reactions, might seem too radical, although it is not necessarily committed to the view (as it is affirmed by Davidson) that only linguistic creatures have concepts.

If this approach is adopted, illusions, as errors, cannot be attributed but in the presence of concepts, that is for creatures that possess concepts and in situations where concepts are used. All the other cases are reactions, which can count as non-conceptual components of the perceptual outcome.

[Jacob, 1997] proposes a third alternative and introduces an intermediate state between what I have called reactions and conceptual states.

Non-conceptual systems can have informational states or sensory experiences. A system which has informational states only (as it is the case for thermometers and other artifacts) has no possibility of converting information into concepts and has no feeling about its representational state. Having sensory experiences on the contrary makes something to the one who has them (Jacob uses the terminology introduced by [Nagel, 1974]), but still sensory experiences are not conscious mental states in the sense of mental states that the creature can meta-represent. In fact, sensory experiences can give rise to intentional actions, but not to voluntary actions. This second level situated between simple reactions of the system and conceptual treatment of the information hosts illusions.

According to [Jacob, 1997] before an illusion (say, the Mueller-Lyer illusion) is experienced as such, there is a pre-illusory level of treatment of the information (what [Dretske, 1969] calls simple seeing as opposed to cognitive or epistemic seeing); at this level the two segments of the Mueller-Lyer figure are simply seen, not as being of the same length nor as being of different lengths, but are just seen. The first level corresponds to the purely informational state. It is only when a dose of cognitive or epistemic seeing is injected in simple seeing that the lines can appear as being of different lengths. This level corresponds to the fact of having a sensory experience. It is only when an additional dose of cognition is added and that beliefs are formed and that the subject of the experience can be aware of the fact that he perceives the lines as being different even if he knows that they have the same length. Jacob considers the second level as non-conceptual, even if epistemic, and the third level as both epistemic and conceptual.

Nevertheless, even with the insertion of an intermediate level, it is only at the third level, both epistemic and conceptual, that one can be aware of being victim of an illusion. It would thus be difficult to ascribe at least the class of illusion we are immediately aware of to the second level.

In virtue of the considerations expressed, I propose to keep the notion of error in the characterization of the notion of illusion, but to adopt a broad notion of error which includes violations of coherence and which is not bound to the idea of failed inference or even of departure from facts. Nevertheless I also propose to ascribe illusions and errors to individuals provided with concepts and not to the perceptual system, because I consider the possibility of being alerted of the presence of an error (immediately or not immediately) as a crucial feature of illusory phenomena, which will reveal its importance in the discussion about the functional role of illusions.

2.2.2 Illusions are robust phenomena

Illusions are errors one can be immediately or non-immediately aware of, depending on the type of discrepancy which characterizes the illusion. These are not the only differentiating characteristics of illusory phenomena.

Errors in perception are in fact of various kinds and it is necessary to add other specifications in order to distinguish illusions from other errors in perception, such as hallucinations, local errors and typical errors.

Illusions are in fact often confounded with other types of errors in perception. [Gregory, 1997] includes in his classification of illusory phenomena local errors, such as errors provoked by the presence of mist or errors that depend on the sensory limitations of the subject. [Ayer, 1955]'s examples for the argument from illusions include hallucinations or delusions. Finally, the phenomenon of the stick which looks bent in water and other errors that can be considered as typical are commonly considered as illusions.

It will be shown in the next section that the presence or absence of a reaction of surprise constitutes an additional character that enables the distinction between illusions and typical errors, thus excluding the analogous phenomena of the stick which looks bent in water from the class of illusory phenomena.

For the moment a differentiating feature of illusory phenomena in respect with hallucinations and local errors is presented: the robustness of illusions. Illusions are robust in two different senses: they are systematic (intersubjectively and intrasubjectively) and they are resilient to knowledge.

Both systematicity and resilience to knowledge have emerged at various points during the discussion about the characterization of illusions as errors. Systematicity, both intersubjective and intrasubjective, distinguishes illusions from local errors; intersubjective systematicity, or the public character of illusions, is a differentiating mark relative to hallucinations.

The resilience of illusions to knowledge has been described in the context of the discussion about the SWI, where it has been underlined that the knowledge about the real weight of the sensed object does not change the characteristics of the perceptual experience.

The systematic character of illusions has been described by Gregory, but it has been underestimated by the supporters of the indirect approach to perception, because their interest has been focused upon the inferential processes involved, rather than on the specific nature of illusions. Also, the supporters of the ecological view seem to have overlooked the systematic and robust character of illusory phenomena, because their attention has been captured only by the notion of error.

On the contrary, the notion of robustness has a great importance in the individuation of illusory phenomena and in the characterization of illusions as a special class of errors in perception.

As we have seen during the discussion of the notion of error, the notion of robustness can also be invoked in order to respond to the objection that a characterization of illusions which is purely immanent to the characteristics of illusory phenomena cannot differentiate between errors in perception and errors in knowledge (as in the example of false testimony). The cited characteristics of illusions, in fact, only belong to the immanent or external properties of illusory phenomena, with no reference to their causes or to more transcendent notions. Perceptual errors that are typical of illusions are nevertheless robust, they resist knowledge and they are stable within the same subject and between subjects; knowledge as it is implied in false testimony, on the contrary, in principle can be revised.

Another property of the notion of robustness, in the sense of resilience to knowledge, lies in the possibility of explaining the co-existence of systematicity and surprise in the characterization of illusory phenomena. In spite of their systematic character and of the possibility of experiencing the same illusion many times, the experience of the illusion always provokes surprise in the subject. Knowledge in fact does not alter the illusory character of the perceptual experience and surprise arises as a consequence of the error.

The resilience of illusory phenomena to knowledge creates a typical discrepancy between the actual perceptual experience and the knowledge about the perceived object. The subject cannot solve the ambiguity between these two states because the perceptual experience is not modified by new evidence. In the case of illusions one is not immediately aware of, the reaction of surprise which arises at the discovery of the error is also to be attributed to the strength of the perceptual experience which resists knowledge: two discrepant states (the one relative to the perceptual experience and the other to the evidence based on knowledge or further exploration) co-exist thus giving rise to a condition of ambiguity.

Systematicity distinguishes illusions from local errors and hallucinations

An attribute that has referred to more than once till now is the systematic character of illusory phenomena.

The systematic character of illusions has two aspects. First, a subject confronted at different times with the Mueller-Lyer figure will always experience an illusion of the same form, that is, the lines will always look the same to him. In this sense illusions are intrasubjectively systematic: they are stable through different occurrences for one and the same subject.

Systematicity helps distinguish illusions from *local errors*. [Austin, 1962] treats local errors as unusual cases which are neither illusions nor delusions but are simple mistakes. He cites as examples the error in misreading a word and after-images.

Local errors are errors that can be committed just once, by one person; the same person in a different situation may not be mistaken.

In addition, in the case of local errors another person in the same situation may not be mistaken at all. Local errors are then not intersubjectively systematic.

Local errors can be differentiated from illusions also on the basis of the ease with which the perceptual experience can be revised. Local errors in fact can be accompanied by doubts about the experience, but one can also be openly mistaken. Anyway the error can be corrected with not eager surprise: one can admit being mistaken. In other words, in the case of local errors false beliefs can be easily revised.

This correction and revision are more acceptable when the perceptual situation is confused (the weather is misty, the distance between the perceiver and the object is great) or when the perceiver's capacities are limited, as in the case of a short-sighted person who makes a mistake or commits an inaccuracy in recognition. As philosophers know since long, the perceptual experience is in fact surrounded by doubt since its very beginning.

This is not the case for illusions, which do not depend on perceptual limitations on the side of the perceiver or of the perceived situation. Wearing glasses or renewing the experience in a non-disturbed situation may not influence the experience of illusions, while it may eliminate or change the type of error committed in virtue of the perceptual limitations.

The second aspect of the systematicity of illusory phenomena is represented by their public or intersubjective character. Different subjects confronted with the Mueller-Lyer figure will all experience the same form of illusion, the lines will appear the same for all the subjects that look at them. Illusions such as the Mueller-Lyer one are then not only intrasubjectively but also intersubjectively systematic phenomena.

Intersubjectivity introduces a difference between illusions and *hallucinations*.

Hallucinations are in fact private phenomena: when one is victim of a hallucination one has the impression of seeing or feeling things that other people around him do not perceive, even if they are in the conditions for perceiving the very same things.

Additionally, hallucinations can vary for the same subject, not necessarily occurring in the same way in the same situations.

Finally, the subject of the hallucination cannot necessarily be aware of his mistake, as it is for illusions.

[Austin, 1962] attempts to distinguish illusions from *delusions* – that include what we have called hallucinations - (such as in the case of the patient who sees pink rats, or in the case of delusions of persecution) through the recourse to the criterion of the presence or absence of the object. Illusions (and Austin cites geometric illusions, after-effects and the tricks played by magicians as examples) do not suggest that something totally unreal is conjured up; in the case of geometric illusions, for instance, there is just the rearrangement of lines. On the other hand, ‘delusion’ suggests the conviction in the existence of something that is unreal (even if the example of the Kanizsa triangle shows that the frontier is not so sharp, since a rearrangement of lines suggests the existence of an object, a triangle, which is not present in the sense of the presence of a complete pattern of stimulation). According to Austin, in the case of delusions something went really wrong. Optic illusions do not imply that something is wrong with the perceiver: illusions are not an idiosyncrasy or peculiarity on the part of the perceiver, they are public and in many cases standard procedures can be laid down for reproducing them. Illusions may well be errors but they are not pathological; delusions are pathological.

The argument of the presence or absence of the object risks bringing the definition of illusions on the unstable ground of the reference to something external to the perceptual experience. Also, as illustrated by the example of the Kanisza triangle, the difference between perceiving a different arrangement of lines and perceiving an object which is not actually present stimulates the discussion about the conditions that are necessary and sufficient for perceiving an object as present. The Kanisza triangle and other exemplary cases suggest that a complete pattern of stimulation is not necessary [Casati & Pasquinelli, 2005].

According to Austin, hallucinations can also assume a more complex appearance than illusions: an illusion often concerns a simple perceptual pattern, as the dimension of lines, the weight of an object, then single qualities of a perceived structure; a hallucination might concern the global appearance of an object or a scene. But this too might be a risky way to draw the line, in that it appeals to the content of the illusory phenomena. Still, the public or intersubjective character of illusions seems to be a more general difference with hallucinations.

I am thus inclined to accept only one suggestion from the argument cited by Austin for the differentiation of illusions from hallucination, that is, the public character of illusory phenomena.

Another argument regarding hallucinations is represented by the case of veridical hallucinations; this case has been proposed by [Lewis, 1980] in order to individuate the essential characteristics of genuine seeing. According to [Lewis, 1980] true seeing cannot be distinguished from veridical hallucinations on the basis of the fact that veridical hallucinations are occasional lucky accidents, since it might be the case that such lucky accidents happen for a long time and genuine seeing happens only once or only seldom.

Again the notion of systematicity might help distinguishing hallucinations (even veridical hallucinations) from both illusions and genuine seeing.

First, to say that illusions have a systematic intrasubjective character is to say something more than that they might happen for a long run. Intrasubjective systematicity implies that the same illusion is experienced each time certain conditions obtain. And also, that it is not experienced when the conditions are far from being suitable. Intersubjective systematicity thus instantiates a form of dependence of the fact of having a certain experience upon wordly conditions.

Second, if illusions are intersubjectively systematic, that is, if they are public, it cannot be the case that only one subject meets with a lucky accident. A lucky accident that happens for all subjects would be very lucky indeed. The hypothesis of an evil genius provoking diffused veridical hallucinations is rejected by the existence of a form of dependence between the state of the world and the (illusory) perceptual experience.

Systematicity, both at the intrasubjective and at the intersubjective level is a form of robustness which also allows to differentiate illusory phenomena from other types of perceptual errors that can be occur just once or in different ways or just for some subjects in a certain way. For this reason, illusions cannot depend on the presence of subjective disturbances that could involve the sensory organs (such as defects or pathologies of the sensory organs that are proper to the subject) or on disturbances in the environment between the perceived object and the sensory organ that cannot be reproduced with the same characteristic for every subject at any moment (such as local conditions that are not controlled by the experimenter). In this way, the systematic character of illusions allows the exclusion of some causes of perceptual errors as causes of illusions. Short sight and mist do not cause illusions, but cause local errors, because the errors of the short-sighted person are not intersubjective and the errors caused by mist or other non-systematic external conditions are not intrasubejctively and intersubjectively systematic.

Resilience to knowledge distinguishes illusions from local errors

Illusions are robust in another sense. One can check the Mueller-Lyer figure, look at it for a long time, go back and forth, change one's position and still maintain one's first impression about the length of the lines. Typically a third person informs the victim of illusion that he has been taken in. In other cases, as we have seen, the subject is aware of being victim of an illusion and at the same time cannot do anything against it: there is no way of correcting the mistake.

This form of robustness is the resilience of illusions to knowledge, also known as *impenetrability of illusions to cognition*. Cognitive impenetrability consists in the fact that one cannot avoid perceiving the weight of the smaller of two objects as greater, even if one knows that the objects have equal weight. Cognitive impenetrability is possibly a characteristic of hallucinations as well, but not of normal perception.

The resilience of illusions to knowledge has been invoked to deny the conceptual content of perception. [Evans, 1982] cites the case of the Mueller-Lyer illusion and he argues that, since in experience it can look to me as if the two lines of the Müller-Lyer illusion differ in length even when I have drawn them myself and know them to be of identical length, perceptual experience is belief-independent. This independency can be advocated as a demonstration of the non-conceptuality of perception.

[Noë, 1999, 2000, 2002, Forthcoming] contests Evans' claim and argues that, in spite of the resilience of illusions to knowledge, perception cannot be considered as belief-indifferent, because perceptual experiences, by their very nature, raise the question about what one ought to believe, on the basis of the experience, were one to take the experience at face value.

The idea of the impenetrability of perception to cognition, which constitutes one of the main tenets of the modularism of mind proposed by [Fodor, 1983], is discarded by the existence of phenomena such as the golf-ball illusion. The golf-ball illusion, a variety of the SWI, seems in fact to attest that knowledge and expectations about objects can in fact influence perception and themselves give rise to illusory phenomena.

The experiments about the golf-ball illusion show how experienced subjects in possession of a specialized knowledge about the weight of golf-balls used for training or for play are taken in by the suitable manipulation of the two types of balls in experimental conditions; while subject who have no experience and no knowledge about the characteristics of typical golf-balls are not taken in. Previously acquired knowledge can thus influence perception and produce illusions. But an illusory experience cannot be simply annihilated by the knowledge that it is just an illusion and that the world is not as the illusory perceptual experience presents it to be.

Another example of influence of previously acquired knowledge upon perception and recognition can be found in the effects of the discrepancy between present experiences and previous experiences that have come to constitute knowledge about specific objects. In order to avoid the conflict, the incoming information might result in modifications in accordance with the previously acquired knowledge. Previous experiences and knowledge are then taken into account to the extent that they can modify the actual perceptual content. This point is illustrated by an experiment by [Bruner & Postman, 1949] where the aspect of trick playing cards is misperceived by the subjects of the experiment in accordance with the aspect of normal playing cards (the experiment will be dealt with in detail in the following chapter, in the context of the discussion about the errors induced in perception by diachronic violations of coherence).

Box 11. Modular theories of mind

The modularity of mind presents a cognitive architecture structured into vertical systems: the modules that are deputed to the computational transformation of the incoming inputs into representations; the representations are thus offered to the central part of the cognitive system, which is not modular, and then transferred to the modules that are deputed to the output, such as linguistic and motor modules [Fodor, 1983].

The input or perceptual modules are domain specific, their action is mandatory, the central processes have access only to their final issue and they are encapsulated.

All these characteristics define the independence of the input systems from the action of the central cognitive processes; in particular, the encapsulatedness indicates that the action of perceptual systems cannot be influenced by the action of the central processes.

Perceptual illusions such as the Mueller-Lyer are cited in order to illustrate the fact that some of the general information at disposal is nevertheless inaccessible at least for some of the perceptual mechanisms.

2.2.3 Illusions provoke surprise reactions

Surprise as a reaction to illusory phenomena has emerged both in the case of illusions we are immediately aware of and in the case of illusions we are not immediately aware of.

Illusions and surprise can in fact stand in a direct or indirect relation. In the direct relation, illusions are accompanied by surprise. In the indirect relation, surprise does not accompany the illusory experience, but arises as a consequence of the revelation of the experience as illusory. The reaction of surprise is thus connected to the discovery of an error or a discrepancy.

In virtue of the reaction of surprise they provoke, illusions can be distinguished from typical errors, which do not genuinely tempt us to believe in their appearances.

The presence of a reaction of surprise can also be associated with the presence of unfulfilled expectations. The frustration of expectations can be considered as a violation of a diachronic form of coherence because inconsistency stands between the content of the actual experience and the content of an expectation based on past experiences or knowledge. Some illusions show that the expectations involved in diachronic violations of coherence can issue from forms of knowledge that are not symbolic in their nature, but are relative to the acquisition of pragmatic motor skills. In these cases expectations do not need to be expressed linguistically and moreover they possibly do not need to be expressed by some form of internal representation which would constitute the medium between action and perception: the content of perception would immediately be shaped by the presence of a certain motor ability or motor skill. The motor skill creates a non-representational expectation in the sense that it creates a strong connection between action and perception which disposes the subject to perceive in the particular way specified by the motor-perceptual connection.

Moreover, the case of some illusions indicates that illusions are not always provoked by the frustration of expectations. The example of proprioceptive illusions of impossible movement provoked by vibration and the example of the experience of paradoxes illustrate the situation in which a discrepancy stands between two or more actual experiences. The presence of a discrepancy between actual information can be considered as the violation of a synchronic form of coherence.

Illusions thus show the existence of two types of *violation of coherence: synchronic and diachronic*. Illusions we are immediately aware of have a special role in revealing to the subject the presence of inconsistencies in his experience, and eventually of awaking his awareness of expectations he is normally not aware of.

The study of illusions suggests that in the case of diachronic violations of coherence, the detection of inconsistency can be grounded on purely empirical basis. Something is perceived as unexpected, uncommon, hence surprising and potentially disruptive.

In the case of synchronic violations of coherence two hypotheses can be formulated in order to explain the reaction of surprise and the sensation of wrongness, bizarreness or even impossibility which is associated with the illusion.

The first explanation suggests that surprise can directly arise in connection with all kinds of violations of coherence, with no recourse to any type of expectations.

The second explanation suggests that even when synchronic coherence is violated and inconsistency stands between the contents of perception of two actual experiences, the reaction of surprise is nevertheless connected with the violation of an expectation, for instance the general expectation that perception is coherent. In relation to the specific conditions in which the illusion occurs, the general expectation of coherence might generate specific, volatile expectations.

Surprise distinguishes illusions from typical errors

One is surprised when one is informed that he has been the victim of an illusion. Also, one is surprised when, being victim of an illusion, he is aware of as of something bizarre or impossible.

Surprise is not restricted to illusory phenomena. Nevertheless, there are errors that do not cause surprise, such as in the case of the impression that a stick looks bent if a part of it is immersed in water and in the case of other typical errors.

According to [Austin, 1962] surprise is a distinctive character of illusions because illusions must genuinely tempt us to believe in their appearances: surprise indicates that the subject has really been taken in. The stick which looks bent in water is not an illusion because we are not genuinely tempted to believe that the stick is really bent. Experience teaches us that the stick is perceived bent in that particular situation.

> "What is wrong, what is even faintly surprising, in the idea of a stick's being straight but looking bent sometimes? Does anyone suppose that if something is straight, then it jolly

> well has to *look* straight at all the times and in all circumstances? Obviously no one seriously supposes this. So what mess are we supposed to get into there, what is the difficulty?" [Austin, 1962, p. 29]

According to Austin, the phenomenon of the stick which looks bent in water is too common to be considered an illusion. In fact, when we see a stick partially immersed in water we are not surprised by its bent aspect. The same thing is true of the special perceptual effects produced by mirrors or by perspective that can thus be considered as typical errors rather than as illusions.

> "That a round coin should 'look elliptical" (in one sense) from some points of view is exactly what we expect and what we normally find…Refraction again –the stick that looks bent in water – is far too familiar a case to be properly called a case of illusion. We may perhaps be prepared to agree that the stick looks bent; but then we can see that it's partly submerged in water, so that is exactly what we should expect it to look." [Austin, 1962, p. 26]

Austin thus excludes from the class of illusions those phenomena that are too familiar and that meet our expectations.

Austin aims at dissolving the alleged difficulty related to phenomena such as the bent stick because these phenomena are part of the so-called argument from illusion. The argument from illusion is a classical argument against direct realism and in favour of phenomenalism (idealism), representationalism or indirect realism. Nevertheless, the characterisation of illusions provided by Austin is not committed to a form of indirect perception theory. The criticism of indirect realism or phenomenalism is in fact perfectly compatible, in Austin's approach to the problem, with the existence of illusions.

Box 12. The argument from illusion

The argument from illusion (see [Ayer, 1955] for its classical formulation) can be schematized as follows [Dokic, 2004]:

1. all experiences have an object
2. the experience of illusions lacks a material object
3. the objects of experiences are all the same, both for illusory and veridical experience
4. therefore
5. the objects of experience are not material objects.

The immaterial objects that are supposed to be directly perceived in illusory and non-illusory experiences are the sense-data. In the case of the stick that looks bent, for instance, the experience of the pretended illusion is assimilated to the experience of a delusion, which lacks of any reality.

Thus, since no real object is perceived, but some kind of object must be, the existence of immaterial objects or sense-data is postulated.

Austin opposes two main criticisms to the argument from illusion.

First, the argument from illusion is based on a wrong definition of illusion. Illusions are different from delusions and from familiar mistakes and unusual perceptual phenomena. The class of illusions only include public, reproducible and surprising phenomena such as the geometric illusions or the tricks of the magician.

Second, it is not strange or surprising that an object that is in a certain way, looks in another, in special conditions. Thus there is no need for postulating special objects that are directly perceived: what we perceive are the ordinary things.

Box 13. Different positions toward the argument from illusion

Different positions can be traced in respect to the argument from illusion that belong to different views of perception and illusions [Dokic, 2004]. The argument from illusion is defended by phenomenists and the indirect realists and it is rejected by three theories of perception: the disjunctive theory, the bipolar theory and the adverbial theory.

Phenomenisms sustains that all we can perceive are sense-data and that perception does not involve objects that are external and independent from the perceiver [Berkeley, 1948-1957. Original work published 1710].

According to indirect realism perception can only give access to sense-data, but reality is not limited to sense-data: the physical world exists and can be known because of the structural, causal relations between physical reality and sense-data [Russell, 1912].

The adverbial theory considers that the so-called objects of perception are in reality modifications of the verbs of perception, as adverbs are. Hence the distinction between veridical experiences and illusions depends on the fact that veridical experiences are appropriately caused by elements of the physical reality [Sellars, 1968].

The bipolar theory considers that perception does not consist of the experience and of the intentional object only, but also of propositional contents of perception. Propositional contents describe the conditions of truth of the experience: the experience can be true or false depending on the fact that the world is in accord or in disaccord with the content. Since an experience is defined by its propositional content, the fact of being veridical or illusory is just contingent to the conditions of the world. Illusions and veridical experience can thus have the same content but not the same object (only veridical experiences have an object) [Husserl, 1973. Original work published 1900-1901. Second revised edition 1913]; [Searle, 1983].

In the disjunctive theory of perception illusions and veridical perception are considered as two different phenomena. Perception, or the mental states that are described by the verb "to perceive that *p*", depends for their nature on the existence of a physical fact which is external to perception: *p.* The content of the experience is the perceivable object of the physical world. When one is fooled by the world one is not perceiving a fact of the world, but he is only having a perceptual experience.

Perceptual experiences, or the mental states that are described by the verb "having the perceptual experience that *p*", can both be veridical or illusory; but the two states, the one of having a veridical experience and the one of having an illusory experience, are different in their essence, because only the first one has for object a state of the world. Illusions can simply have no object or they can have sense-data for objects [Hinton, 1973]; [McDowell, 1998].

Surprise is connected to the awareness of committing an error

Illusions we are immediately aware of and illusions we are not immediately aware of are both accompanied by reactions of surprise: in the former case surprise is directly associated with the illusory experience, while in the latter surprise arises as a consequence of the revelation of having been victim of an illusion. In both cases, as we have seen, there is a discrepancy between two discrepant mental states. The discrepancy can be felt as immediately wrong, bizarre or impossible or can be judged as an error when recognized.

The reaction of surprise is thus connected with the awareness of the error. As we have also seen, errors one can be aware of are true errors in Davidson's terminology. According to [Davidson, 2004] in fact, one is surprised when he discovers that something he believed is false, that he has committed an error.

Someone who is surprised had a belief, an *expectation*, and realizes what it is to be confronted with a different reality. In other words, one is surprised when he acquires a new belief about some thing or event which entails that a previously conceived belief about the same thing or event was false. Thus, in Davidson's opinion, it is not possible to be surprised without possessing some beliefs (in the holistic view of Davidson to possess a belief is to possess a set of interconnected beliefs). Reciprocally, if one possesses some beliefs he is exposed to the possibility of being surprised. In fact, something can happen, that makes him change his mind.

Indeed, [Davidson, 1982] proposes a "*surprise test*" for errors. Someone puts his hand in his pocket and finds a coin. If he his surprised in finding the coin, then he comes to believe that his previous belief about his pockets and coins was false. Hence, he is aware that there is an objective reality which is independent from (previous) beliefs. In fact, as we have seen, the possibility of making mistakes is a crucial requisite for possessing thought, and thus, in Davidson's, view, for possessing the notion of an objective world. With all this, surprise is not at the origin of the concept of objective truth or of error.

Surprise is connected with unfulfilled expectations

In addition to being a suitable test for the possession of the notion of error, [Davidson, 2004] characterizes surprise as being the reaction to the frustration of an expectation. The presence of an expectation which is frustrated is thus necessary for being surprised.

> "Someone who believes there is a dragon in the closet opens the door and sees there is no dragon. He is *surprised*; this is not what he expected. Awareness of the possibility of surprise, the entertainment of expectations – these are essential concomitants of belief." [Davidson, 2004, p. 7]

In a similar vein, [Dennett, 2001] characterizes surprise as the outcome of an unfulfilled expectation.

> "Surprise is … a telling betrayal of the subject's having expected something else." [Dennett, 2001, p. 982]

If the subject is surprised when he was expecting something else, the reaction of surprise can be used in order to shed light on the expectations of the subject. The expectations which are revealed by surprise are not necessarily linguistically expressed.

> "Surprise is only possible when it upsets belief. But there are examples of non-linguistic expectations." [Dennett, 2001, p. 982]

In virtue of the reaction of surprise and of the sense of wrongness or impossibility that emerges in connection with them, illusory phenomena can be considered as having functional value for the subject, in that they reveal the presence of expectations and beliefs of which he is not necessarily aware all the time.

Not only the expectations invoked for explaining surprise in illusions could not be expressed in a linguistic form, but it seems that they could also present a non-representational nature, in the sense that they would not be necessarily based on a symbolic form of knowledge, but on an implicit, pragmatic form of knowledge which consists in the acquisition of motor skills and in the practice of motor habits.

A typical example of non-linguistic expectation is represented by the pre-shaping of the hand when approaching an object for reaching; in general all the adjustments of the body that anticipate and prepare the action with specific objects are based on the expectation about the aspect and behaviour of the object itself. This is an example of expectation based upon knowledge acquired in the past about the object's characteristics of shape and movement of which the subject is not necessarily able to give a linguistic expression. Nevertheless, in this case both explanations based on the presence of internal representations and explanation based on the direct connection between movement and perception can be advanced.

An example of the existence of non-linguistic expectations that are also not based upon representational knowledge or explicit beliefs might be represented by Aristotle's illusion.

Aristotle's illusion

The phenomenon described as Aristotle's illusion[38] presents the following characteristics: if one crosses two adjacent fingers one over the other and then touches with the two crossed fingertips a small ball, one will have the feeling of touching two balls. [Benedetti, 1985] points out that we are so accustomed to feeling one single object between the fingers, that feeling two objects with crossed fingers provokes surprise.

A variant of Aristotle's illusion consists in the two crossed fingers touching one's nose, giving rise to the impression of perceiving two noses[39]. Another variant is obtained

---

[38] Aristotle's illusion is one of the oldest observations about perception; in fact, the phenomenon was first described in Aristotle's *Metaphysics* and *On Dreaming*. Successively, it was analyzed at the end of the XIX century and at the beginning of the XXth (see [Ponzo, 1910]; [Tastevin, 1937]) and finally by [Benedetti, 1991, 1985, 1985, 1988, 1988, 1990]. Aristotle's illusion is also taken into account by [Merleau-Ponty, 1945].

[39] The phenomenon is not only restricted to the fingertips, but has also been described at the level of lips, tongue, face, scrotum and ears (see [Ponzo, 1910]; [Tastevin, 1937]): when the skin is displaced from its resting position, and a small ball is touched with the displaced skin, the perception of a double ball arises.

A different form of the phenomenon is described in 1855 by Czermak as inversion of the sensation when the fingers are crossed (see [Ponzo, 1910]; [Tastevin, 1937]): if one touches with crossed fingers an object which presents a sharp point on one side and a convex surface on the other, then one perceives the sharp point in the location where the convex surface is and *viceversa*.

More recently, the phenomenon has been investigated by [Benedetti, 1985, 1986] who has described Aristotle's illusion as a form of somesthetic or tactile diplopia. The doubling of the object perceived with crossed fingers reminds in fact the doubling of a visual image. Even if an analogous of the Aristotle's phenomenon exists for the visual system, the haptic modality presents the specificity (as previously stated even in the case of the SWI) that two types of receptors are involved: superficial, tactile receptors and deep kinesthetic receptors (which is characteristic of the haptic touch).

without crossing fingers, by displacing the cutaneous surface of the fingertips [Benedetti, 1985]. The fingertips are pressed against each other by the aid of two devices placed laterally to each finger (in this case, the third and fourth fingers). A plastic sphere is pressed against the fingers and subjects are asked whether they perceived one or two touches. This condition provokes the occurrence of Aristotle's illusion. This finding is in agreement with the fact that it is possible to evoke tactile diplopia even at other body sites, through skin displacement. Nevertheless, the occurrence of Aristotle's illusion seems also to be connected to the range of action of the fingers.

It has been proposed that the lack of unity of the object perceived with crossed fingers is due to the fact that the perception with crossed fingers is not normal [Husserl, 1990. Original work published 1952] and that the position with crossed fingers is not part of the normal bodily motor activities [Merleau-Ponty, 1945].

According to Merleau-Ponty, the body schema is composed of the familiar motor skills or motor habits of the body. Since skills or habits have both motor and perceptual properties, the body schema is composed of both the motor and perceptual possibilities of the body. The acquisition of a new motor skill or habit is equivalent to the reorganization of the body schema[40].

Crossing the fingers, for instance, is an artificial movement which goes beyond the motor possibilities of the fingers. For this reason, the body schema is not able to comprise

---

[40] The concept of body schema is highly relevant for Merleau-Ponty's theory of perception and cannot be identified with an association of images or representations. In the classic meaning given by [Schilder, 1935], in fact, the body schema is a sort of summary in form of images of our body experience, that begins to constitute itself in childhood as associations of kinesthetic, visual and joint impression.

the crossed fingers as one organ directed to one and the same motor project or intention. Thus, the crossed fingers act separately and give rise to separate sensations that cannot be unified in one percept. The existence of motor habits of the fingers can be considered as responsible for the occurrence of Aristotle's illusion, that is, for the experience of perceiving two objects instead of one when the object is sensed with two crossed fingers.

[Tastevin, 1937] has provided an explanation for the occurrence of the Aristotle's illusion which is based on the activity of the neuromuscular apparatus: the two crossed fingers are perceived to be at the position they would achieve with voluntary muscular effort; beyond that limit, the neuromuscular apparatus does not provide any further information. When the fingers are passively crossed in an artificial position (beyond the limit of the voluntary movement) and stimulated, the sensation of the stimulus is referred back to the limiting position. Thus, the spatial location of the stimulus is perceived in the natural limit position.

The experiments recently conducted by Benedetti indicate that it is not simply the distance from a normal position that provokes the illusion, but the existence of skills with uncrossed fingers (the normal position) that are no more valid with crossed fingers (the anomalous position). The perception with crossed fingers is thus referred back to the position with uncrossed fingers, which is the normal position and the position for which the subject has developed perceptual and motor skills. In fact, Aristotle's illusion disappears following suitable training with crossed fingers in association with the acquisition of new motor and perceptual skills.

The experiments conducted by Benedetti on Aristotle's illusions will be illustrated in detail in the following chapter. These experiments indicate that it is possible to consider a wide set of behaviours as relevant to the question of surprise and illusions, including motor preparation and other forms of expectations based upon direct connections between the motor and the perceptual systems.

The direct connection between the motor and the perceptual systems and the role played by sensorimotor connections in the aspect of the perceptual outcome is a tenet of the direct, non inferential approaches to perception. Aristotle's illusion can thus be considered as an interesting case for appealing to a wider audience interested in the study of illusory phenomena.

Figure 5. Aristotle's illusion

Crossed fingers touch a little ball in Aristotle's illusion

It is not always the case that illusions originate from frustrated expectations

As we have seen, the illusions of impossible movement provoked by vibration do not necessarily originate in the frustration of expectations. The discrepancy the subject recognizes as wrong, bizarre or impossible can stand between two synchronic sources of information (information from the receptors at the joints and information from the muscles' receptors) rather than between two diachronic states (such as expectations based upon past knowledge and present experience).

The same thing can be affirmed of the experiences with paradoxes: illusions provoked by ambiguous figures present a discrepancy between synchronic states and not between expectations and actual perception.

A distinction can be traced between *synchronic and diachronic violations of coherence* in illusory phenomena.

In the case of synchronic violations of coherence inconsistency stands between contents that are actually experienced.

In the case of diachronic violations of coherence inconsistency stands between an actual content and the content of an experience or of knowledge which is not actual. In some way, synchronic violations of coherence can be considered as violations of the logical coherence of the experience, with no need of empirical knowledge based on previous experiences.

Illusions we are immediately aware of have a special role in immediately revealing to the subject that coherence has been violated. The recognition of violations of coherence, both diachronic and synchronic seems to present a functional role, as it will be shown in the following chapter. Illusions we are immediately aware of can in fact inform the subject about expectations he is not aware of all the time and also about the existence of synchronic or diachronic inconsistencies in his perceptual experience.

It should nevertheless be underlined that illusions we are immediately aware of are not necessarily coincident with the presence of a synchronic violation of coherence, where the discrepancy stands between the contents of two or more present experiences. The immediate awareness that something is wrong can also be alerted by the presence of a diachronic violation of coherence between the content of present experiences and the content of past experiences or knowledge. The type of discrepancy is the same as the one described for illusions, such as the SWI, where the awareness is not immediate. Nevertheless, for some reasons, in some cases the subject becomes immediately aware of diachronic discrepancies. In the same way, in some cases synchronic discrepancies do not immediately come to awareness. The former case is described as a possible issue by [Bruner & Postman, 1949] in the case of violation of expectations based on past experience; the latter constitutes the case of solved conflicts, where the perceptual system operates in such a way on discrepant, synchronic stimuli (i.e. multisensory discrepancies) that the subject does not experience a conflict or a sense of wrongness, since coherence is re-established in the perceptual result.

The study of illusions in general is hence suitable for better understanding the relation between surprise, errors, the frustration of expectations and other violations of coherence.

Surprise in the case of synchronic violations of coherence

In illusions we are immediately aware of, both for diachronic and synchronic violations of coherence, surprise reveals to the subject that the experience he is undergoing is incoherent, thus the contents of the experience are inconsistent and that there must be a discrepancy at some point.

The idea that surprise originates in the frustration of expectations seems to come into conflict with the fact, illustrated by proprioceptive illusions of impossible movement, by the experience of paradoxes and by other examples of illusions we are immediately aware of, that a reaction of surprise also arises in connection with illusions where no specific expectation can be individuated.

Thus it could be proposed that surprise emerges as a reaction both to synchronic and to diachronic violations of coherence, that is, surprise is not only a reaction to frustrated expectations but also to violations of coherence with no expectation involved. In the case of the awareness of synchronic violations of coherence the subject would directly perceive the existence of a logical impossibility or inconsistency, because it is not based on empirical information or knowledge.

Some authors deny the existence of convincing examples of direct perception of logical impossibilities.

[Sorensen, 2002] for instance distinguishes depictions of empirical impossibilities from depictions of logical impossibilities. Children's picture puzzles including incongruities to be discovered, such as a goat in a library or ostriches that fly, depict empirically impossible situations. Impossible situations do not involve impossible objects but just ordinary objects in physically impossible relationships; Magritte's painting *Zeno's arrow*, for instance, shows a rock that fails to be gravitationally related to the earth. According to Sorensen, empirical background is needed to infer that the situation cannot be actual. An acceptable depiction of the logically impossible requires that the description is detailed enough to convey the nature of the impossibility, there is no use of unfamiliar, alternative systems of representation (as anamorphic perspective), the content of the picture is logically impossible and not its depiction, the contradiction is within the picture and not between the object represented in the picture and, say, the title or the caption of the picture.

The case of the waterfall illusion and the perception of logical impossibility

When looking at a waterfall for some time, the subsequently viewed rocks around the waterfall appear to move upwards.

The waterfall illusion is one of the most well-known examples of visual movement after-effect: when staring at movement in a particular direction for even a short time, subsequently viewed stationary scenes briefly appear to move in the opposite direction[41].

---

[41] The waterfall illusion is at the center of a philosophical debate about the conceptual content of perception.

T. Crane [Crane, 1988] makes reference to the waterfall illusion to show that the content of perception cannot be conceptual: in the waterfall illusion the observer believes that the rocks are moving and that the rocks are not moving: ambiguity is avoided only if concepts are not part of visual judgments.

D. Mellor [Mellor, 1988] denies that the waterfall illusion implies the belief in a contradiction: there are two attitudes and not two contents in one attitude; the disagreement stands between two self-consistent experiences.

Movement after-effects are also described for the tactual modality[42]. Subjects holding a hand cupped around a moving drum for some minutes, successively experience a tactile aftereffect consisting of sensations of movement opposed to the direction of the adapting stimulus and located on and deep to in the skin, lasting for about one minute [Hollins & Favorov, 1994].

[Frisby, 1979] in the psychological domain and [Crane, 1988] and [Mellor, 1988] in the philosophical context propose the waterfall illusion as an example of perception of logical impossibility.

[Sorensen, 2002] does not accept the example of the waterfall illusion as a perceptual impossibility. In his opinion, the observer is not seeing a logical contradiction (the rocks move and do not move). The observer just sees ordinary rocks via an inconsistent homuncular process: while staring at the waterfall some position detectors adapt to the movement while others do not. The classic explanation based on the adaptation of neurons to movement is due to [Barlow, 1963]. When turning to the rocks, the adapted detectors indicate a movement in the opposite direction to the waterfall, while the unadapted detectors indicate that the rocks are not moving. The waterfall illusion and after-effects in general are thus provoked by the discrepant information provided by two different groups of neurons. Sorensen suggests that the existence of two inconsistent perceptual processes is not necessarily connected with the perception of a situation as impossible.

---

[42] [Singer & Day, 1965, 1966]; [Thalman, 1922]; [Vogels, Kappels & Koenderink, 1996a, 1996b, 1997, 2001]; [Hollins, Favorov & Singer, 1994]; [Collins, 1968]; [Fisher, 1966].

The discrepancy indicated by Sorensen as an inconsistent homuncular process is similar to what we have called a synchronic violation of coherence because in the case of synchronic violations of coherence two or more actual sources of information are inconsistent. This is in fact the case of the explanation of illusions of movement and position provoked by vibration according to which the information from the joint receptors is inconsistent with the information from the muscular receptors.

We can thus extend to the waterfall illusion the idea that a violation of coherence is at the origin of the illusory phenomenon because of the presence of two inconsistent perceptual processes that are synchronically active.

Nevertheless the reaction of surprise and the awareness of the existence of a violation of coherence might be caused by the violation of general expectations such as the expectation that perceptual experience is coherent or expectations based upon general knowledge about natural laws.

Surprise can be a reaction to the violation of volatile expectations

In the case of the waterfall illusion the movement of the rocks is immediately recognized as false by the observers: the observer is surprised by the movement.

> "[when I] suddenly directed my eyes to the left to observe the face of the sombre age-worn rocks immediately contiguous to the waterfall, I saw the rocky surface as if in motion upwards." [Addams, 1834]

Nevertheless, the role of knowledge or experience cannot be excluded from being at the origin of the reaction of surprise.

In fact, the experience of movement after-effect does not necessarily provoke an immediate reaction of surprise, as it is the case for the waterfall illusion. That is, illusions of movement after-effect are not necessarily illusions one is immediately aware of, as it is the case of the waterfall illusion.

The reaction of surprise of the waterfall illusion might then be a specific consequence of the violation of some form of knowledge, which is not necessarily the case for the perception of other movement after-effects in general.

We can suggest that in the case of the waterfall illusion previous knowledge is violated because rocks do not normally fall against gravity, and this is a knowledge that we perceivers have acquired (more or less explicitly). The sensation of wrongness might then arise from this inconsistency with past experience or with the knowledge of natural laws.

The waterfall illusion would thus be a case of synchronic violation of coherence, in virtue of the presence of two actual, inconsistent perceptual processes. But the reaction of surprise, which accompanies the immediate awareness of the illusion, would only arise due to the existence of a general expectation about the natural laws of the movement of objects; the content of the expectation that objects fall downwards and the content of the actual experience are in fact inconsistent.

In the following chapter I will analyze the case of intersensory conflicts; intersensory conflicts are violations of coherence that do not entail specific expectations, because they only depend upon the characteristics of the actual experience and the information presently available. They resemble the case of perceptual paradoxes and in particular of ambiguities. Nevertheless, the presence of a general expectation of coherence cannot be excluded that could explain the reaction of surprise which is produced by the experience with intersensory conflicts and paradoxes.

The hypothesis of the existence of a very general expectation regarding the coherence of perception is directed to avoid the multiplication of expectations that a subject should hold at every moment of his life. Many and different situations can be experienced as impossible and can provoke surprise. For instance, as we have seen, a variety of paradoxes can be experienced. For every paradoxical experience a general expectation of coherence exists; this general expectation produces occasional, volatile expectations (that a figure must represent a duck or a rabbit, that an object is a piano or a violin, etc.) that are related to the specific situation [Casati & Pasquinelli, Submitted].

Chapter 2. Summary and conclusions.

The discussion of the SWI reveals the existence of a controversy about the notion of illusion which is primarily related to the characterization of illusions as errors. This controversy must be analyzed before a less controversial proposal of characterization of the notion of illusion can be put forward.

The notion of error which is in use in the characterization of illusory phenomena offers two main difficulties to proposing a largely acceptable notion of illusion.

First, indirect, inferential approaches to perception identify errors in perception with failures during an inferential process. This characterization appears to be unacceptable for other approaches to perception such as the sensorimotor and the ecological view.

Second, the notion of error is associated with the idea of departure from facts and reality (both in the common sense use and in the psychological literature, with examples in the indirect, inferential one). This characterization is too narrow for a classification of illusory phenomena which includes the experience with paradoxes and other illusions (such as the proprioceptive illusions of impossible movement provoked by muscle vibration) where not facts but the coherence of the perceptual experience is violated; additionally, the characterization of errors as departures from facts does not account for the possibility of veridical hallucinations, where perception is erroneous but adheres to the facts.

The case of paradoxes and of illusions of impossible movement provides a suggestion for enlarging the notion of error in illusory phenomena so as to overcome the two objections: the idea is to adopt a broad notion of error which includes violations of coherence.

In spite of the difficulties with the notion of error, it seems useful to adopt a broad notion of error as one of the main specifications of the notion of illusion, in virtue of the fact that the experience of illusions, and in particular of illusions we are immediately aware of, is related with a sense of wrongness or impossibility.

The distinction between illusions we are immediately aware of and illusions we are not immediately aware of is described with the help of proprioceptive illusions produced by muscle vibration; it illustrates the possibility for the subject to be immediately or not immediately alerted of the presence of an error (something wrong) by the identification of the presence of a discrepancy in the experience. The notion of error as associated to violations of coherence is thus relevant in order to point out the epistemic role of illusions.

The idea that illusions are errors one can be aware of is conducive to a discussion about the attribution of illusions. It is proposed that the attribution of illusions to individuals rather than to perceptual systems could go in the direction of providing a less controversial characterization of illusions because of the positions represented by the ecological approach, which denies that perceptual systems can be wrong.

Two other characteristics immanent to the features of illusory phenomena are represented by the robust character of illusions and by the existence of a reaction of surprise. These characteristics are not mere additions to the notion of error.

The notion of robustness is composed of two notions: the notion of systematicity, both inter and intrasubjective, and the notion of resilience to knowledge.

The notions of systematicity and resilience to knowledge help distinguish illusions from local errors and hallucinations, thus better defining illusions as specific perceptual phenomena.

Moreover, the notion of resilience to knowledge is useful in order to distinguish illusions as perceptual errors from cases that present a discrepancy but in which the error is on the side of knowledge and not on the side of perception (cases of false testimony, for instance).

The notion of resilience to knowledge finally helps to explain the co-presence of systematicity and surprise in the characterization of the notion of illusion: the repetition of the same illusory experience does not diminish the surprise effect because the occurrence of illusions is not modified by the knowledge.

The reaction of surprise is the final feature which is suggested for the characterization of illusions.

The reaction of surprise accompanies errors in general, but not typical errors.

Surprise is also a reaction to the frustration of expectations. Two suggestions have been made at this proposal.

First, cases of illusions such as Aristotle's illusion seem to indicate that surprise can be provoked by the frustration of a special form of expectation, which is not only not linguistically expressed but also not symbolic in nature; this form of expectation is based on the existence of motor skills and habits, thus on a pragmatic form of knowledge.

Second, illusions do not depend only on violations of coherence that involve the frustration of expectations. Two classes of violations of coherence are in fact described here in relation to illusions: diachronic violations (with the involvement of expectations) and synchronic violations (where the discrepancy stands between two or more synchronic experiences, with no involvement of expectations). On the basis of the different awareness arisen by after-effects in general and a special type of after-effect known as the waterfall illusion, it is suggested that even in the case of synchronic violations of coherence surprise might arise as a consequence of the violation of general, volatile expectations.

It seems possible on the basis of the presented features of illusory experiences (violation of coherence which alert to the presence of errors, robustness, surprise), to propose a neutral characterization of the notion of illusion which could serve as a basis for investigations on perception and pragmatic applications, with no specific commitment to any theoretical approach about perception.

The investigation of illusions has a special role in gaining a better understanding of perceptual violations of coherence in general, of the role of coherence and of the mechanisms that maintain coherence in perception. As we have seen, in fact, illusions (and in particular illusions we are immediately aware of) are suitable to reveal to the subject the presence of some form of inconsistency

The considerations about illusions, expectations and coherence and the heuristic role that illusions might play in the study of perception will be further developed in the following chapters.

Table 2. Elements that characterize the notion of illusion

General charactersof illusions	***Specific characters of illusions***	***Detail of the specific characters of illusions***	***Role of the general and specific characters***	***General considerations about illusions***
Broad notion of error	Violation of coherence	Synchronic violation of coherence	The notion of error distinguishes illusions from normal conditions of perception with no error	Illusions are not bound to violation of knowledge, failed inferences, departure from facts
		Diachronic violation of coherence		Illusions do not necessarily involve symbolic representations
	Awareness	Immediate (illusions we are immediately aware of)	Awareness distinguishes illusions from cases of reaction with no error	Illusions belong to the individual
		Not immediate (illusions we are not aware of)		Illusions belong to the individual
Robust character	Systematicity	Intersubjective	Systematicity helps distinguishing illusions from hallucinations and local errors	Public character
		Intrasubjective		
	Resilience to knowledge		Resilience to knowledge helps distinguishing illusions from local errors and illusions as perceptual errors from cases of error in knowledge and not in perception (false testimony)	Illusions provoke surprise in spite of their systematicity
Surprise reaction	Violation of expectation	Specific expectations	Surprise reactions help distinguishing illusions from typical errors	
		General or volatile expectations		

Chapter 3. Illusions have a heuristic role for theories of perception

The heuristic role of illusions for the investigation of the functioning of perception has been stated by different authors.

In analogy with pathological processes, the failure of the perceptual process or the modification of the normal conditions of the perceptual process allows a better insight into the functioning of normal perception.

Contrary to pathological processes, illusions can be produced at will by creating the proper conditions for the illusion to take place. As we have seen in fact illusions are systematic phenomena.

An aspect of the systematicity of illusions is their public character: every subject will experience the same illusion in the same conditions. This characteristic is important in order to produce experimental results that are intersubjectively valid.

Finally, illusions provoke a behavioural response to the awareness of the error, which can be immediate or not. Hence, the assessment of the awareness of being victim of an illusion is not exclusively based on language, but on the observation of behavioural reactions too.

All these characteristics provide illusions with a heuristic value for the investigation of perception at two levels: they have the capacity of revealing specific mechanisms of perception and also general rules about perception.

The study of illusions presents a heuristic role both for gaining a better understanding of the general functioning of perception and the qualities of the environment the perceptual systems are sensitive to, and for acquiring an insight into more specific issue, such as the role of movement and of different forms of knowledge (including knowledge based on motor skills and habits) in perception. The latter issue represents a privileged line of studies for the direct theories of perception that criticize the classic characterization of illusory phenomena, such as the ecological and the sensorimotor view.

3.1 Illusions provide an insight into specific mechanisms and general rules of perception

Gregory claims that

> "illusions are important for investigating cognitive processes of vision" [Gregory, 1997, p. 1121]

> "Paradoxically, […] truths of perception are revealed most dearly through illusions. Quite simple figures or objects can be ambiguous, spontaneously changing into other orientations or other objects, although there are no changes of the images in the eyes. This is evidence of changes of the brain's hypotheses of what is out there." [Gregory, 1998, p. 1693]

As we have seen, according to Gregory, the occurrence of an illusion points out the existence of a failure in the perceptual process, thus revealing some aspects of the general nature of the process. In addition, the collection of the descriptions of different illusions makes it possible to divide the process into its components (by indicating at which moments the process can fail). Thus, the study of illusions allows the researcher to investigate the physical processes and the cognitive processes (in terms of specific types of knowledge and general rules) that participate in the construction of the final percept.

In a much more neutral vein [Welch & Warren, 1981], highlight the value of misperception for gaining insight into normal perception. Adult human perception is developed, accurate and served by a multiplicity of different cues. This makes it difficult to extract the mechanisms that subserve proper functioning.

> "For this reason the understanding of perceptual processes exploits different kinds of malfunctioning (i.e. colour blindness or congenital cataracts for visual perception) and illusions. Illusions are a better source of knowledge, because malfunctioning is rare and illusions can be deliberately provoked." [Welch & Warren, 1981, p. 638]

For instance, for the understanding of (normal) multimodal perception, of the mechanism of intersensory integration and bias, many illusions can be provoked by creating discrepancies in the stimulus situation and conflicts between two or more sensory modalities. These illusions are created by a rearrangement of the sensory environment. The rearrangement of the sensory environment constitutes a physiological disturbance or malfunctioning. Illusions are then suitably provoked malfunctionings, in order to gain insight into the normal mechanisms of perception.

Capacity of the SWI of providing insight into perceptual mechanisms

As a matter of fact, with the aim of discovering the role played by different contexts in the perception of horizontal and vertical lines, or the quantities the haptic perceptual system is sensitive to, the research guided by ecological principles makes use of phenomena such as the ones involved in the SWI – although the ecologists would not dub them 'illusions', as we have seen.

Even if the notion of error is dissolved within this approach, and illusory phenomena are considered in continuity with normal perception, illusions are in some way distinguished from other 'normal' perceptual phenomena, and suitably used for digging into the inner mechanisms of perception.

In fact, what is really at stake in the campaign of the ecological perception approach towards illusions is the notion of perceptual error as the latter stems from the idea that perception is an indirect process of inference from sensory data, involving knowledge. In the case of the SWI, for instance, it is accepted that a discrepancy exists between the task described as 'weight perception' and the performance of the haptic system, which is considered to be sensitive to inertia tensor variations, and not to weight itself. The discrepancy leads to the experimenter's inappropriate belief that there is an illusion in weight perception. But the SWI phenomenon is distinguished from normal weight perception in virtue of the fact that ordinary language descriptions do not corroborate the real functioning of the haptic perceptual system. Since non-ecologist psychologists adopt the ordinary language descriptions, they are deceived in their research. It is, in a sense, an experimenter's illusion which is at stake.

Illusions prove general rules of perception

According to [Berthoz, 2002], the study of illusions is suitable for proving a general rule: perception is active, in that hypotheses are continuously emitted by the brain regarding the state of the world and confronted with the actual stimulation. In particular, the brain possesses mechanisms for anticipating the perceptual consequences of action and the perceptual results of the changes that the subject has provoked in the environmental condition.

Illusions show that the perceptual system is much more than a system for the passive reception of stimuli because they can reveal which kind of solution, which type of hypothesis the brain has been emitting.

One of the most important tasks for perception is, according to Berthoz, the construction of coherence. The sensory data are in fact, in this view, often discrepant in the natural conditions of perception. Thus, as we have seen for the special case of suitably produced intersensory discrepancies, in its normal functioning the perceptual system must supply active solutions for combining sensory data into a coherent unit. Illusions are in some cases the results of such active solutions.

3.2 Some illusions offer an insight into the role of movement and implicit knowledge in perception

Some illusions offer an insight into the role of movement in perception. The study of illusions can thus have a heuristic role in clarifying the structure of the interaction between movement and perception.

As we have seen, this is the scope of the research conducted on the SWI, also for those researchers who refuse to adopt the notion of illusion: in the frame-work of the ecological approach to perception, in fact, the study of the SWI has thrown light on the role of the muscular activity in response to variations in the inertia tensor of an hand-held object.

Other examples can be proposed about the role of movement in the occurrence of perceptual illusions that are less controversial than the explanation of the SWI.

The role played by movement in the occurrence of perceptual illusions is also significant for the characterization of a form of knowledge (which could be at the origin of some illusory phenomena) which is not the explicit, representational form of knowledge which indirect, inferential approaches to perception make reference to for the explanation of illusions.

This form of knowledge can be considered implicit because it is related to the acquisition of pragmatic skills and habits and shows a direct connection between perception and movement, with no need for symbolic, representational intermediaries.

Some illusions could thus originate from the inconsistency between actual experience and expectations based upon implicit knowledge. Hence, some illusions could originate from some form of expectation without being committed to the assertion of the role of inferential processes and representations in perception.

The strong relationship that some illusions show to movement and implicit knowledge presents a heuristic value for those psychological theories that affirm that action and perception cannot be dissociated and that perception is in some way shaped by action. These theories are generally labeled 'motor theories of perception'. Motor theories of perception include the ecological and the sensorimotor approach to perception.

Box 14. Motor theories of perception

Theories of perception that assign to the motor experience a significant position in the explanation of perceptual phenomena are called 'motor theories of perception' (for an historical review of motor theories of perception, see [Viviani, 1990] and [Berthoz, 2002]).

Motor theories of perception are compatible with the existence of internal representations, i.e. of movement; in particular they are not necessarily committed to the denial of the role of representations or computations in the case of "higher order" cognitive processes. Anyway, action and perception are conceived as directly linked as in the case of a sensory-motor loop, with no mediation of cognitive processes (the central processor positioned between the input and the output signals).

An example of neurophysiological model for this closed relationship is represented by the functioning of mirror neurons. "Mirror neurons" is the name given to a particular group of neurons which are activated both by the execution and by the observation of some specific motor actions, as reaching and manipulating (see [Rizzolatti, *et al.,* 1996]). It is suggested by [Rizzolatti, Fogassi & Gallese, 2001] that mirror neurons have a role in the imitation and understanding of perceived actions. The connection between performed actions and perceived actions is then direct, with no form of interpolated cognitive mediation.

Box 15. Motor theories of perception assign different roles to movement

It is possible to distinguish two different claims within the assertion of a key role played by action in perception.

The first claim is that action directs perception through the exploration of the environment: it is impossible to separate perception from action, since there is no perceptual activity without the movement of sensors and the active exploration of the environment. The second claim is that motor competences and motor acts shape the perceptual content.

As an example of the first claim of motor theories of perception, [Berthoz, 2002] proposes a theory of perception as simulated action: perceptual activity is not confined to the interpretation of sensory messages but anticipates the consequences of action, so it is internal simulation of action. Each time it is engaged in an action, the brain constructs hypotheses about the state of a variegated group of sensory captors throughout the movement; the brain of the skilled skier for example does not control the state of all the body captors in a continuous and permanent way, instead it internally simulates the trajectory and controls the state of a specified group of captors only intermittently. The ensemble of the captors that are implicated in the analysis of movement and space (movement of the body and of the environment) are particularly important for this task; they circumscribe what [Berthoz, 2002] calls the '*sense of movement*' or kinaesthesia (with a broader extension than the classic term kinaesthesia which included only the tactile captors located within the muscles, tendons and joints). When the product of the integration of the different kinds of captors that participate in the sense of movement is not coherent the brain suffers from perceptual and motor troubles to which perceptual illusions can offer a solution. In general, within the theory of the sense of movement, illusions can be considered as solutions that the brain creates when faced with discrepancies between sensory information and the internal pre-representations or anticipations.

In the sensorimotor vision of perception [Noë, 2003; O'Regan & Noë, 2001], perceptual experiences depend upon sensorimotor acitivity: movement is necessary in order to perceive objects as unitary, coherent and present entities. Thus, action shapes the formal aspects of the perceptual content.

In the frame of the ecological approach the aspect of perceptual content depends upon action. [Turvey, *et al.*, 1981]; [Gibson, 1979, 1966]; [Stoffregen & Bardy, 2001] emphasize the relevance of activity in defining the stimulus to be perceived and the structure of the animal-environment coupling. In fact, according to the ecological approach what we directly perceive is affordances, that is, possibilities for action [Turvey, *et al.,* 1981]; [Gibson, 1979]: the 'walkability' of a surface, the 'sittability' of a chair, etc.

3.2.1 The role of knowledge in perception is debated

As the discussion about the SWI shoiws, the role of knowledge in perceptual phenomena is debated.

Ecological theories of perception [Gibson, 1979] on their side consider perception as direct, thus the role of inferential processes based on knowledge is discredited in favor of the direct picking-up of the relevant information from the ambient array.

Modular theories of mind, such as the classic view proposed by [Fodor, 1983] assert the separation between input systems, such as perception, and central processes, such as cognition: perception is organized into modules that are encapsulated and that cannot be influenced by cognitive process.

Motor theories of perception and theories of active perception tend to consider the direct loop between action and perception and to highlight the constructive role of perception, independently of cognitive processes.

I will take into account the suggestion that perception is influenced by a form of knowledge which has been variously called *implicit knowledge*, *praktognosia*, *sensorimotor knowledge*.

Implicit knowledge based on the direct connection of movement and perception is mainly characterized by the fact of not being propositionally and symbolically represented and by the fact of being strictly connected to the possession of motor abilities, with the mastery of motor skills or with motor habits.

As we have also seen, the refusal to take into account the role of knowledge in perception leads to different positions towards illusions. While modular theories of mind make reference to classic optic geometric illusions and their resilience to knowledge as an evidence for their position, ecological theories, as in the case of the SWI, refuse the notion of illusion.

The motor theories of perception I am going to introduce are committed to the role of implicit knowledge in perception and to the existence of expectations based upon this form of knowledge. Thus, the motor theories of perception I will present are compatible with the existence of illusory phenomena that originate from the inconsistency between actual experience and expectations, without being committed to the role of inferential processes and propositional representations in perception.

Perception is influenced by the mastery of motor habits

[Merleau-Ponty, 1945] introduces the term "*praktognosie*" in order to characterize a form of implicit knowledge which is not grounded on explicit, symbolic representations, but precedes thought and abstract knowledge and is based on the practical mastery of some classes of movements. This practical form of knowledge is instantiated by the mastery exerted in the performance of *habitual concrete movements*, such as tailoring a dress, driving a car, typing a letter. The acquisition of new *motor skills* is considered by the author as equivalent to the acquisition of new knowledge about the bodily movements and about the parts of the world that are involved in the body actions.

This acquisition is not an intellectual or symbolic function, even if it represents the acquisition of new knowledge about the body and its possibilities.

> "The acquisition of a habit corresponds to the acquisition of a new meaning, a motor habit and a motor meaning […]. If I have the habit of driving a car, I enter into a passage and I see that I am able to « drive through it » without comparing the dimension of the passage with those of my car, as I pass through a door without comparing the dimension of the door with that of my shoulders;" [Merleau-Ponty, 1945, p. 167. My translation]

The kind of knowledge which is necessary in order to avoid familiar obstacles and perform habitual movements with or without the help of familiar objects as the car is an immediate knowledge that the body deploys without the intervention of the intellect, that is, of central cognitive processes. This knowledge is both motor and perceptual since the body has acquired both motor and perceptual skills or habits.

> "Really, every motor habit is at the same time a motor rand a perceptive habit […]; " [Merleau-Ponty, 1945, p. 177. My translation]

The white stick for blind people for instance requires the acquisition of new motor habits for being properly used; its skilled use reveals the acquisition of motor capabilities, thus of motor knowledge. In the mean time, the skilled use of the white stick allows the blind person to perceive areas of the space that were previously inaccessible. When the stick has become familiar, new perceptual habits are then acquired that concern the perception of the objects at the end of the stick. The perceptual habit is not an intellectual function; on the contrary, the acquisition of perceptual habits in the perceptual use of the stick, releases the user from the necessity of interpreting the positions of the stick and the sensations that arise.

Two examples follow that show in what way implicit forms of motor knowledge based on the mastery of motor skills or on the bodily motor habits can influence the aspect of the perceptual outcome. The examples are constituted by two different kinds of illusions: illusions of trajectory produced in an experimental context by suitably modifying the characteristics of dynamic events (we will refer to them as Viviani's illusions, because they are part of the work of Viviani on the perception of dynamic events) and Aristotle's illusion. In both cases the experimental research conducted on the occurrence of the illusion indicates that the motor competence and the motor habits of the subjects can be considered as responsible for the illusory phenomena.

3.2.2 Some illusions of trajectory prove the role of implicit knowledge of motor competence in the shaping of the perceptual content during the experience with dynamic events

Proving evidence for the role of motor habits and capacities in the shaping of the perceptual outcome is equivalent to demonstrating the role of implicit knowledge related to movement in perception and of equally implicit, motor-based expectations. The possession of motor skills and capacities in fact allows the subject to make (implicit) previsions about the perceptual consequences of the movements he accomplishes.

Merleau-Ponty introduces a notion of body schema that includes all the motor-perceptual possibilities of the body, all the actions that are familiar to the body and the perceptions that are related to those actions. In addition, according to Merleau-Ponty, action and perception are related in a double manner: action creates the access to the object and thus allows the perception of the object, but in the mean time, the perception of the object evokes the motor actions that can possibly be accomplished with regard to it. This relation can be considered an ‘action-perception loop’ since the evoked possible motor actions evoke on their side the possible perceptual effects of action.

When an object, such as a cube, is sensed, only a part of it touches the organs of perception; for instance, only a face can be directly viewed. But all the faces of the cube are present in perception because of the knowledge about the perceptual consequences of the familiar action of exploring the object. When the body explores the object, all the faces of the cube are viewed one after the other. The faces are synchronously present in the possibility of seeing them by the same movement that makes them successively present and in the implicit knowledge of this possibility.

> “I know that objects have many faces because I can move around them […].” [Merleau-Ponty, 1945, p. 97. My translation]

Thus, even if some aspects of the objects are hidden from the senses, they are potentially present because of the motor actions that are not actually performed upon them, but that could be, since they are part of the body schema, of the motor habits, of the subject.

The existence of expectations based upon motor knowledge and its role in the shaping of the perceptual outcome is illustrated by some experiments conducted by Viviani and colleagues on the perception of dynamic events.

Illusions of shape can be produced by implicit knowledge of motor competence

[Viviani, 1990, 1997, 1989] states that the human observer has a tendency to project his implicit knowledge about biological motion in the observation (and kinesthetic perception) of dynamic events, such as a moving light point.

This is shown by some experiments on the misperception of the aspect of a trajectory. The form-velocity relation is described by an equation (known as the '2/3 Power Law'): instantaneous velocity and the radius of curvature of the trajectory of voluntary gestures are related by an expression where the former ranges between 0 and 0.1, depending on the average velocity and the latter has a value very close to 2/3 in adults and slightly more in young children.

The 2/3 Power Law predicts (and experiments confirm) that circles, and only circles, are traced at constant velocity. The results of different manipulations of the trajectory and velocity relationship indicate that the perception of the aspect ratio (vertical axis/horizontal axis) is biased when the stimuli are not compatible with the biological model.

In one of the experiments described by [Viviani, 1989], the subjects were shown a light point tracing elliptic trajectories of various eccentricities and are asked to indicate the orientation of the major axis of the ellipse (whether vertical or horizontal).

The procedure was repeated under three cinematic conditions: in the first condition the velocity of the light point was constant (only circles are traced at constant velocity), in the second the velocity was made equal to that of a biological motion tracing an ellipse with a horizontal major axis and in the third the velocity was that of a biological motion tracing an ellipse with a vertical major axis. None of the trajectories corresponded to a circle, thus the first cinematic condition did present a discrepancy between velocity and trajectory as they are related in biological movement.

In the second condition ellipses with vertical major axis and with large eccentricities were even more deviant with respect to the biological model. The situation was reversed in the third condition. The results indicate that there is no bias in the perception of the aspect ratio for the first condition. In the second one, subjects perceived as circles trajectories that were actually quite elongated in the vertical direction. No systematic bias emerged in the third condition.

The authors summarize the results in the following way: an interaction between form and kinematics is shown in which the decisive factor is whether or not the velocity-curvature relation is similar to that found in human limb movements. In particular, the large bias in the latter indicates that subjects have a tendency to fit the stimuli within the biological model. When the fit is poor, they smooth out the discrepancy by deforming the geometry in the direction dictated by the 2/3 Power Law. Indeed, perceiving a vertical ellipse as a circle implies a compression of the vertical extent, that is, a flattening of the portions of the trajectory where velocity is higher.

Thus the observer has a tendency to project his implicit knowledge about the motor rule expressed by the 2/3 Power Law upon movement perception.

Other experiments confirm the same findings for the kinesthetic modality [Viviani, 1997].

In the new setting, the elliptic stimuli are presented to the arm of a blindfolded subject by feeding it into a computerized robotic arm. The arm of the subject is thus made to move passively until the subject has identified the orientation of the major axis of the ellipse. The eccentricity of the first trials is large so as to facilitate recognition, but they decrease after correct responses in order to make the task harder. The tested cinematic conditions are the same as in the visual setting: constant velocity, velocity profiles that would be biological if the trajectory were an ellipse with horizontal axis, and velocity profile that would be biological for an ellipse with vertical axis, respectively.

The results indicate that even for the kinesthetic modality, when the kinesthetic information fits well with the biological model, as when constant velocity is associated with quasi-circular trajectories, the aspect of the stimulus is perceived with a small error. On the contrary, large errors are measured when the modulation of velocity is inconsistent with the quasi-constant curvature of the trajectory.

The fact that two sensory modalities express the same sensitivity to the relation between form and velocity as it is represented by the 2/3 Power Law is an indication that the influence of motor competence and motor expectations over perception is somehow generalized. A general competence about biological motor behavior produces general expectations for motor perception.

Also in this case, the competence and the expectations that are expressed on its bases are implicit in that they are not mediated by internal representations but consist in *limits* to the perceptual activity posed by the laws that direct self-generated motor activity.

When the dynamic stimulus situation is discrepant with the laws that guide self-generated motor activity (the laws of biological movement) the incoming information is modified correspondingly with the characteristics of self-generated motion. Biological motion is in fact adopted as a general model for the perception of dynamic events, even when it is not the most suitable.

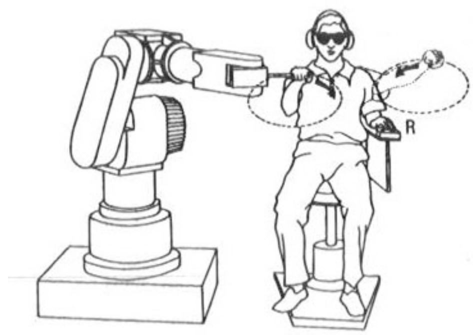
The example of Viviani's illusions shows that illusions in the perception of dynamic events can be provoked by suitably manipulating a form of knowledge which biases the perception of movement for different sensory modalities. On the basis of this example we can also suggest the existence of an expectation regarding the content of perception which is grounded in the existence of motor competences.

The form of motor knowledge and expectations that bias perception and are present at the origin of the occurrence of perceptual illusions is not linguistically expressed, as it is the case for Viviani's illusion, since the perceiver has no explicit knowledge about the 2/3 Power Law. Since the 2/3 Power Law states the specific structure of biological motion, it is also possible to conceive the projection of the 2/3 Power Law on the perceptual content (for any kind of dynamic object, biological or not) as a direct influence of the motor properties of the subject (a biological entity) over the perception of dynamic events. In this way, no internal representation about biological motion would be necessary in order to explain the bias exerted by motor competence over perception (asserting that internal representations are not necessary is not the same thing as asserting that they do not exist). Simply, the things the subject can or is able to do and the way the subject does these things would contribute to the shaping of the perceptual content. In other terms: the existence of certain motor competences would dispose the subject to (perceptually) react in a certain way. A similar reaction does not need intermediaries; in fact, we can imagine a reaction of this kind in terms of a sort of ‘perceptual reflex’: in virtue of the existence of certain competences, automatic perceptual responses are stimulated (motor reflexes are motor, automatic responses to certain perceptual stimuli; the comparison with motor reflexes cannot however suggest a real analogy between the case of perception and the case of automatic motor responses, because the latter are normally based on peripheral loops with no major role played by the central nervous system).

The role played by the motor skills and habits of the perceiver on the shaping of perceptual content seems to be confirmed by recent studies on Aristotle’s illusion. Aristotle’s illusion well illustrates the role of acquired competences and the possibility of modifying the perceptual result following the acquisition of new motor habits and skills.

Figure 6. Viviani's illusions

Experimental setup for the kinesthetic version of Viviani's illusions [Viviani, 1997]



3.2.3 Recent studies on Aristotle's illusion support the role of motor habits in the construction of coherent percepts

As we have seen, a particular phenomenon known since long as 'Aristotle's illusion' shows that the occurrence of some illusions can be explained by the recourse to motor skills of the perceiver.

In the case of Aristotle's illusion too, it does not seem necessary to fall back on internal representations and inferences in order to explain the illusory phenomenon. Nevertheless, the illusion seems to be related to some form of mastery and apprenticeship of motor actions and relative perceptual consequences. The illusion is in fact related to the motor possibilities of the fingers of the subject and disappears after the subject has followed a long training and he has acquired new motor skills with his fingers. In seems thus plausible, in the light of some experiments conducted by Benedetti, to suggest that the motor skills of the fingers are relevant for Aristotle's illusion to occur and to disappear.

Aristotle's illusion also represents the exception to a fundamental rule in haptic object recognition, as described by [Gibson, 1962]: according to Gibson, in fact, the information that arises from the activity of the superficial and deep receptors of the exploring hand allows the recognition of the following features of the manipulated object: unity, stability, rigidity or plasticity, shape. For what concerns unity, Gibson states that an object explored by any pair of fingers is perceived as a unitary object, despite the fact that contact is established with two different fingers.

In terms of integration, partial information gained from the fingers is normally combined into a unitary, coherent percept. Within this view, the perception of an object with two fingers presents a problem of binding together separate bits of information: the stimulus is perceived to be single although two different receptor surfaces are stimulated.

In any case, Aristotle's illusion represents a violation of the normal rule of unity of the object explored with two fingers. Hence, the conditions for Aristotle's illusion to occur are relevant for investigating the factors that influence the constitution of coherent unitary percepts.

The reaction of surprise which arises when two objects are perceived instead of one might be provoked by the conflict between the visual and the tactile information or between the tactile sensation which is presently experienced and the knowledge that only one object is really sensed with the two fingers. In both cases surprise arises in response to a violation of the coherence of the perceptual experience which is immediately signaled to the subject.

The reaction of surprise which is associated with Aristotle's illusions, as with the others illusions, hence alerts the subject to the presence of a violation of coherence.

Aristotle's illusion depends on the normal range of action of the uncrossed fingers

In a first experiment, [Benedetti, 1985] has tested the hypothesis that tactile information with crossed fingers is processed as if the fingers were not crossed. Subjects are asked to identify the position of a small ball. The position is expressed as the angle between the ball and a sharp point which is equally in contact. In the uncrossed condition the third finger is in contact with the sharp point; the sharp point is placed at the center of a circle and the ball is placed at 0° at the right of the sharp point. In the crossed condition the fourth finger is in contact with the sharp point and the third finger the ball, which is still in the same position, even if the subjects are informed that the ball may assume different positions. In the uncrossed position the ball is judged to be at an average angle of 3° with the point; with the third finger crossed over the fourth, the perceived angle increases to 96°; with the third finger crossed under, the perceived angle decreases to -115°. Both 96° and -115° values are located on the left of the fourth finger touching the point, even if in the crossed position the third finger is on the right of the fourth one.

Thus, when the fingers are crossed, tactile spatial information seems to be processed as if fingers were uncrossed (third finger on the left of the fourth one).

In addition, a difference is noticed between the situation with the third finger crossed over the fourth finger and the situation with the third finger crossed under. When the third finger is crossed over, the ball is perceived to be above the sharp point in contact with the fourth finger; when the third finger is crossed under, the ball is perceived below the sharp point and the fingers are perceived as uncrossed. In fact, when the third finger is under the fourth, the third finger is referred to a position which is also lower than the fourth finger.

A second experiment is directed to test the second part of the hypothesis emitted by Tastevin, that is, beyond certain limits the perceived location of tactile stimuli does not vary.

[Benedetti, 1985] assumes that the limit is not the limit of the voluntary movement; in fact, the illusion occurs even when the fingers are crossed voluntarily. Since the sensation with crossed fingers is referred back to the position with uncrossed fingers, the individuated limit is the limit of crossing: the point at which the transition between the position with uncrossed fingers and the position with crossed fingers occurs (with the hand in the position in which the two fingers are aligned with one finger under the other).

Tactile sensations with crossed fingers are referred to two points (96° and -115°); these points are assumed to represent the limits of the functional range of action of the fingers: the spatial excursion of the fingers beyond which the perceived location of tactile events does not vary. 96° is nearer to the objective limit of crossing of the fingers (which is 90°). The difference can be explained by the fact that the movement of the third finger under the fourth is more limited, thus, the perceived location of tactile stimuli will become invariant farther from the objective limit of the crossing.

The second experiment makes use of a different apparatus than the first one (the 0° is on the left, while in the first experiment it was on the right; the range of normal position is between 90° and -90°; the range with the third finger crossed over the fourth is between 90° and 180°; for the third finger crossed under is between -180° and -90°), so that the limits are 84° (180° - 96°) and 65° (180° - 115°) and saturation of tactile information (no variations in the perceived position) is expected at these points. The fourth finger of the subjects is immobilized and put in contact with a sharp point and the third finger is again passively moved over and under the fourth one and in contact with a small ball. The results seem to confirm the expected saturation effect: tactile sensations with crossed fingers are perceived at 80° and -70°. Within this functional range of action the tactile spatial sensation follows and reproduces almost exactly the effective spatial position of the fingers; beyond the indicated values, the experience does not change.

The experiments by Benedetti show that the perception of tactile stimuli with crossed fingers is referred to the perception of tactile stimuli with uncrossed fingers, that is, to the normal situation and the normal position of the fingers. A given pair of fingers has a functional range of action within which spatial perception is correct and beyond which the location of tactile stimuli is perceived incorrectly. The objects touched with crossed fingers are perceived as having the spatial properties of the extreme limits of the range of action of the fingers. What mediates the perception of the object with crossed fingers is thus something related to the range of action of the fingers, but not the representation of the position of the fingers, which is not altered by the fact of crossing (the subject of the illusion describes his fingers as crossed). Aristotle's illusion is thus related to a form of knowledge which is based on the acquisition of skills and not on the existence of explicit representations of the position of the body parts (fingers)[43].

---

[43] Benedetti also excludes the possibility that Aristotle's illusion depends on the perception of the position of the fingers. The perceived location of the tactile stimulus in fact does not co-vary with the perceived position of the fingers [Benedetti, 1988]. When the two perceptions are compared, it appears that whatever the position of the crossed fingers (specifically 0°, 45° and 90° are tested for the third finger being crossed over the fourth), the perceived position of the stimulus (a ball, whose position, as in the previously described experiments, is plotted against the position of a sharp point stimulus applied to the fourth finger) remains unvaried (when subjects are asked to place the third finger at 0° they place it at -5° and perceive the ball to be located at -4°; for the request of placing the finger at 45°, the finger is placed at 40° and the ball perceived at 3°; for the finger to be placed at 90°, it is really positioned at 87° and the ball is perceived at -10°). In this experiment the fingers are crossed voluntarily and the third finger is charged with a little weight in order to make it necessary for it to exert a continuous muscular effort to maintain the position. Thus, Aristotle's illusion occurs both in the passive and active condition of crossing fingers and position sense has no effect on the perceived position of the stimulus, at least with crossed fingers.

Aristotle's illusion testifies the role of sensorimotor learning. Another experiment by [Benedetti, 1991] investigates the effects of motor-perceptual learning on the disappearance of Aristotle's illusion. In fact, [Benedetti, 1991] has tested whether or not the individuated range of action of the fingers can be modified by a long-lasting crossing. The subjects crossed the third finger over the second and were asked to go back to their daily lives with crossed fingers for variable periods, from 60 to 183 days (with short periods of rest with uncrossed fingers); some of the subjects also underwent special training. Spatial perception with crossed and uncrossed fingers and the perception of the position of the fingers were tested at intervals in the modality adopted for the experiments described in [Benedetti, 1985] and [Benedetti, 1988]. Again, since the actual position of the ball is at 0°, an error greater than 90° indicates that the ball is perceived as if the fingers were uncrossed, while an error smaller than 90° indicates that the ball is perceived on the correct side. A decrease of the error from 90° is observed for all subjects. Hence, all the subjects learned to perceive the ball on the correct side with the second and third finger. A test performed over the non-trained third and fourth finger always elicited perception as if the fingers were uncrossed.

The results indicate that Aristotle's illusion disappears after a period of training with crossed fingers.

Even when perception with crossed fingers became correct, perception with uncrossed fingers still remained correct too. In addition, no saturation effect is observed for the trained fingers, but there is linear co-variation between the effective position and the perceived position of the stimulus. The last observations indicate that no adaptation has occurred, but there has been an extension of the range of action of the fingers, which now includes the crossed position.

The observed perceptual modifications (extension of the range within which perception varies following the variations of the stimuli) are accompanied by corresponding motor modifications. The percentage of correct movements (the number of times a stimulus is rejoined correctly) greatly improves in correspondence with the dropping of perceptual errors. Thus motor and perceptual performances show a good correspondence.

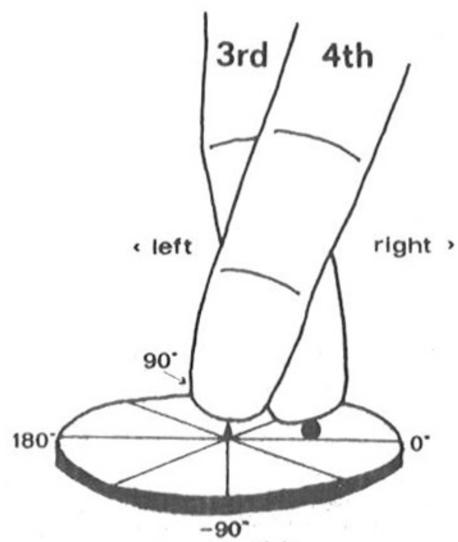
The extension of the range of action suggests the existence of plastic changes: the touch system seems to develop according to the pattern of hand exploration and is not to be rigidly pre-determined. If the fingers are located in new and unusual positions, the touch system develops in a new and unusual way. In this sense, the acquisition of a new perceptual competence implies the acquisition of a new motor capability.

The studies conducted by Benedetti on Aristotle's illusion confirm the role of motor competences and habits in perception in general and in the occurrence and appearance of certain illusion in particular. The explicit representation of the body of the perceiver seems to play no role in the illusion, so there is no linguistic expectation. Additionally, the existence of a 'normal' range of action of the fingers beyond which the perceptual content does not vary seems to indicate that the type of bias played by motor possibilities on the perceptual content is direct, as a sort of anatomic limit, with no need of interposed representations. In the case of the position of the fingers, the limit can be displaced by the means of a long training, as a real anatomic limit can be displaced through the intervention of prostheses (such as the stick of the blind, which also requires training for being correctly used).

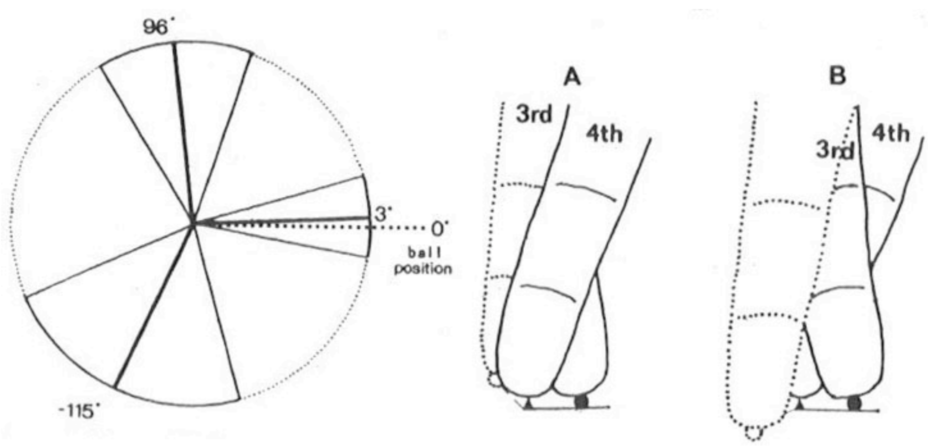
Training could hence be considered as a significant mean not only for acquiring new motor skills but also, because of the existence of direct connections between movement and perception and of the plasticity of the nervous system, as a significant mean for creating new perceptual responses. These new perceptual responses would not depend on the acquisition of new representations but would stand in a direct connection with the new motor skills, as sorts of ‘perceptual reflexes’.

Figure 7. Experimental setting testing Aristotle's illusion

a. Paradigm for testing Aristotle's illusion; b. Schema of the testing disk; c. Perceptual experience occurring when the third finger is crossed over fourth; d. Perceptual experience occurring when the third finger is crossed under fourth [Benedetti, 1985].



a.



b. c. d.

Chapter 3. Summary and conclusions.

In spite of the criticisms of the direct approaches to perception of the notion of perceptual error and illusions, the notion of illusory phenomena seems to have a positive pragmatic value for the empirical investigation of perception.

As a conclusion of this short review of the various accounts, in fact, we can assert that it turns out to be useful to isolate special, illusory phenomena in normal perception and eventually to create variations in the stimulus situation that provoke special reactions, that are not in accordance with the measured (Gregory) or the linguistically described (Turvey) reality. The perceptual phenomena that the indirect approach describes as illusions are, as a matter of fact, considered as pragmatically useful also by the supporters of the ecological view.

This value cannot be bound to specific theoretical commitments, such as the indirect inferential vision of perception; in fact, the study of illusion is also suitable for showing the role played by movement in perception, which is one of the main tenets of the opponents of the indirect inferential approach (ecological approach and sensorimotor approach).

As it appears from different examples, such as the case of proprioceptive illusions induced by vibration and the case of Aristotle's illusion, illusions seem to present a heuristic value also for what regards the investigation of the role of coherence and movement in perception.

One of the consequences of the experiments conducted by Benedetti on Aristotle's illusion is in fact the observation that the unity of the tactile percept is achieved in the normal situation with uncrossed fingers, while it is not in the new configuration with crossed fingers. The configurations with uncrossed or crossed fingers include motor and perceptual components which are intertwined. In fact, the extension of the perceptual efficiency to the position with crossed fingers which follows a suitable training is accompanied by a corresponding extension of the motor ability of reaching a target with crossed fingers. A skilled perceiver with uncrossed fingers becomes an unskilled perceiver with crossed fingers because he lacks the proper skills.

The information gathered from two different fingers is combined when a corresponding motor skill is acquired. The acquisition of motor skills thus seems to play a role in the integration of partial percepts into one coherent unit instead of splitting them into two separate units.

Moreover, it seems that motor competences and habits have a direct influence on the shaping of the perceptual content and on the occurrence and appearance of certain illusions (such as the ones described by Viviani and Aristotle's illusion), with no necessity for representational intermediaries. This does not mean that representations of motor skills and possibilities do not exist, but only that it seems that the perceptual behavior can be explained with no recourse to them. Perception arises as a sort of 'reflex' that depends on the existence of specific expectations based on motor competences and motor habits.

Motor competences and habits constitute an implicit form of knowledge and give rise to implicit expectations, both in the sense that this knowledge and expectations are not necessarily linguistically expressed and in the strongest sense that they are not symbolic and representational. Implicit knowledge and expectations bias perception in a direct way, by disposing the subject to (perceptually) react in a certain way in the presence of certain stimuli.

In virtue of the arguments treated in *Chapter 2* and *Chapter 3*, it seems to be pragmatically useful and even theoretically advisable to preserve the notion of illusions without being committed to a general theory of perception such as those put forward in the direct and indirect approaches. *Chapter 4* will thus deal with the investigation of the role that illusions might possibly play in the cognitive functioning.

Table 3. Heuristic values of the notion of illusion

Qualities of the notion of illusion that make it suitable for the study of perception	***General value of the notion of illusion for the study of perception and cognition***	***Specific value of the notion of illusion for the study of perception***	***Specific value of the notion of illusion for the study of the role of movement and of motor competences in perception***
Misperception (analogy with the role of pathology)	Insight into perceptual and cognitive mechanisms	Study of the role of internal representations and cognitive inferences in perception [Gregory, 1997]	Study of the role of motor knowledge in perception (example of Viviani's illusions) [Viviani, 1997]
Systematicity: illusions can be reproduced at will	Role of coherence	Study of the mechanisms of intersensoy integration, and intersensory effects and reaction of the perceptual system to discrepant stimuli [Welch & Warren, 1981]	Study of the role of motor possibilities and skills in perception (example of Aristotle's illusion) [Benedetti, 1991]
Robustness: illusions are not influenced by the past experiences and knowledge of the subjects	Role of expectations	Insight into the qualities of the environment perceptual systems are sensitive to (example of the SWI) [Turvey, 1996]	
Surprise reaction: Illusions present behavioral consequences that can be observed	Role of movement	Study of perception as an active process [Berthoz, 2002]	

Chapter 4. The functional role of illusions: epistemological and adaptive value of the awareness of illusions

The study of illusions seems to provide indications about some important characteristics of perceptual experience, and particularly about the role of motor knowledge and motor skills in the construction of a coherent unitary percept (as we have seen in the case of Aristotle's illusion) and in the shaping of perceptual content (as we have seen in the case of the illusions described by Viviani).

The study of illusion also suggests that the subject of an illusion has the possibility of gaining an immediate insight on the possibility of being wrong. This insight is related to the recognition of the presence of a violation of coherence and constitutes the epistemological value of the awareness of illusions. Illusions we are immediately aware of, in particular, provide the subject with an immediate insight into the possibility of his experience of being wrong.

The alerting feature of illusions to the possibility of being wrong seems to present an adaptive value too for the subject of perception.

Different studies, both phenomenological studies on intersensory conflicts and neurophysiological studies on multisensory integration, suggest that violations of coherence (as the ones related to illusions we are immediately aware of) present a negative adaptive value. Coherence and the recognition of violations of coherence could, on the contrary, have a positive adaptive value for the subject.

Some authors in fact underline the importance of the coherence of the perceptual experience for the action and the adaptation of the organism with regard to the environment. Coherence is asserted to have a positive adaptive value, while violations of coherence have disruptive effects on adaptive behaviors.

The rarity of the experience of explicit conflicts in presence of discrepant information and the existence of solutions to the presence of discrepancies that restore coherence seem to confirm the idea that coherence has an important adaptive value, especially for the correct programming of action, and that violations of coherence have a negative adaptive value.

In fact, the existence of discrepant information does not necessarily give rise to illusions or even to reactions of surprise, and thus does not generate the awareness that something is wrong in the perceptual experience.

The issue of an explicit violation of coherence, both at the diachronic and at the synchronic level, seems to be only one of the possible options for the perceptual system when confronted with a discrepancy.For instance, as it is shown by some experiments conducted on intersensory discrepancies and on the violation of perceptual expectations, the incoming information can be suitably modified. As a consequence no explicit conflict is experienced and coherence of the perceptual experience is maintained.

4.1 Possible outcomes of discrepancies at the diachronic and at the synchronic level

The occurrence of illusions and the awareness that something is wrong with the perceptual experience is not the only possible result of the presence of discrepancies within the incoming perceptual information or between past experience and knowledge on one side and incoming perceptual information on the other.

Two cases are illustrated in order to show the possible solutions that the perceptual system can adopt when faced with synchronic and diachronic discrepancies: an experiment conducted by Jerome Bruner on the effects of the violation of expectations and a review of the psychological studies on intersensory discrepancies, intersensory effects and intersensory conflicts. In both cases the emergence of an explicit conflict or the immediate recognition of a violation of coherence comes out as one among other possible perceptual outcomes in which the subject does not experience a violation of coherence.

In the case of discrepancies in the stimulus situation, the perceptual system has in fact the possibility of choosing between different, mutually exclusive reactions:

- combining the stimuli in one and the same percept;
- or constituting two distinct percepts.

Only the first case of combination of the discrepant stimuli can give rise to a conflict, explicit (perceived as such) or implicit (not experienced as a conflict because of the modification of the incoming information). Implicit conflicts are experienced as coherent units.

When presented with discrepant stimuli (i.e. when two discrepant stimuli are presented to two sensory modalities), the creation of an incoherent percept is not a necessary outcome for the perceptual system. As we can also derive from the experiment conducted by [Bruner & Postman, 1949], in fact, the perceptual experience can be suitably modified in order to maintain coherence, and thus to avoid surprise.

If we generalize these considerations to the case of illusions, we then assume that, in case of discrepancy between past and present experiences or between present experiences, surprise as reaction is not necessarily present, but it depends on the type of solution the system has been able to adopt towards ambiguity or inconsistency with past experiences. In other cases, there could be no modification or the modification may be ineffective, and the system would be exposed to lack of coherence and experience surprise.

4.1.1 The possible outcomes of the discrepancy between expectations and actual perceptual experience

An experiment performed by [Bruner & Postman, 1949] provides an example of violation of diachronic coherence and illustrates that surprise and the sense of wrongness is only one possible reaction to the existence of a discrepancy between the content of past and present experiences. In particular the authors defend the hypothesis that

> "given a stimulus input of certain characteristics, directive processes in the organism operate to organize the perceptual field in such a way as to maximize percepts relevant to current needs and expectations and to minimize percepts inimical to such needs and expectations". [Bruner & Postman, 1949, p. 207]

Confirmation of expectations has a central role in this view, since when well-established expectations fail being confirmed the organism may envision perceptual reorganization. The violations of perceptual expectations consist in

> "an unexpected concatenation of events, a conspicuous mismatching, an unlikely pairing of cause and effect" [Bruner & Postman, 1949, p. 208]

They pose a problem to the organism. In Bruner and Postman's view in fact the organism can perceive the incongruity (be aware of the contradiction), but, as long as possible,

> "the organism will ward off the perception of the unexpected" [Bruner & Postman, 1949, p. 208].

An experiment shows different options for the violation of expectations

In the experiment described by [Bruner & Postman, 1949] the subjects are rapidly exposed to normal playing cards (five of hearts, ace of hearts, five of spades, seven of spades) and trick playing cards (i.e. black three of hearts or red two of spades, which are incongruous with ordinary cards), and are asked to name them. The results indicate that the recognition threshold for the incongruous playing cards is significantly higher than the one for normal cards; four reactions to incongruity are described.

Dominance and compromise reactions are characterized by a perceptual denial of the incongruous elements in the stimulus pattern; in the first case either form or colour dominates and the subject reports perceiving a normal card, i.e. a normal, red three of hearts instead of a black one, or a black three of spades. The perceptual result then meets the expectations about normal playing cards. In the second case a compromise object is perceived which constitutes the conflict, i.e., a greyish three of hearts.

The perception of incongruity can also produce disruption, in that the subject cannot solve the recognition task. This failure in perceptual recognition provokes an inhibition of action, since it diminishes the efficiency of the organism. It seems to be infrequent.

Finally the incongruity can be recognized. In this case, the recognition of the incongruity is accompanied by a *sense of wrongness*: the subject suddenly or gradually begins to feel that there is something wrong with the stimulus; this sensation can turn to disruption or give rise to recognition of the incongruity. The subjects of the experiment then manifest a resistance to incongruity between the actual stimulus and their own expectations. When the incongruity is not suitably modified the subject has the sensation that something is wrong since he is faced with an ambiguity that he can accept (recognition) or not accept (disruption). In the case of disruption the violation of the coherence turns out to be paralyzing: ambiguity is a hard condition to be managed by action and perception.

Diachronic coherence can be considered as a value for the perceptual system

[Bruner & Postman, 1949] describe coherence between past and present experiences as a value that the perceptual system attempts to maintain: when the actual information is in disaccord with the expectations based on past experience, the incoming information may incur in alterations.

This does not mean that perception is ‘wishful’ or subjective, only that the perceptual outcome is a construct which is determined by factors additional to the stimulus situation.

These factors include the relevance for the exigencies and tasks that the subject of perception has to achieve. The directive factors that contribute to the shaping of the perceptual outcome are thus operating in the interest of the actions of the perceiver.

In this vein, the directive factors that modify the incoming information gathered with trick playing cards operate with the aim of maintaining the coherence of the perceptual experience.

In the case of the experiment performed with trick playing cards, the presentation of stimuli that are incongruous with past experience mainly results in the perceptual denial of the incongruous elements in the stimulus pattern, so that the perceptual result conforms to the expectations about normal playing cards (27 of the 28 subjects of the experiment showed dominance responses).

The authors seem to suggest that incongruous perceptions are discarded because of their disruptive power over the (motor or cognitive) performances of the organism. Bruner's experiment exemplifies the definition of perceptual coherence as accord of present and past experiences and the definition of violation of coherence as unfulfilled expectations.

4.1.2 The possible outcomes of the discrepancy between intersensory stimulations

As we have seen, the experience of perceptual paradoxes and proprioceptive illusions of impossible movement is immediately detected as wrong and surprise arises as a direct reaction. There is no need to compare the actual experience with previous knowledge for coherence to be violated because the inconsistency stands between two synchronic states. When proprioceptive illusions provoked by vibration are interpreted in the light of the role of muscle receptors in the perception of position and movement, information provided by muscle receptors and information provided by joint receptors is discrepant, because vibrated muscle receptors signal movement, while joint receptors signal the absence of movement. In response to discrepant information, a conflict may be experienced.

The study of the reactions to discrepant intersensory information indicates that the experience of a conflict is not the only possible issue at stake.

Discrepancies between sensory modalities may produce intersensory conflicts

Consider a subject looking at an illusory figure such as the spirals designed by Fraser, which are in fact concentric circles; if the figure was reproduced in a 3D form, the subject could discover by touch the 'real' shape of the lines he is following by his hand and eyes (unless there is, as in the case of many a geometric illusion, a haptic version of the same illusion). In this case he could be aware of the existence of a discrepancy between the information delivered by the two sensory modalities involved in the exploration. We can suppose that he would also describe his situation as that of someone who is victim of an illusion, even if we cannot predict which one of the two sensations he would trust.

This experiment has not been conducted, but the situation has been interestingly explored by the literature dedicated to intersensory discrepancies, intersensory effects and intersensory conflicts[44].

The notion of intersensory conflict

Before analyzing the literature on intersensory discrepancies, effects and conflicts it is important to introduce some terminological and conceptual distinction and specifically to provide a definition of the notion of perceptual conflict.

First, it is possible to speak of perceptual conflict only in relation to perceived properties: we cannot claim the existence of a conflict from the simple existence of discrepant stimuli, since they do not necessarily constitute a perceptual unit. An experimenter who presents a subject with discrepant information is not necessarily presenting conflicting information, until the subject combines the discrepant element into a unitary percept. It is trivial that, for instance, there is no contradiction in perceiving something red and something blue until red and blue qualities are attributed to different objects or to the same object at different moments.

Second, for a conflict to be possible, the perceptual system must operate on separate unisensory information before the final, multisensory percept is produced. In other words, in order to speak of perceptual conflict it seems to be necessary to be able to identify separate elements in perception that are then combined into a common unit or set.

---

[44] Studies on intersensory conflicts are also useful in order to understand how different sensory properties are bound together in one perceptual unit.

It is not a simple matter, since in normal perception the properties coalesce in such a way that it is difficult to disentangle them or to observe them combining. But in the case of intersensory conflicts the disentanglement is constitutive, when two or more discrepant experiences are proposed to the subjects.

This statement is not compatible with theories of perception that deny the existence of distinctions between sensory modalities, but it is not necessarily committed to a classical definition of the senses.

The problem of the separate extraction of unisensory partial percepts

A classic debate on the distinction between sensory modalities and their further integration in a multisensory, final perceptual outcome is related to the so-called 'binding-problem'. As for intersensory conflicts, the problem of how different perceived features (eventually intersensory features) are bound in a unitary percept only arises when it is supposed that the different features (the intersensory information) are separately extracted so that they have to be combined successively. Evidence for the existence of a binding problem is constituted by the existence of illusory conjunctions. Illusory conjunctions are erroneous combinations of perceived features, as it happens when, in presence of items of different colours, the subject incorrectly associates a colour with the wrong item [Treisman & Schmidt, 1982]. It is suggested that attention plays a crucial role in the binding of different features and that the distraction of attention might cause illusory conjunctions [Treisman, 1996]. Categorization of the items seems to play an important role too [Esterman, Prinzmetal & Robertson, 2004]. It is also suggested that the existence of illusory conjunctions supports a Feature Integration Theory, which affirms that in vision features are separately extracted and successively integrated [Treisman & Schmidt, 1982].

Some authors deny that the binding of different features constitutes a problem for the perceptual system because a global, multisensory array is directly perceived [Stoffregen & Bardy, 2001]. Within this approach the sensory modalities are hardly differentiated.

[O’Regan & Noë, 2001] also contest the necessity of internal mechanisms for the solution of the binding problem. The sensorimotor approach to perception [O'Regan & Noë, 2001] affirms in fact that there is no need for the perceptual system to construct a complete internal representation to produce the experience of a unitary perception: the unity of, say, a multisensory experience is warranted by the simultaneity of exploratory actions with multiple sensory modalities. Within this approach each sensory modality is defined by a specific set of laws connecting current/possible behaviors and their sensory consequences, that is, by a specific set of sensorimotor contingencies.

Even if the different sensory modalities are not identified on the basic of the characters that are indicated by the classic classifications of the senses, the existence of different sets of sensorimotor contingencies allows distinguishing between different sensory modalities. Thus, even if the authors of the sensorimotor approach deny the necessity of constructing internal representations of the unitary percept, the door is open for the possibility of conflicts. Sensorimotor contingencies of the experience of red for instance would not be compatible with sensorimotor contingencies of the blue-experience. Their co-presence would then constitute a conflict. The same can be true of multisensory experiences: the experience of the subject who looks at the Fraser’s spirals while touching their three-dimensional equivalent might be unitary in virtue of the fact that the two motor explorations are conducted at the same moment; it is in virtue of this experiential unity that the haptic sensorimotor contingencies and the visual sensorimotor contingencies that are extracted in this particular situation might give rise to a sensation of wrongness in the subject and to the perception of an intersensory conflict.

Box 16. The binding problem

Understanding how several properties from different sensory modalities are bound in order to form the percept of a multimodal object is one of the aspects of the research on the so-called 'binding problem' (see [Roskies, 1999] for a review of the problem).

[Treisman, 1996] describes the case of erroneous associations of features (illusory conjunctions) and then presents the correct binding of properties as a problem for the perceptual system.
Among the solutions suggested for the binding problem neurophysiology has identified mechanisms related to the temporal synchrony of the perceived features [Crick, 1990], the existence of neurons that receive information from multiple sensory modalities and the presence of parallel processing of stimuli from different sensory modalities at the level of the superior colliculus [Stein & Meredith, 1993].

Other approaches to the problem of multisensory perception deny the necessity of such mechanisms in order to explain the experience of a multisensory percept.

[Stoffregen & Bardy, 2001] suggests the existence of a global array that includes different environmental properties that are directly perceived as combined.

[O'Regan & Noë, 2001] affirm that the binding problem is a pseudo-problem because the unity of the sensorimotor experience is a sufficient condition for explaining the sensation of unity: a unitary internal representation is not needed, so special mechanisms for constructing such a unity are not needed.

Following the sensorimotor approach to perception proposed by [O'Regan & Noë, 2001], the experience of a coherent, unitary percept depends upon the movements that are accomplished or can be accomplished during the exploratory activity. The object is experienced as unitary and coherent because it is sensed in the course of a unitary exploratory activity.

Thus, perceivers do not experience the objects as unitary because of some inner mechanism that would actually unify (bind) and adjust the incoming information. In fact, the experience of a unitary perceived object does not entail the existence of unitary representations of the object.

The experience in each sensory modality can be identified on the basis of specific sensorimotor contingencies.

> "A first law distinguishing visual percepts from perception in other modalities is the fact that when the eyes rotate, the sensory stimulation on the retina shifts and distorts in a very particular way, determined by the size of the eye movement, the spherical shape of the retina, and the nature of the ocular optics. In particular, as the eye moves, contours shift and the curvature of lines changes." [O'Regan & Noë, 2001, p. 941]

But turning one's head does not change anything to the haptic appreciation of the object grasped with the hands. Thus, the experienced different quality of the sensory modalities can be ascribed to differences in the rules of sensorimotor contingencies, too.

Box 17. The classification of sensory modalities

Common sense distinguishes between five classic sensory modalities. This classification is supported by some traditional criteria for distinguishing between the senses [Casati & Dokic, 1994]:

1. the kind of property which is represented in a privileged way (for instance, vision is the modality through which we have a privileged access to colours and shapes)
2. the characteristics of the subjective experience (the qualia which is associated with touching an object instead of seeing it)
3. the medium of perception (for instance, the sound waves for audition)
4. the kind of sensory organ (for instance the tactile receptors and the central projections of their activity)

None of these criteria, taken in isolation from others, is sufficient for identifying a sensory modality [Grice, 1962].

The sense of touch is a striking example of the difficulties encountered by a classification of the sensory modalities, because of the complexity of the components that are commonly indicated as 'touch': kinaesthesia, perception of object's micro-properties such as texture, perception of object's macro-properties such as shape, perception of vibration, perception of pain, perception of temperature. Moreover, the sense of touch includes different types of sensory organs. Sensory organs as the receptors within the muscles both serve kinesthesia and the perception of the macro-properties of objects, as shown by the studies on dynamic touch. Also, the sense o touch is sensitive to different media, suc as mechanical stimulation, heath and chemical stimulation.

It is possible to combine two or more criteria, or to abandon the 5 senses in favour of a different choice of the individuating criteria, which do not necessarily collimates with the 5 senses classification, as: the type of representation which is generated (it is possible to see an object which is in front of us but not behind) [Nelkin, 1990]; or sensorimotor contingencies (the laws that connect possible actions with consequent perceptual experiences), which express the necessary connection of perception and action [O'Regan & Noë, 2001].

Different possible reactions to discrepancies

The conditions for experiencing a *conflict* have been established: a conflict is the result of the combination of contents that are separately perceived as discrepant and that are nevertheless combined in one and the same unity. The conditions for having a conflict are thus not identical to the presence of discrepancy in the stimulus situation.

Another distinction must be introduced between the situation in which the conflict is explicitly perceived and the situation in which the conflict is not experienced as such.

An *explicit conflict* is a conflict which is experienced as such. As in the case of the perception of proprioceptive illusions of impossible movement or in the case of the experience of paradoxes, the experience of an explicit conflict should arouse a reaction of surprise and is immediately recognized as wrong, bizarre or impossible.

The conflict can be *implicit* if the incoming, discrepant information is combined in a single unit but the information is suitably modified and the final, multisensory percept is not experienced as a conflict but as a coherent unit. In this case, the subject experiences a coherent percept even in presence of discrepant information combined in the unitary final percept (eventually, the perceptual system could maintain the conflict at a sub-personal level).

The characteristics of the final percept depend on the kind of modification the contents of the incoming information have undergone. As a first possibility, one of the stimuli might dominate over the others and thus by itself determine the features of the final percept. As a second possibility, all the incoming stimuli might contribute to the character of the final percept, by mutually influencing each other in various degrees.

Both in the case of explicit and implicit conflicts, the discrepant stimuli are combined in a single unit. The possibility exists that this combination does not occur. The discrepant stimuli are maintained separately and no conflict, neither explicit nor implicit, subsists. This is what normally happens when multiple features are perceived but only some of them are combined in the perception of one object, while others are attributed to other objects. The conditions for combining or not combining two stimuli in one and the same unit are investigated in the studies of the binding problem and ini the studies of the reactions of the perceptual system to discrepancies.

A detailed discussion follows in relation to specific examples of each of the described possibilities from the psychological literature on intersensory influences, discrepancies and conflicts.

The discrepant contents are attributed to different final percepts

As we have seen, a conflict exists only when the discrepant information is conveyed in one and the same final percept, but this is not always the case.

In a classic investigation of a visual-proprioceptive discrepancy [Hay, Pick & Ikeda, 1965] have shown that a stationary hand viewed through a 14° displacing prism feels as if it is located very near its seen location (bias of visual over proprioceptive information). If the displacement is bigger, the visual and the proprioceptive locations are not merged and the perceptual result of the discrepancy consists in two separated unisensory percepts. In this case there is no conflict: the partial percepts are distributed in different units.

When the discrepancy is large, the perceptual system could thus treat the two stimuli as not relating to one and the same unit, but to two distinct objects.

Conflict is explicitly experienced

When the final percept explicitly contains two discrepant contents the subject experiences an explicit perceptual conflict.

This doesn't seem to be a common situation. But it is an interesting possibility since the perceptual system can immediately detect the presence of an explicit conflict. Such could be the case of the subject of the proprioceptive illusion of position previously described, who reported his arm feeling as if it were "*in two places at once*". In this case, information from the joints and information from the muscles would be merged by the perceptual system into one unity without undergoing modification. This situation provokes a reaction of surprise, and is described as impossible by the subject. The impossibility is, in this case, related not to some form of prior knowledge but to the intrinsic ambiguity of the final percept. Something must be wrong, even if the subject, lacking knowledge sufficient to endorse the two possibilities, cannot say where things went wrong. The subject knows that the percept must be wrong because an object cannot be ambiguously placed or characterized.

Conflict is not explicitly experienced

When two discrepant contents are suitably modified they enter the final unit without giving rise to an explicit conflict. The conflict is solved in favour of a non-ambiguous unity. This solution seems to be more frequent than the experience of explicit conflicts, since many descriptions exist in the psychological literature. Hence, it seems that the perceptual system has a propensity in composing its experiences in a coherent form, avoiding the possibility that one perceived object can be at the same time, for instance, big for touch and small for vision.

As for the solutions the perceptual system can employ when faced with discrepancies, [Rock & Victor, 1964] have established that the final percept is dominated by the visual appearance. The observers are at the same time touching a square object and looking at it through the interposition of minifying lenses that reduce its visual dimensions (the subjects are unaware of this modification, and they assume they are looking at and touching one and the same object). We know that the perceptual system appreciates the difference of the two partial percepts, since the judgments given in the purely visual and in the purely tactile situations are different. The dominance paradigm proposed by [Rock & Victor, 1964] seems to be confirmed by this experiment: the multisensory percept corresponds to the visual one; the tactile percept is ignored. This is what happens for example in other well-known illusions such as the ventriloquist effect, where the voice of the puppet master is perceived as coming from the puppet's mouth: vision seems to totally bias audition.

[Ramachandran & Hirstein, 1998]; [Ramachandran, 2002]; [Ramachandran & Rogers-Ramachandran, 1996] describe a simple device, the '*virtual reality box*', as being effective in reducing the painful palsy of the phantom limb, by visually inducing an illusory sensation of movement and position.

The device is composed of a box with two holes in the frontal part of it and a mirror inserted in the middle. The patient who suffers from phantom palsy (which provokes pain) of his phantom hand (a quite common phenomenon in subjects who have been amputated after experiencing a palsy of the affected arm) inserts his hands in the holes. Naturally he really inserts just the normal hand, but, since he can feel his phantom hand's position and movement, he has the feeling of having inserted the phantom limb too. The mirror allows the patient to visualize the phantom hand that he can only feel: it is the reflection of his normal hand. The patient is asked to open his real hand and move it, and at the same time to 'try' to open his phantom hand. In this way he provokes the vision of the phantom hand as moving normally and opening against the palsy.

Other cases of visual influence over proprioception are described in normal subjects.

[Gibson, 1933] describes the following illusion: a subject moves his hand along a straight surface while looking through a prism that causes the surface to look curved; he feels it to be curved as well.

[Nielsen, 1963] introduces the use of the mirror. The subjects follow a straight line with their hand in full sight; on some of the trials, a mirror is introduced, unbeknownst to the subjects, so that they see another person's hand (that they believe to be their own): the subjects continue to have the sensation that the seen hand is their own, but they also feel as if they had lost control over its movement.

In all these cases discrepant visual and proprioceptive information does not produce an experience of conflict, but a vivid proprioceptive experience.

The experience may appear bizarre to the subject who undergoes it, as in the experiment described by Nielsen, when the visual and proprioceptive perception is compared with other synchronous experiences (such as proprioceptive information of another kind) and an explicit conflict arises.

Inter-modality influence and multiple contributions to the final percept

The classical study presented in [Rock & Victor, 1964] has been reconstructed by [Heller, *et al*., 1999].

According to [Heller, *et al*., 1999] the perceptual system seems to be able to find other solutions than to simply ignore one of the two discrepant modalities. The solution the perceptual system finds appears to depend on the context of the experiment.

When the judgment requested of the subjects is framed in terms of a precise measure (by indicating a visual measure on a ruler or by showing the measure by shaping a pinch with the fingers), there is dominance of a sensory modality over the other. In the case of the ruler vision dominates, but in the case of the pinch touch dominates over vision. On the other hand, when the subjects are asked to match the perceived extension with one object from a group of haptic or visual standards, the judgments seem to take into account both vision and touch in an equal manner (with no difference between the visual matching and the haptic matching).

Similar results have been obtained in other situations: for instance, (discrepant) visual and tactile stimuli seem to equally participate in the perception of a textured surface.

[Lederman & Abbott, 1981] have presented the subjects of their experiments with two different abrasive surfaces, one to be examined by vision and the other by touch; the subjects were lead to believe that they were exploring one and the same surface (the experimenters induced an assumption of unity). When asked to match the perceived surface with one from a set of surfaces, the subjects tended to choose a textured surface that didn't correspond either to the purely visual or to the purely haptic control situation; the results showed that, in the discrepant condition, the perceptual system assigns the same weight to the visual and to the tactile information about texture. In the case of the micro-structure of an object as well in the case of its macro-structure, the relative bias depends on the context of the perceptual task.

Nevertheless, even if both modalities contribute to the perceptual result, some differences in the respective influence may appear [Lederman & Abbott, 1981]. For instance, touch is more influential when the subject is requested to evaluate the roughness of a surface, while vision is more influential when the subject is requested to evaluate the spatial distribution of the dots for the same surface [Lederman, Thorne & Jones, 1986].

[Lederman, Thorne & Jones, 1986] have thus shown that the kind of solution adopted varies with the verbal instruction assigned to the subjects. In the situation in which the subjects are asked to evaluate the roughness of a raised dots surface, the tactile information seems to dominate the visual information in a proportion of about 70%, and the visual information to dominate the tactile one in a proportion of about 30% (this is a measure of the relative weight of the haptic and the visual information in the final percept, obtained by comparing the discrepant situation with purely visual and purely haptic situations). When the subjects are asked to evaluate the spatial distribution of the raised dots, the perceptual result changes in such a way that vision dominates touch by about 70% and touch biases vision by about 30%. It seems then that the cognitive knowledge implied by the verbal instruction is relevant for the features of the final percept. Anyway, it seems that in a general manner both visual and haptic cues contribute to the aspect of the final, multisensory perceptual unity, even when the partial percepts are discrepant.

The difference between the two judgments about the same surface is explained in terms of a different salience between material and spatial properties of the objects for touch. Even if touch and vision are equally accurate in the perception of textured surfaces, even if bimodal perception seems to be superior, perhaps in reason of the better motor control of hand movements gained with vision ([Heller, 1982]), touch is associated with a greater salience for material properties rather than spatial characteristics of objects [Klatzky & Lederman, 1987]. Thus information extracted by touch would dominate in case of discrepancies over vision for material judgments.

The appearance of the final percept in case of discrepant information

[Welch & Warren, 1981] describe many different conditions that are susceptible to influence the perceptual outcome, in addition to the stimulus variables, such as the characteristics of the modalities involved, the allocation of attention and historical factors.

Past experience with the event being perceived and general experience with modalities involved might in fact affect the observers' assumption of unity (if the stimuli are to be considered as coming from one and the same source or from two individual objects) and thus the perceptual outcome; the result of a strong assumption of unity is a perceptual outcome consonant with a single physical event.

The assumption of unity can be influenced by the experimenter's instructions, and other cognitive hypotheses and considerations.

[Welch & Warren, 1981] propose a model of modality precision or modality appropriateness in order to explain the appearance of the multisensory percept once the unity is established, both for discrepant and non-discrepant information. For discrepant information relative to an object quality, the more appropriate modality for that quality (or the more precise) dominates.

This proposal can be made precise by referring to a model called the '*Maximum Likelihood Estimation Model'*.

In a certain view of perception it is assumed that the final goal of perceptual judgments is to gain the more reliable estimate (taking into account the fact that all sensory signals, thus all sensory estimates, are noisy), thus to reduce as much as possible the variance of the final estimate [Ernst & Buelthoff, 2004].

The estimate with the lowest variance is the *Maximum Likelihood Estimation*, where the integrated estimate is the weighted sum of the individual estimates with weights that are proportional to their inverse variances. It is shown by [Ernst & Banks, 2002]; [Ellis, Flanagan & Lederman, 1999]; [Ernst, Banks & Buelthoff, 1999a, 1999b] that weighting changes with the reliability of the signals: in the case of visual and haptic discrimination of the size of an object, when noise is added to the visual stimulus, the weight changes from visual dominance (when there was no noise added to the visual stimulus) to haptic dominance.

The reaction of surprise in presence of an explicit violation of coherence

We have seen that, in the presence of illusions, surprise arises as a reaction to the awareness of a violation of coherence. In particular, in the case of illusions we are immediately aware of, the subject is directly aware of something going wrong with his experience, that coherence is violated at the synchronic or at the diachronic level. Surprise arises directly because of the recognition of the violation of coherence or because of the violation of a more or less general expectation, such as an expectation of coherence.

Explicit violations of coherence, both diachronic and synchronic, are not necessary issues of the presence of a discrepancy. In many cases, coherence is warranted also when the information is discrepant.

In fact, the seminal experiment conducted by [Bruner & Postman, 1949] and the different studies on intersensory discrepancies, effects and conflicts indicate that, in case of discrepancy between past and present experiences or between present experiences, surprise as reaction is not necessarily present, but it depends on the type of solution the system has been able to adopt towards ambiguity or inconsistency with past experiences.

In the case in which the violation of coherence is explicitly experienced, such as in the case of explicit conflicts and illusions we are immediately aware of, the discrepancy has not been solved in favour of a coherent solution.

In analogy with the case of intersensory discrepancies, it can be suggested that, in general, we are immediately aware of the illusions for which no solution has been found by the perceptual system, while illusions we are not immediately aware of are related to a violation of coherence which is temporarily solved. Only the discrepancies for which there is no solution become aware. When, for instance in the case of the SWI, the subject enterprises a second round of exploration of the hand-held objects, or when he is informed by the experimenter about the measured weight of the objects, the subject is faced with a discrepancy which cannot be ignored: he becomes aware of the existence of a violation of coherence. It is the cognitive system of the subject, with the intervention of a cognitive judgment of high level, that successively chooses to trust one of the sources of information over the other.

[Bruner & Postman, 1949] suggest that the existence of different solutions to the presence of a discrepancy that have the effect of maintaining coherence is related to the positive value of coherence for action and perception.

As a matter of fact, our experience is normally coherent. If not, incoherent or ambiguous experiences would not strike us as surprising. Surprise arises only for uncommon experiences.

4.2 The adaptive and epistemic value of coherence in perception

As we have seen, explicit conflicts (the violations of synchronic coherence) are rarely perceived as such, and the discrepancies of the stimuli are mostly solved into coherent final percepts that do not adhere to the stimulus conditions. The modifications discrepant elements run into when combined in a final non-conflicting percept have the effect of maintaining the coherence of the perceptual experience in spite of some discrepancies in the incoming information. The perceptual outcome is erroneous, in the sense that it is not adequate to any of the incoming stimuli. Also in the case of discrepancy between expectations based upon past experiences and actual perception (violation of diachronic coherence) the incoming information is in some cases modified in order to better fit with the expected stimulus so as not to incur perceptual reorganization.

Previous knowledge and assumptions that produce expectations about the perceptual outcome might be differently weighted. For instance, in the case of the golf-ball illusion, the fact of developing a specialized competence about golf-balls and the absolute rarity of counter-experiences about the weight of golf-balls for training and for play might substantially weight past experience and undermine the actual experience of perceived weight. In other cases, such as in the evaluation of the heaviness of familiar objects, past experience might be weighted less in reason of the variety of the experiences and objects, thus there is greater chance of misjudgement.

Anyway, when perception is a guide for action, ambiguities and inconsistencies in perception necessarily misguide action in such a way that action based upon perception is not simply unsuitable for interacting with a certain object or inadequate to the state of the world. A difficulty arises in the programming of action and in the choice of the action to be performed. Thus, a difficulty arises before action is performed.

Violations of coherence, both at the synchronic and at the diachronic level, seem then to have a negative adaptive value. In the case of multisensory perception, for instance, neurophysiological studies show that the integration of information from different sources presents a positive effect on the neural activation even for low stimulations; when information is inconsistent, on the contrary, the effect is disrupting upon action: the action is either inhibited or directed toward a wrong target. Some mechanisms are also individuated that prevent inconsistency between sensory modalities.

The issue of the adaptive value of coherence raises two questions relative to the adaptive value of truth and to the epistemological value of coherence. The reestablishment of the coherence of the perceptual experience is not necessarily coincident with the reestablishment of truth, in the sense that the content of perception corresponds to the stimulus situation. Also, violations of coherence, much more than coherence itself seem to play an epistemic role in perception, because they alert the subject to the possibility of error.

4.2.1 The perceptual system has a propensity to maintain coherence

It is plausible to hypothesize that the consequence of an explicit conflict or of a violation of coherence in general is the inhibition of action, a break in decision making because of the ambiguity of the sensory information available.

The subject prepares himself for action (at a personal or at a sub-personal level) in a way that is attuned with the perceptual characteristics of the object that is the target of the action. When the content of perception is ambiguous or when some of the qualities of the object are actually perceived as mutually inconsistent, then the indications or the action might be ambiguous too, as different experimental protocols might confirm.

Let us imagine the following experimental situation: a subject is riding a vehicle in a room and he wears a head mounted display through which he visualizes his movement. At a certain moment the display for the visualization begins to show a different pattern of movement which is not coherent with what the subject feels he is doing. We can expect that the subject will probably stop, inhibited, because he will be in a difficult situation. In the same way, an object which is simultaneously perceived as having different characteristics for vision and touch might produce disturbances in the motor plans for reaching and grasping it.

The idea that when perception is a guide for action, the experience of a perceptual conflict has a disrupting effect in the starting of the action, is demonstrated by certain studies conducted by [Stein & Meredith, 1993] on the *superior colliculus* of the cat and on the behavioural responses of the cat to multisensory discrepancy. It is shown that the behavioural result of perceptual conflict is not simply an error in action and perception relative to the external reality (an illusion): it is a paralysis of action.

Perceptual conflicts seem then to have a negative value for programming actions, since they inhibit our decisions and diminish our capacity to behave in the world.

The positive value of the coherence of the stimulus situation

[Stein & Meredith, 1993] affirm the positive value of multisensory integration for the good adaptation of the animal to the environment. The authors also point out the role played by coherence in multisensory integration and adaptive behaviours.

At a neurophysiological level, in fact, a stimulus that is not sufficiently salient for producing neural activity may become salient when combined with another stimulus from another modality if their combination produces the enhancement of the neural activity (other combinations may result in a depression of the neural activity). [Stein & Meredith, 1993] suggest that the facilitation of attentive and orientation responses for minimally effective stimuli is one of the primary adaptive advantages of multisensory enhancement.

According to [Stein & Meredith, 1993], multisensory integration in the *superior colliculus* of the cat depends on two concomitant factors: neural organization and presence of coherent stimuli. On the side of the stimulus situation, [Stein & Meredith, 1993] consider the coherence of the stimulus situation as a fundamental factor for multisensory integration and as consequence they consider the coherence of the stimulus situation as having a positive adaptive value. The coherence of the stimulus situation plays two roles in the multisensory integration.

First, the enhancement of the response in presence of multisensory stimulations seems to depend on the existence of a meaningful relationship between the stimuli that are combined. [Stein & Meredith, 1993] consider spatial and temporal coincidence to be of the utmost importance because it is suitable for signalling common causality. Stimuli that are discrepant for space location and/or time occurrence are unlikely to be related and are suitable to produce depression or no interaction rather than enhancement of the neural activity.

Second, the authors hypothesize that the alignment of the different sensory maps is driven by the repeated exposition to a coherent world, where stimuli that share spatial and temporal characteristics are likely to have common causality, thus to come from the same object. Experience plays a role in the alignment of the maps, both during phylogenetic and ontogenetic development, but the experience of the individual with specific cues is not considered as sufficient for changing the interaction of a combination of stimuli from enhancement to depression [Stein & Meredith, 1993]. Specifically, animals seem to have the capacity of developing aligned maps (visual and auditory for instance) in response to atypical experiences, as when an animal (an owl) is raised with one ear plugged. On the contrary, it seems that the alignment of the maps is precluded by an alteration of the cues the animal is exposed to in its early development such as the absence of visual stimuli or the exposition to omni-directional sound. [Stein & Meredith, 1993] conclude that

> "it is not the simple experience with cues from different sensory modalities that is essential for intersensory map alignment. Presumably, normal map alignment reflects experience with visual-auditory stimuli that are produced by the same event so that they are linked in space and time." [Stein & Meredith, 1993, p. 166]

The coherence of the stimuli then constitutes the main guide to the organization of the maps in the *superior colliculus* and to the sensory-sensory and sensory-motor integration which depend on the organization of the *superior colliculus*.

In the mean time, the experiments described by [Stein & Meredith, 1993] show that when the stimulus situation is not coherent negative effects are produced on the adaptive behaviours of the animal.

Discrepant stimuli produce disruptive consequences upon adaptive behaviour

Misalignments of sensory organs are all but uncommon in the daily experience of animal and human organisms. Movements of the eyes, for instance, produce the misalignment of the visual and the auditory and somatotopic maps. In fact, moving the eyes and thus the retinas produces a shift in the area of the *superior colliculus* which is activated by a stimulus fixed in space. A cat staring at a singing bird and suddenly turning its eyes toward a point in space next to the bird, but not to the bird itself, has its visual and auditory maps misaligned and risks to overlook slight stimuli from the bird. The cat could fail to catch the bird or hesitate too much.

[Stein & Meredith, 1993] describe a behavioural experiment where cats are exposed to discrepant stimuli. An analogy can be made between the responses of the experimental cats to spatially discrepant stimuli and the reactions of human beings to perceptual discrepancies in general (not only spatial ones). In particular, the two reactions described in the experiment with cats seem to fit with the cases of conflict, both experienced explicit conflict and solved conflict, that is, with the cases of combination of discrepant stimuli in one and the same unit. The experiment with cats thus confirms that different outcomes are possible when the perceptual system is faced with a discrepancy in the stimulus situation.

Cats are trained to orient and move toward a visual and/or an auditory stimulus to receive a reward. An enhancement of correct responses with combined stimuli is observed for stimuli of low intensity (visual stimuli of high intensity are already highly effective, thus the addition of auditory stimuli does not seem to produce enhancement). In another situation, the cats are trained to respond only to the visual stimulus (auditory stimuli not being rewarded); during the testing condition the auditory stimulus was simultaneous to the visual one, but it came from a different position (60° away from the visual one). The presence of a discrepant auditory stimulus makes the probability of correctly responding to the visual one decreasing: the cats fail to respond in an overt fashion or they move to a position which is halfway between the visual and the auditory stimuli (high-intensity visual stimuli are well responded).

The two reactions of the cat when presented with discrepant stimuli correspond to the experience of conflict and to the presence of a conflict which is not explicitly experienced but solved with the combination of the multisensory information. The results of the experiment also indicate that the experience of an explicit conflict in presence of spatially disparate stimuli presents a negative value for adaptive behaviour, at least for the orientation and the direction of attention. In fact, the cat fails to respond in an overt fashion: the explicit experience of a conflict provokes an inhibition of action. When the conflict is not explicitly experienced and the incoming information is suitably modified, the cat acts in a way that does not correspond to either of the stimuli. This outcome corresponds to the described solution to conflicts that consists in equally weighting the information from both modalities hence producing a midway final percept.

Some mechanisms are put in action that prevent violations of coherence

[Stein & Meredith, 1993] suggest that the animal actively operates in order to avoid intersensory conflicts and that the motor system plays a specific role in the coherence of the perceptual outcome. The violation of coherence at the level of intersensory percepts has in fact a negative value on adaptive behaviour.

As we have seen during the discussion on intersensory conflicts, one possible strategy that has the effect of avoiding conflict in presence of discrepant stimuli is represented by the functional decoupling of conflicting sensory inputs: in this way the inconsistent contents are attributed to different perceptual outcomes and do not interfere with each other. The possibility of reacting to misalignment by functionally decoupling the incoming stimuli resembles the case of the constitution of two separate units in response to discrepant information.

Other strategies for preventing the violation of coherence are described that involve the active orientation of the sensory organs, thus the motor system of the animal [Stein & Meredith, 1993]. In situations of focused attention, for instance, the animal has a tendency to precisely coordinate and align movements of the sensory organs, thus to maintain the sensory organs and their corresponding maps aligned. The active alignment of the sensory organs produced by suitable movements prevents the occurrence of discrepancies in normal situations. Also, the movement of one sensory organ in the direction of a target stimulus has the effect of misaligning the different sensory maps.

Compensatory shifts in the other sensory maps when one sensory organ is moved are described that favor the alignment of the maps. In particular, it has been shown in the observation of primates that when the rhesus monkey moves its eyes while keeping the head and ears in their original position, a compensatory mechanism alters the effective site of the auditory stimulus that activates a *superior colliculus* neuron. In other words, the auditory receptive field of the monkey shifts with changes in the eye position.

Box 18. Neurophysiological conditions of multisensory integration

A multiplicity of sensory modalities is represented within the *superior colliculus*, since it contains projections from the visual, the auditory and the somatosensory systems. The *superior colliculus* also hosts efferent projections that are part of pre-motor circuitries (involved, for instance, in the activation of eye movements).

At a behavioural level the *superior colliculus* is recognized to perform a role in the direction of attention and in the orientation of the animal, in particular, the *superior colliculus* is involved in the orientation of the sensory organs of the head toward the source of visual and auditory stimuli. The primary role of the *superior colliculus* seems in fact to be the translation of sensory stimuli into motor commands producing the appropriate orientation of the periphery sensory organs of the animal.

The sensory neurons are organized in a map-like fashion (visuotopic, somatotopic and auditory maps) and the three different maps are aligned one with the others. The visual neurons that are located rostrally in the *superior colliculus* are activated by stimulation in the visual space which is in from of the animal, while the stimulation that arrive from the back of the animal are represented caudally in the *superior colliculus*. Hence, the representation of the horizontal meridian of the visual space is oriented from the front to the rear of the *superior colliculus*. In the same way, the representation of the vertical meridian is oriented along the medial to the lateral part of the structure. The same orientations are respected for the somatotopic map (and analogies with the auditory map can be traced, in the limits of the specificity of aural processing).
[Stein & Meredith, 1993] attribute the efficiency of the *superior colliculus* in orientation tasks to the fact that the sensory neurons in the *superior colliculus* are not segregated but they intermix between them and eventually converge on the same efferent neurons.

[Stein & Meredith, 1993] describe the existence of at least two different neural mechanisms in the *superior colliculus* that have the effect of coordinating sensory information originating in different sensory modalities and of sensory information with motor effectors. These mechanisms are considered as responsible of the coherence of the final percept in presence of multisensory stimulations.

The first mechanism is the existence of a correspondence between the representations of the visual, somatosensory and auditory space/ the same axes are used to represent all three sensory modalities, providing a good parallel between multisensory representations in the *superior colliculus*.

[Stein & Meredith, 1993] describe the regular relationship between maps as functional rather than coincidental: an object that approaches the left side of the animal face is signalled by the activation of aligned visual and somatosensory neurons that co-vary with the appropriate motor maps. The alignment of the sensory maps, in fact, runs in parallel with the alignment of sensory and motor maps. The representation of a region of sensory space and the representation of the signals required to orient the head of the animal in the same direction have the same location.

The second mechanism that supports integration within the *superior colliculus* is the existence of multimodal sensory-motor neurons, that is, the convergence of information from audition, vision and touch on one and the same neuron that accomplishes also pre-motor functions.

Could there be an adaptive value in the violation of coherence?

It needs to be discussed if violations of coherence might possibly have an adaptive value too.

If we assume that violations of coherence in perception have a sort of “freezing” effect upon action and action programming, then we should ask if, at least in some cases, the inhibition of action might hold effects that have a positive adaptive value.

It might be suggested, for instance, that in some situations the inhibition of action allows the subject to re-consider the stimulus, to perform an additional exploration in order to solve the ambiguity in a sense. Or it may be possible that the inhibition of action gives the subject the chance to consider the situation in a lore complex cognitive light, without directly giving rise to action as a response to perception, but helping himself to considerations that include different types of reasons.

If we can imagine situations in which action is not immediately requested (as in the case of chase or escape behaviors, which are the basic adaptive behavior taken into account by [Stein & Meredith, 1993] for instance) and the recourse to thought and the use of higher level concepts is prized, then we could accept that the freezing of action has an adaptive value.

Even in this case, nonetheless, the system demonstrates the ability to immediately detect violations of coherence and to act in order to reduce inconsistency.

In fact, the freezing of action can be considered to have a positive value when it leads to subsequent exploration and to a more reflective response to the stimulus situation. But a response must be given. It will then be demanded of the successive exploration and of the conceptual reflection to provide a decision for action which is univocal.

A solution that was impossible at an automatic level (through the intervention of the neurophysiological processes described above as solutions to conflicts) has to be found at the conceptual level. Hence, in some way coherence is restored.

It seems thus that violation of coherence doesn't have a positive adaptive value in itself. In fact, the freezing of action which is provoked by violations of coherence has positive consequences only when the subject has the possibility of putting into action other explorations or higher order reasoning. On the contrary, the destructive consequences of discrepant stimuli over maps alignment and the existence of mechanism for the organization and the maintenance of the alignment of the maps seems to prove that coherence (in the sense of the coherence of the incoming stimuli) is an important quality of the perceptual outcome.

The adaptive value of coherence vs. the adaptive value of truth

As a matter of fact, one can be wrong in modifying the actual perception of some state of affairs or in holding it as false just because it contradicts some previously acquired knowledge or some previous experience.

What is adaptively negative here is not the recognition of a conflict between past and present experiences or between present experiences, but the type of solution which is adopted in order to reestablish coherence. The decision about which experiences or cognitive states are to be modified and how, constitutes a further step. As we have seen in the case of intersensory conflicts, different hypotheses can be expressed about the conditions the perceptual system takes into account when choosing between combining or non-combining two discrepant stimuli, and about their respective role in the final combined percept.

Anyway, being unable to recognize the state of conflict cannot be more valid from an adaptive point of view than identifying it and trying to solve it along one direction.

4.2.2 The epistemic value of violations of coherence in perception

A question arises about the relationship between the adaptive value of coherence as described by [Stein & Meredith, 1993] and the question of truth, in two senses:

- in the sense of a possible conflict between the adaptive value of coherence as compared to the adaptive value of truth;
- and in the sense of the adaptive value of coherence as compared to the epistemological value of coherence violation, that is, the possibility for violations of coherence to reveal the falsity of perceived states of affairs or of cognitive states.

Even if coherence seems to present an adaptive value for perception that violations of coherence might not have, nonetheless the reestablishment of coherence is not necessarily coincident with the reestablishment of the truth. On the contrary, the reduction of inconsistency could work against truth, as it happens in the case of solved perceptual conflicts, where the perceptual result is coherent but it doesn't adhere to either of the incoming stimuli.

The theory of cognitive dissonance confirms that the human mind tends to reduce inconsistency between cognitive states and indicates different strategies for carrying out this reduction. Nevertheless, as the theory of cognitive dissonance points out, there could be negative effects in pricing coherence between cognitive states (such as beliefs) more than the truth of the belief which is held. Since cognitive dissonance is assimilated to a state of distress, such as thirst, the subject seems to be strongly driven to the modification of his beliefs in order to reduce the state of stress. The reduction of the inconsistency thus presents a positive value for the well being of the subject. But, in order to gain a more comfortable condition, the subject might be inclined to give away true beliefs just for reestablishing harmony between his cognitive states. This choice could entail negative consequences upon adaptive behavior.

As we have seen, the identification of a violation of coherence might signal the presence of some form of error and the necessity of modifying some cognitive states or some experiences. This is a different question from the question of the adaptive value of coherence, because it concerns the epistemic value of coherence or of violations of coherence: their possibility of revealing truth or falsehood.

The reestablishment of coherence vs. the reestablishment of truth

We have seen that coherence seems to present a positive adaptive value and that violations of coherence have disruptive effects on adaptive behaviours. Nevertheless, the reestablishment of coherence in perception is not necessarily coincident with the reestablishment of truth.

There is a possible conflict between the adaptive value of coherence as compared to the adaptive value of truth.

The theory of cognitive dissonance poses for instance an implicit objection to the adaptive value of the reestablishment of coherence. In fact it assumes that truth has an adaptive value, that is, that good decisions and bad decisions reciprocally adhere or do not adhere to truth; but the subject might tend to reduce inconsistency between his cognitive states independently of the truth or falsity of their content, because of the inner tension dissonance produces. The subject might thus tend to keep false beliefs or modify his beliefs and other cognitive states in a way that reduces inconsistency and in the mean time reduces the adhesion to truth: false beliefs are held, that guide the subject to wrong decisions, decision that lack an adaptive value.

The example of cognitive dissonance indicates that coherence might not be coincident with truth.

This assertioin is not necessarily valid for a wide set of beliefs or other intentional states. [Davidson, 1984, 1986] for instance denies the possibility for a large set of coherent beliefs to be false, and in general for a large set of beliefs to be false. On the basis of the principle of charity, the interpreter must make the assumption that the beliefs the speaker holds as true are mostly true and coherent, as the beliefs of the interpreter are mostly true and coherent. Since communication normally works and speakers and interpreters normally gain reciprocal comprehension their beliefs must be mostly true, also because they are caused by exposure to one and the same world of objects and events. The possibility is nevertheless open, in Davidson's opinion, for local falsehood and inconsistency. Beliefs are mostly true, not always true. But it is only in virtue of a large accord that an interpreter can deal with the speaker's false beliefs.

Box 19. Cognitive dissonance

The theory of cognitive dissonance was first proposed by L. Festinger in 1957 [Festinger, 1957] and is especially applied to decision-making and problem-solving.

According to the theory of cognitive dissonance, the human mind tends to adopt thoughts or beliefs so as to minimise the amount of dissonance (conflict) between cognitions. In other words, subjects are assumed to seek consistency among their beliefs and other mental states. The existence of a dissonance or inconsistency between beliefs or other mental states is resented as negative by the subject (Festinger proposes that cognitive dissonance is a psychological tension similar to hunger and thirst and that for this reason people will seek to resolve this tension) and the subject reacts by changing his beliefs and other mental states in order to reduce the dissonance and re-establish the balance between the cognitions.

Two factors in particular are described that affect the strength of the dissonance: the number of dissonant beliefs, and the importance attached to each belief. Dissonance thus occurs when the subject must choose between incompatible beliefs and when the alternatives are all attractive.

Also, different strategies are described that are put into action in order to reduce cognitive dissonance: the reduction of the importance of the dissonant beliefs, the addition of more consonant beliefs that outweigh the dissonant beliefs and, finally, the operation of changes in the dissonant beliefs so that they are no longer inconsistent.

The psychological effect of the reduction of cognitive dissonance is the reduction of the tension. But the modification of dissonant beliefs might involve a distortion of truth and might cause wrong decisions.

The epistemic value of the recognition of violations of coherence

The adaptive value of coherence should also be compared to the epistemological value of coherence or coherence violation, that is, to the possibility for violations of coherence of revealing the falsity of perceived states of affairs or of cognitive states.

As we have seen, [Davidson, 1984] charitably assigns to one mostly true beliefs, even though any of one's beliefs can be false. Anyway, one considers one's beliefs as true until one discovers that a certain belief is false, whence the reaction of surprise.

If there are no particular reasons to doubt, hence, perceptual experience is normally assumed to be believable. It is only in special conditions that one puts one's perception into doubt and asks oneself if one should believe or not in what one perceives or believe in what one believes.

An experience which is inconsistent (synchronically or diachronically) with other experiences and knowledge alerts the perceiver to the possibility of error, by causing surprise and a sense of wrongness, bizarreness, impossibility. In these conditions, actual perception is not suitable to immediately give rise to a corresponding belief which is held as true.

When the content of the experience that *p* is recognized as inconsistent with the contents of other experiences or past knowledge and when the experience that *p* provokes a reaction of surprise or a sense of wrongness, bizarreness, impossibility, the judgment that *p* is taken as possibly false. The world is unlikely to be as the experience that *p* presents it to be.

The immediate recognition of the possibility of an error in the perceptual experience carries an epistemological value for the subject.

Illusions (and in particular illusions we are immediately aware of) and their behavioural and phenomenological consequences (surprise, sense of wrongness) thus represent an epistemological value for the subject because violations of perceptual coherence might be significant signals for the possibility of actually being mistaken. Thus, violations of perceptual coherence can be used by the subject as criteria for establishing the credibility of the perceptual experience.

In the case of illusions we are immediately aware of and also in the case of illusions we are not immediately aware of, whether or not perception is compared to knowledge about the stimulus condition, in fact, surprise arises and the possibility of falsehood and error is at least taken into account. New considerations and explorations are performed until coherence is re-established.

In this sense, illusions and coherence in general have not only an adaptive, but also an epistemic value, in that they allow to judge the truth or falsehood of an experience or of the corresponding belief.

The epistemic value of illusions

In principle, it would be possible to accept discordant determinations or discordant sensory experiences if perception were to consist in an association of separate purely sensory states. But, as a matter of fact, in the normal system of experience perception is multisensory and it is coherent. In virtue of the normal coherence of the perceptual experience, the existence of a violation of the synchronic or diachronic coherence is the signal of an anomaly in perception, thus of the possibility of being mistaken.

In virtue of the normal coherence of the perceptual experience the discrepancy between the information provided, for instance, by different sensory organs provokes both a synchronic and a diachronic violation of coherence. In fact, in addition to the inconsistency between sensory modality, inconsistency stands between the actual experience, which is incoherent, and the normal perceptual experience which is coherent. As I have previously suggested, the reaction of surprise and the sense of wrongness and impossibility that accompany synchronic violations of coherence might be related to the violation of a general expectation of coherence.

Both inconsistencies are indicative for the subject of an anomalous situation, thus, of the possibility of there being an error.

The particular epistemic value of the recognition of inconsistencies in the case of illusions we are immediately aware of and in explicit conflicts consists in the fact that the recognition of falsity is totally internal to the experience. The subject does not need, as it is the case for illusions we are not immediately aware of, to gain information from another subject or from another round of perceptual exploration.

Violations of coherence give access to the notion of truth and objectivity (Husserl)

According to [Husserl, 1990. Original work published 1952] it is in virtue of the existence of violations of coherence (when the experience is no more concordant) that even the subject in isolation from other subjects can have access to the notions of truth and objectivity only on the basis of his sensory experience. [Husserl, 1990. Original work published 1952] suggests in fact that a subject can distinguish between a veridical experience and an illusory one without making reference to an object which is autonomous from the solipsistic subject because of the fact that an illusion is discordant relative to a stream of experiences which is continuous and coherent [Dokic, 2004].

When one sensory organ is in anomalous conditions while the other senses are in normal conditions, Husserl affirms, the apprehension of the thing is concordant until the sense enters the anomalous condition or, after the condition is established, when the anomalous sense is excluded. The modified given can thus be compared with the normal given, because the modified given recalls and is associated to the normal given.

Additionally, the subject might compare the sensations originated by the anomalous sensory organ (the modified given) with the given as it is normally sensed in absence of anomalous conditions. In fact, when an anomaly is produced, the anomalous sense demands a general modification of the thing as it was given in previous experiences. This demand is not supported by the other senses and in fact it vanishes when the anomalous sense is excluded.

When things are perceived by sensory organs that are in anomalous conditions, appearances are thus new and non normal. Hence, a discrepancy stands not only between actual sensations of different sensory organs, but also between the appearance of the thing that the sensory organ reveals in normal conditions and the appearance of the thing as it is given by the anomalous organ.

Nevertheless, even if all the senses but one are concordant, the only sense which is in contradiction with the others cannot be simply discarded and the coherence of the experience reestablished by trusting the senses that are in accord.

In fact, coherence *per se* is not considered by Husserl to be a sufficient indication of truth. Only ruptures in the coherence of the normally concordant experience force the subject to consider the difference between appearances, that can be true or false, and reality. If the experience of the subject is always normal and concordant, and the subject is in isolation from other subjects, the subject is not capable of constituting the objective nature, that is, of distinguishing the appearances from the real thing.

We have seen that different studies suggest that coherence presents an adaptive value for perception; but it seems that only violations of coherence, and not coherence in itself, present an epistemological value.

Violations of coherence diminish the credibility of the perceptual experience

On the basis of the evidence from illusion, it can be suggested that the subject of perception may make use of coherence hints in order to decide the truth value of his experiences; in particular the subject would make use of violations of coherence as indications of the possible falsity of his experiences.

The analysis of the behavioural consequences of violations of coherence and illusions does not allow inferring that truth is a matter of coherence rather than, for instance, a matter of adequacy ([Davidson, 1986]). In order to establish that truth is a matter of coherence, in fact, one should assert that truth is not only positively related to coherence, in such a way that coherence can be used as a justification condition for truth, but that truth essentially consists in coherence ([Kirkham, 1992], [Blanshard, 1939]). All what is possible to affirm on the only basis of this analysis is that a violation of perceptual coherence might be an indication that the experience does not correspond to objective facts.

The special value of violations of coherence and of illusions (with special evidence for illusions we are immediately aware of), whatever the theory of truth which is adopted, is represented by the reaction of surprise and by the consequent possibility of immediately issuing a judgment about the truth value of the experience.

The capability of judgment is in fact internal to the experience and does not require the subject to 'step outside' his perceptual experience in order to judge of its credibility (probability of truth). In other words, the credibility of an experience can be judged on the basis of the internal characteristics of the experience only.

Chapter 4. Summary and conclusions.

Both the characterization of the notion of illusion and the pragmatic role played by this notion for perceptual studies suggest the existence of a specific role for illusions in the context of the cognitive functioning. This role is connected to the close relation that the notion of illusion entertains with the problem of coherence and coherence violations in perception; in particular with the possibility of revealing the presence of a violation of coherence, thus the possibility of error, without requiring the subject to step out from his own course of experiences.

As we have just seen, violations of coherence can be described at the diachronic and at the synchronic level. At both levels, some seminal studies conducted on the violation of expectations and a number of studies dedicated to the reaction of the perceptual system to the presence of discrepant multisensory stimuli, show that:

- the experience of explicit conflict is not the only possible issue at stake;
- coherence tends to be re-established even in presence of discrepant stimuli.

The rarity of explicit experienced conflicts and the reactions to ambiguous stimuli could be attributed to a negative value of ambiguity for adaptive behaviours.

The studies on the *superior colliculus* and on animal behaviour in presence of multisensory, stimuli, both consistent and inconsistent, seem to confirm that the perceptual system has a general propensity to avoid conflicts and violations of coherence in general.

Illusions as related to the presence of discrepancies thus present two functional aspects.

The first aspect is connected with the positive adaptive value of coherence and with the negative adaptive value of violations of coherence.

[Stein & Meredith, 1993] have conducted experiments that prove that the integration of multisensory stimuli is much more efficient for the adaptive behaviour of the animal than the response to unisensory stimulation. In the mean time, discrepancies in the incoming information are proved to give rise to mid-way responses (in analogy with the class of solved conflicts described for human perception of multisensory discrepant stimuli). Such responses are considered by [Stein & Meredith, 1993] as having disastrous consequences on the behaviour of the animal, since the source of the stimulus cannot be correctly identified. An important part in the adaptive behaviour of the animal and in the integration of multisensory stimuli is thus attributed to the coherence of the incoming information: multisensory stimuli belonging to one and the same event share the same spatial and temporal characteristics.

On the basis of such studies, [Stein & Meredith, 1993] affirm that inconsistency between multisensory stimuli presents a negative adaptive value, while the consistency of the multisensory percept presents a positive adaptive value. The main arguments that support this view are the following:

- the phylogenetic and ontogenetic selection of aligned maps that are at the basis of the enhancement of the responses to multisensory integrated perceptions; this selection is produced by the experience with a coherent world; coherence is here intended as spatio-temporal coincidence of stimuli from the same source;

- the disruptive effects of misalignment or inconsistency between sensory stimuli that are attributed to the same source of adaptive behaviour;
- the existence of local mechanisms for reacting to misalignment by reducing its effects (functional separation of the stimuli) or guiding the incoming stimuli in order to obtain a coherent perceptual result (motor coordination and shift of the receptive fields).

On the basis of the considerations relative to the misguiding effect of incoherent perception upon action and on the basis of the mechanisms that are described at the behavioural and neurophysiological level for maintaining coherence in perception, it seems plausible to assert that violations of coherence have a negative value for adaptive behaviours.

The revelation of violations of coherence which has been described as a characteristic of the experience with illusions might thus present a positive adaptive value. In some cases, even the re-establishment of coherence (as it has been described in the case of solved conflicts) might present a positive adaptive value, because the blockage to action is removed and action is made possible. Nevertheless, the positive value of action and the re-establishment of coherence might be in contrast with truth. When coherence is re-established in fact, the final percept does not adhere to the original stimulation.

The second functional aspect of illusions is related to the epistemic value of the revelation of violations of coherence.

The subject is in fact alerted by the characteristics of his own experience that something is going wrong and that an error is present somewhere in his experiences and beliefs. The erroneous content is not indicated, but believability is diminished and the subject can enterprise new rounds of exploration or take the decision of trusting one information over the others.

Table 4. Possible reactions to discrepancies

			Discrepancy between past and present experiences	***Discrepancy between intersensory simultaneous experiences***	***Behavioral reactions to discrepancy in multisensory stimuli described in the cat***
Discrepant stimuli not combined in a unit			Disruption: discrepancy is recognized	No conflict	
Discrepant stimuli combined in a unit	*Coherent final unit*	*Dominance*	Dominance: discrepancy is not perceived and the aspect of the percept is in accord with the past	Solved conflict with dominance of one sensory modality	
	Coherent final unit	*Multiple contributions*	Compromise: the aspect of the percept takes into account past and present experiences	Solved conflict with participation of both sensory modalities	Erroneous response: the response is half-way between the two stimuli
	Incoherent unit		Blocking of action: no decision about the aspect of the perceived object can be taken	Experienced conflict	Paralysis of the response: the animal hesitates
Concordant stimuli	Coherent unit				Enhancement of the response

Conclusions

The present discussion has been introduced by the debate raised by the nature and explanation of a particular perceptual phenomenon, known as 'Size-Weight Illusion' or 'SWI'. The SWI has been variously explained since the time it was first described by Charpentier in 1891. Some of the explanations of the SWI refer to the existence of internal representations of objects and of symbolic knowledge about the nature of objects and the rules of perception; other approaches have suggested that the expectations involved in the explanation of the SWI are more of a sensorimotor nature; but also the role of expectations and knowledge has been criticized. In connection with the different explanations of the phenomenon, different considerations have also been expressed about the nature of the SWI and of illusions in general. It has been suggested that the SWI is not an illusion and it has also been proposed that illusions do not exist and that the kind of explanation which makes the SWI a normal, non-illusory perceptual phenomenon can be extended to every other perceptual phenomenon, thereby eliminating all references to the notion of illusion.

Nevertheless, the SWI presents some distinctive characteristics that cannot be easily extended to all the other, normal (in the sense of non-illusory) perceptual phenomena. The individual who experiences the SWI can compare the content of his perception with the content of the information provided by another subject (the experimenter) about the weight of the objects he has perceived; or he might measure the heaviness of the object by other means than his bare hands: the two perceptual results are not the same; he is hence alerted that at least one of the two must be wrong. On other occasions, this same awareness that something is wrong in the perceptual experience might arise directly during the experience itself. Moreover, the phenomenon of the SWI is robust in many ways: it cannot be overcome by the cognition of the real weight of the sensed objects, it will be experienced in the same way by the same subject at different times and also by different subjects. Finally, the awareness of the fact that something is wrong in the felt weight is associated with a sense of surprise.

These characteristics of the SWI can be considered as sufficient in order to isolate the phenomenon from other normal, non-illusory, perceptual experiences.

As a matter of fact, this is exactly what the approaches that propose to eliminate the notion of illusion from the psychological vocabulary or at least the consideration of the SWI as a normal, non-illusory phenomenon do. The SWI and analogous phenomena are in fact deeply exploited in laboratory experiments and the characteristics that I have described are considered as useful in order to provide evidence for the mechanisms of weight perception and the stimulus characteristics that are meaningful for weight perception. The explanation of the SWI is thus an empirical matter which is not necessarily involved in the debate about the nature of illusions. The SWI can be considered an illusion in virtue of the fact that it is a perceptual phenomenon with some peculiar characteristics, specific behavioural reactions and a certain nature related to the fact of committing an error.

Although the explanation of the SWI is an empirical matter that can be solved by empirical means only, the argument about the nature of the SWI and of illusions in general can hence be addressed on philosophical grounds.

It has been shown that the criticism of the notion of illusion is partly justified by the fact that the classic characterization of illusory phenomena is committed to a specific theoretical approach to perception: the indirect, inferential view of perception.

I have presented some reasons for preserving the notion of illusion.

The notion of illusion is implied in many aspects of cognitive functioning, such as the reaction of surprise, the adaptive role of the coherence of the perceptual experience, the existence of implicit knowledge and expectations based on the direct connection between movement and perception, the awareness of the possibility of being mistaken during a perceptual experience.

The notion of illusion is also intertwined with other conceptual notions, such as the notion of error, the notion of coherence, the notions of expectation and knowledge.

The characterization of all these notions is not unproblematic and some of the problems with the notion of illusion arise due to its connection, for instance, with the notion of error. In fact in the psychological literature on perception, the notion of error can be characterized as a failure in the course of an inferential process, thus implying that perception consists in a suite of inferences that proceed from the extraction of the datum to the ascription of meaning to the perceptual outcome. This view of perception is proper of the indirect, inferential approach. Consequently, the notion of error which is so characterized is problematic for those who assume that perception is direct and that the recourse to inferential processes based upon internal symbolic representations is not necessary in order to explain the appearance of the perceptual outcome.

In the light of the discussion about the heuristic value of the study of illusory phenomena, it seemed pragmatically useful to investigate the possibility of providing a neutral characterization of the notion of illusion, that is, a characterization of the notion of illusion which is not necessarily committed to a specific theoretical approach to the nature of perception.

In fact, it seems that the study of illusions is suitable for a better understanding of perceptual functioning and of cognitive functioning in general. The study of phenomena such as the SWI and analogous perceptual outcomes of the appropriate manipulations of the stimulus conditions, is largely recognized as promising both for the understanding of the mechanisms of perception (in analogy with the study of pathology for the understanding of the physiological functioning) and for the individuation of the proper quantities to which the perceptual modalities are sensitive. As a matter of fact, even when the notion of illusion is rejected (such as in the ecological approach to perception), the perceptual phenomena that are otherwise described as illusions are suitably reproduced in laboratory experiments and exploited in order to provide evidence for some specific characteristics of perceptual functioning that are otherwise not apparent. In general, the study of phenomena that can be described as illusions seems to be promising in order to discover the real functioning of perception as opposed to its common sense description, independently of the theoretical approach which is assumed regarding the nature of perception.

The possibility of providing a neutral characterization of the notion of illusion with respect to the direct-indirect perception debate is also confirmed by the fact that the study of illusions is suitable for the study of the direct connection between perception and movement, for offering evidence in favour of the role of movement in perception and for illustrating the existence of an implicit form of knowledge and expectation which is not based upon symbolic representations but on sensorimotor connections.

The present investigation about the notion of illusion has been conducted by means of the description of some illusory phenomena, mainly with the help of examples from the haptic, tactile and kinesthetic modality (SWI, some tactile analogous of optic illusions, proprioceptive illusions provoked by vibration, Viviani illusions, Aristotle's illusion), and by the analysis of the concepts that are associated with the notion of illusion. The choice of illustrating haptic illusions was motivated by the recognized intimate relationship between motor and perceptual aspects in the haptic modality. The criticism of the notion of illusion and of the role of inferential processes based on internal representations leads in fact to the highlighting of the role of the direct connection between movement and perception. It has thus seemed that the examples from the haptic modality might prove more convincing about the necessity of keeping the notion of illusion and about the possibility of providing a neutral characterization of this notion that could be acceptable also for those who criticize the classical characterization of the notion of illusions.

It has emerged that illusions can be defined as errors, but not necessarily characterized as errors during an inferential process based upon internal, symbolic representations, as it was the case for the classic characterization of illusions provided by Gregory within the frame-work of the indirect, inferential view of perception.

One can be aware, directly or indirectly, of being victim of an illusion, thus one can be aware of committing an error or at least one can be aware that, given the characteristics of the experience, there is the possibility of committing one or more errors, even if the error is not necessarily identified. In the case of illusions one is immediately aware of, for instance, the subject is aware that something is going wrong with his experience. As in the case of intersensory conflicts, nevertheless, he is not necessarily able to say which one of the conflicting experiences is the wrong one or if they are both wrong. The experience with perceptual paradoxes and ambiguities suggests that the notion of error which is at stake in the characterization of illusions cannot be bound to the discrepancy with the reality (in the sense of the physical facts or even of the reality as measured by specific instruments). In fact, during the experience of paradoxes, the subject expresses a sense of wrongness and bizarreness even if the stimulus condition is correctly perceived.

The association of illusions with the awareness of errors has lead to the suggestion that the ascription of illusions should be limited to those entities that can be aware of committing an error, thus to individuals at their personal level. This suggestion encounters one of the main criticisms directed toward the notion of illusion by the ecological approach, that is, that the perceptual system does not commit any error. On the basis of the present characterization of the notion of illusion, illusions are not attributed to sub-personal systems such as the perceptual system.

The notion of illusion has been further characterized on the basis of some specific qualities of the illusory experience. Illusions are robust, in the sense that they are systematic, intra and inter-subjective, and that they are resilient to knowledge. Illusions can then be considered as special forms of perceptual errors. They are not to be confounded with local errors and hallucinations, which are not public (intersubjectively systematic) and which do not necessarily present the same aspect to the same subject in different conditions (intrasubjectively systematic).

The robust character of illusions constitutes a crucial component of their heuristic value. In fact, illusions can be reproduced at will (which is not possible with pathological processes), can be compared between individuals and are not annihilated by the knowledge about the experimental conditions.

Illusions can be distinguished from typical errors in perception on the basis of the functional reactions they produce. Illusions are in fact variously accompanied by reactions of surprise. The reaction of surprise can be direct or indirect, depending on the immediateness or not of the awareness of being victim of an illusion. Particularly in the case of illusions we are immediately aware of, the association with the reaction of surprise provides an epistemic value to illusions, because the subject gains an immediate insight into the possibility of being mistaken during his perceptual experience The subject also gains an insight into some implicit expectations he might hold, such as the expectation that perceptual experience is coherent.

In virtue of the reaction of surprise and of the sense of wrongness or impossibility that emerges in connection with them, illusory phenomena can thus be considered as representing a functional value for the subject, in that they reveal the presence of expectations and beliefs of which he is not necessarily aware all the time.

We have seen that the expectations invoked for explaining surprise in the case of illusions are not necessarily expressed in a linguistic form and that they can also have a non-representational nature. The case of Aristotle's illusion has been illustrated in order to show the heuristic value of the study of illusion with respect to the connections of perception with movement, but Aristotle's illusion can also serve as an example for the existence of non-representational, implicit knowledge and expectations and of the role of this kind of expectations in the aspect of the perceptual outcome.

The epistemic value of the individuation of the possibility of being mistaken should not be confounded with the adaptive value of the coherence. The study of illusions we are immediately aware of and the study of intersensory conflicts seem to confirm the hypothesis emitted in the frame-work of neurophysiological studies that coherence has an adaptive value for the subject and that the subject will actively work for the preservation of the coherence of the experience both at the synchronic and at the diachronic level (that is, both between actual experiences and between actual experiences and expectations based on past experiences or knowledge).

Illusions can thus be considered to present an epistemic function relative to the identification of violations of coherence and the possibility of being in error and the study of illusions can be considered to present a specific pragmatic interest for the investigation of the mechanisms of coherence in perception and cognition.

In particular, two kinds of violations of coherence have been described: synchronic violations of coherence, in which the discrepancy stands between two or more actual contents of experience, and diachronic violations of coherence, in which the discrepancy stands between the perceptual content which is actually experienced and the content of a past experience, of an expectation or of knowledge. In both cases, the study of illusions and conflicts indicates that the discrepancy tends to be solved in favor of a coherent perceptual outcome. When it is not the case, and coherence is violated, a sense of wrongness, bizarreness and even impossibility arises thus signaling to the subject that at least one of the contents of his experience is erroneous. The awareness of the presence of an error in the experience is gathered without stepping out of the experience itself. This is what happens in particular in the case of what we have called 'illusions we are immediately aware of'. In other cases the violation of coherence might be solved and the discrepancy which is present in the stimulus situation is not apparent in the perceptual outcome.

Two classes of illusory phenomena have been distinguished on the basis of the immediateness of the reaction of surprise and of the awareness of there being some mistake in the experience: illusions we are immediately aware of and illusions we are not immediately aware of. In the case of illusions we are not immediately aware of the reaction of surprise arises when the presence of an error is revealed by a second person, by knowledge or by a new round of exploration conducted in modified conditions. A discrepancy in the stimulus situation can be at the origin of the occurrence of the illusion, but the perceptual outcome is not incoherent, or the subject would become immediately aware of there being something wrong.

Finally, it has been suggested that the reaction of surprise that follows the illusory experience could be provoked by the presence of a violation of coherence, both diachronic and synchronic. We have suggested for instance that a violation of coherence is at the origin of illusions such as the proprioceptive illusions of movement and position provoked by vibration and the waterfall illusion: two inconsistent perceptual processes are in fact synchronically active. Nevertheless, it is possible that the reaction of surprise is mostly related to violations of expectations, thus even in the case of synchronic violations of coherence that are accompanied by surprise some general expectation must be generated and violated, such as the expectation that perceptual experience is coherent or expectations based upon general knowledge about natural laws or bodily possibilities.

In the course of the present discussion, in addition to a neutral characterization of the notion of illusion, some suggestions have been advanced about the functional role that illusory phenomena might play in the context of the cognitive functioning and about the heuristic role that the study of illusions might represent for a psychological theory of perception, with no specific commitment to a particular view of perception. The elimination of the notion of illusion thus seems to be too much radical, also in the context of direct, ecological approaches to perception, because it is equivalent to renouncing an useful instrument of investigation and the possibility of shedding light on the role of errors, expectations and coherence in the general cognitive functioning.

The considerations about the functional and the heuristic role of illusions have in fact lead to a discussion about the role of coherence, expectations and movement in perception, thus illustrating that illusions entertain rich relations with different aspects of the perceptual functioning and that the notion of illusion is related in interesting ways to several notions that deserve further analysis. The study of illusions is hence suitable for opening new perspectives in the study of perception.

References

1. Addams, R. (1834). An account of a peculiar optical phaenomenon seen after having looked at a moving body. *London and Edinburgh Philosophical Magazine and Journal of Science, 5*, 373-374.
2. Amazeen, E., & Woodrow, D. J. (2003). The Role of Rotational Inertia in the Haptic and Haptic + Visual Size-Weight Illusions. *Ecological Psychology, 15*(4), 317-333.
3. Amazeen, E. L. (1995). The size weight illusion. In R. J. B. B. G. Bardy, Y. Guiard (Ed.), *Studies in perception and action* (Vol. III, pp. 407 410). Hillsdale, NJ: Lawrence Erlbaum Associates.
4. Amazeen, E. L. (1997). Effects of volume on perceived heaviness. In M. A. Schmuckler & J. M. Kennedy (Eds.), *Studies in perception and action, IV* (pp. 123 -126). Hillsdale, NJ: Lawrence Erlbaum Associates.
5. Amazeen, E. L. (1997). Effects of volume on the perception of heaviness by dynamic touch: with and without vision. *Ecological Psychology, 9*(245-263).
6. Amazeen, E. L. (1999). Perceptual independence of size and weight by dynamic touch. *Journal of experimental psychology: human perception and performance, 25*, 102-119.
7. Amazeen, E. L., & Turvey, M. T. (1996). Weight perception and the haptic size weight illusion are functions of the inertia tensor. *Journal of Experimental Psychology: Human Perception and Performance, 22*(1), 213-232.
8. Anderson, N. H. (1970). Averaging model applied to size-weight illusion. *Perception & Psychophysics, 8*, 1-4.
9. Anderson, N. H. (1970). Averaging model applied to size-weight illusion. *Perception & Psychophysics, 8*, 1-4.
10. Anderson, N. H. (1972). Cross-task validation of functional measurement. *Perception & Psychophysics, 12*, 389-395.
11. Austin, J. L. (1962). *Sense and sensibilia*. London, Oxford, New York: Oxford University Press.
12. Ayer, A. J. (1955). *The foundations of empirical knowledge*. London: MacMillan and Co.
13. Barlow, H., & Hill, R. (1963). Evidence for a physiological explanation for the waterfall phenomenon and figural aftereffects. *Nature, 200*, 1345-1347.
14. Bell, J. (1934). *The hand. Its mechanisms and vital edowments as evincing design*. London: Pickering.
15. Benedetti, F. (1991). Perceptual learning following a long-lasting tactile reversal. *Journal of experimental psychology: Human perception & performance, 17*(1), 267-277.
16. Benedetti, F. (1985). Processing of tactile spatial information with crossed fingers. *Journal of Experimental Psychology: Human Perception and Performance, 11*(4), 517-525.
17. Benedetti, F. (1985). Tactile diplopia (diplesthesia) on the human fingers. *Perception & Psychophysics, 15*(83-91).
18. Benedetti, F. (1988). Exploration of a rod with crossed fingers. *Perception & Psychophysics, 44*, 281-284.
19. Benedetti, F. (1988). Localization of tactile stimuli and body parts in space: two dissociated perceptual experiences revealed by a lack of constancy in

the presence of position sense and motor activity. *Journal of Experimental Psychology: Human Perception and Performance, 14*(1), 69-76.
20. Benedetti, F. (1990). Goal directed motor behavior and its adaptation following reversed tactile perception in man. *Experimental brain research, 81*, 70-76.
21. Berkeley, G. (1948-1957). Treatise Concerning the Principles of Human Knowledge. In A. A. Luce & T. E. Jessop (Eds.), *The works of George Berkeley, Bishop of Cloyne*. London: Thomas Nelson and Sons. Original work published 1710.
22. Berthoz, A. (2002). *The Brain's Sense of Movement*. Harvard University Press.
23. Blake, A., Yuille, A. (1992). *Active Visions*. Cambridge, Mass.: MIT Press.
24. Blanshard, B. (1939). *The Nature of Thought*. London: George Allen and Unwin.
25. Brodie, E. E., Ross, H. E. (1984). Sensorimotor mechanisms in weight discrimination. *Perception & Psychophysics, 36*, 477-481.
26. Bruner, J., Postman, L. (1949). On the perception of incongruity: A paradigm. *Journal of Personality, 18*, 206-223.
27. Burke, M. M., Amazeen, E. L. (1997). Object visibility and the inertia tensor as factors in the size weight illusion. In M. A. S. J. M. Kennedy (Ed.), *Studies in perception and action, IV* (pp. 249-252). Hillsdale, NJ: Lawrence Erlbaum Associates.
28. Burton, G., Turvey, M. T. (1990). Attentionnally splitting the mass distribution of hand-held rods. *Perception & Psychophysics, 50*(129-140).
29. Burton, G., Turvey, M. T. (1990). Perceiving the lengths of rods that are held but not wielded. *Ecological psychology, 2*(295-324).
30. Burton, G., Turvey, M. T., & Solomon, H. Y. (1990). Can shape be perceived by dynamic touch? *Perception and psychophysics, 48*(477-487).
31. Carello, C. (2004). Affordances by Dynamic Touch: hints from the control of movement. *Ecological Psychology*, *16*(1), 31-36.
32. Carello, C., Fitzpatrick, P., Turvey, M. T. (1992). Haptic probing: perceiving the length of a probe and the distance of the surface probed. *Perception & Psychophysics, 51*(580-598).
33. Carello, C., Santana, M. V., Burton, G. (1996). Selective perception by dynamic touch. *Perception & Psychophysics, 58*(1117-1190).
34. Carello, C., Turvey, M. T. (2000). Rotational dynamics and dynamic touch. In M. Heller (Ed.), *Touch, representation and blindness* (pp. 27-66). Oxford: Oxford University Press.
35. Casati, R., Dokic, J. (1994). *La philosophie du son*. Nîmes: Éditions Jacqueline Chambon.
36. Casati, R., Pasquinelli, E. (2005). Is the subjective feel of 'presence' an uninteresting goal? *Journal of visual languages and computing, 16*, 428-441.
37. Casati, R., Pasquinelli, E. (Submitted). How can you be surprised? The case for volatile expectations. In A. Noe (Ed.), *Hetherophenomenology and Phenomenology,* special issue of *Phenomenology and the Cognitive Sciences*.
38. Chan, T., Carello, C., Turvey, M. T. (1990). Perceiving object width by grasping. *Ecological Psychology, 2*, 1-35.
39. Chan, T. C. (1994). Haptic perception of partial rod-length with the rod held stationary or wielded. *Perception & Psychophysics, 55*, 551-561.
40. Chan, T. C. (1995). The effect of density and diameter on haptic perception of rod length. *Perception & Psychophysics, 57*(6), 778-786.

41. Chan, T. C., Turvey, M. T. (1991). Perceiving the vertical distances of surfaces by means of a hand-held probe. *Journal of experimental psychology: Human perception and performance, 17*, 347-358.
42. Charpentier, A. (1891). Analyse experimentale quelques elements de la sensation de poids [Experimental study of some aspects of weight perception]. *Arch. Physiol. Normales Pathologiques, 3*, 122--135.
43. Churchland, P. M. (1989). Eliminative materialism and propositional attitudes. In Churchland (Ed.), *A neurocomputational perspective, the nature of the mind and the structure of the science*. Cambridge, Mass.: MIT Press.
44. Collins, J. K., Singer, G. (1968). Interaction between sensory spatial aftereffects and persistence of response following behavioral compensation. *Journal of experimental psychology, 77*, 301-307.
45. Coren, S., Girgus, J. S., Erlichman, H., Hakstian, A. R. (1976). An empirical taxonomy of visual illusions. *Perception & psychophysics, 20*(2), 129-137.
46. Corey, J. (2004, March). *A Demonstration of Charpentier's Illusion* (SkepticReport.com). Available: http://www.skepticreport.com/tools/charpentier.htm.
47. Crane, T. (1988). The Waterfall Illusion. *Analysis, 48*, 142-147.
48. Craske, B., Cranshaw, M. (1974). Differential errors of kinaesthesis produced by previous limb position. *Journal of motor behavior, 18*, 17-54.
49. Craske, B. (1977). Perception of impossible limb position induced by tendon vibration. *Science, 196*, 71-73.
50. Craske, B., Kenny, F. T., Keith, D. (1984). Modifying an underlying component of perceived arm length: adaptation of tactile location induced by spatial discordance. *Journal of experimental psychology: human perception and performance, 10*, 307-317.
51. Crick, F., Koch, C. (1990). Towards a neurobiological theory of consciousness. *Seminars in the neurosciences, 2*, 263-275.
52. Cross, D. V., Rotkin, L. (1975). The relation between size and apparent heaviness. *Perception & Psychophysics, 18*(79-87).
53. Davidson, D. (1982). Rational animals. *Dialectica, 36*, 318-327.
54. Davidson, D. (1984). *Inquiries into truth and interpretation*. Oxford: Oxford University Press.
55. Davidson, D. (1986). A Coherence Theory of Truth and Knowledge. In E. LePore (Ed.), *Truth and Interpretation, Perspectives on the Philosophy of Donald Davidson* (pp. 307-319). Oxford: Basil Blackwell.
56. Davidson, D. (2004). Problems of rationality. Oxford: Clarendon Press.
57. Davis, C. M., Roberts, W. (1976). Lifting movements in the size-weight illusion. *Perception & Psychophysics, 20*(1), 33-36.
58. Davis, C. M., Brickett, P. (1977). The role of preparatory muscle tension in the size-weight illusion. *Perception & Psychophysics, 22*(3), 262-264.
59. Davis, C. M., Taylor, M., Brickett, P. (1977). A weight illusion produced by lifting movements. *Perceptual & Motor skills, 44*(299-305).
60. Day, R. H., Wong, T. S. (1971). Radial and tangential movement directions as determinants of the haptic illusion in an L figure. *Journal of experimental psychology: Human perception and performance, 87*(1), 19-22.
61. Day, R. H., & Gregory, R. L. (1965). [reply to Day] "Inappropriate Constancy explanation of spatial distortions.". *Nature, 207*(4999), 891-893.
62. De Camp, J. E. (1917). The influence of color on apparent weight. A preliminary study. *Journal of experimental psychology, 2*, 347-370.
63. Dennett, D. C. (2001). Surprise, surprise, commentary on O'Regan and Noë. *Behavioural and Brain Sciences, 24*(5), 982.

64. Dokic, J. (2004). *Qu'est-ce que c'est la perception?* Paris: Vrin.
65. Dresslar, F. B. (1894). Studies in the psychology of touch. *American journal of psychology, 6*(313-368).
66. Dretske, F. (1969). *Seeing and knowing*. Chicago: Chicago University Press.
67. Dretske F. (1981). *Knowledge and the flow of information*. Cambridge, Mass.: MIT Press.
68. Dretske, F. (1995). *Naturalizing the mind*. Cambirdge, Mass.: MIT Press.
69. Eklund, G. (1969). Influence of muscle vibration on balance in man. *Acta societaris medicorum upsaliensis, 74*, 113-117.
70. Eklund, G. (1971). Some physical properties of muscle vibrators used to elicit tonic proprioceptive reflexes in man. *Acta societatis medicorum upsaliensis, 76*, 271-280.
71. Eklund, G. (1972). Position sense and the state of contraction; the effects of vibration. *Journal of neurology, neurosurgery, and psychiatry, 35*(606-611).
72. Ellis, R. R., Flanagan, R., & Lederman, S. J. (1999). The influence of visual illusions on grasp position. *Experimental Brain Research, 125*, 109 114.
73. Ellis, R. R., & Lederman, S. J. (1993). The role of haptic versus visual volume cues in the size-weight illusion. *Percept Psychophys., 53*(3), 315-324.
74. Ellis, R. R., & Lederman, S. J. (2000). Anticipatory effects underlie the golf ball illusion. *Golf Research News, World Scientific Congress of Golf Trust, 1*(3), 18-23.
75. Ellis, R. R. L., S. J. (1998). The "golf ball" illusion: Evidence for top down processing in weight perception. *Perception & Psychophysics, 27*(2), 193 202.
76. Ernst, M., O., & Buelthoff, H. H. (2004). Merging the senses into a robust percept. *Trends in cognitive sciences, 8*(4).
77. Ernst, M. O., & Banks, M. S. (2002). Using Visual and Haptic Information for Discriminating Objects. *Perception, 31 supplement*, 147b.
78. Ernst, M. O., Banks, M. S., & Buelthoff, H. H. (1999). Haptic feedback affects slant perception. *Investigative Ophthalmology & Visual Science, 40*, 802.
79. Ernst, M. O., Banks, M. S., & Buelthoff, H. H. (1999). Haptic feedback affects visual perception of surfaces. *Perception, 28*, 106.
80. Esterman, M., Prinzmetal, W., & Robertson, L. (2004). Categorization influences illusory conjunctions. *Psychonomic Bulletin and Review*.
81. Evans, G. (1982). *The varieties of reference*. Oxford: Clarendon Press.
82. Farah, M. J. (1990). *Visual agnosia*. Cambridge, MA: MIT Press.
83. Fellbaum, C. (Ed.). (1998). *WordNet. An electronic Lexical Database* (Cognitive Science Laboratory at Princeton University ed.). Cambridge, Mass.: MIT Press.
84. Festinger, L. (1957). *A Theory of Cognitive Dissonance*. Stanford, CA: Stanford University Press.
85. Fisher, G. H. (1966). Autokinesis in vision, audition and tactile-kinaesthesis. *Perceptual motor skills, 22*(2), 470.
86. Fitzpatrick, P., Carello, C., Turvey, M. T. (1994). Eigenvalues of the inertia tensor and exteroception by the "muscular sense". *Neuroscience, 60*(2), 551-568.
87. Flanagan, J. R., Beltzner, M. A. (2000). Independence of perceptual and sensorimotor predictions in the size–weight illusion. *Nature Neuroscience, 3*(7), 737-741.

88. Flanagan, J. R., Beltzner, M. A. (2003). Independence of perceptual and sensorimotor predictions in the size-weight illusion. *Nature Neuroscience, 3*, 737-741.
89. Flanagan, J. R., King, S., Wolpert, d. M., & Johansson, R., S. (2001). Sensorimotor Prediction and Memory in Object Manipulation. *Canadian Journal of Experimental Psychology, 55*(2), 89-97.
90. Flournoy, T. (1894). De I'influence de la perception visuelle des corps sur leur poids objects [The influence of visual perception on the apparent weight of objects]. *L'Annee Psychologique, 1*, 1989--1208.
91. Fodor, J. A. (1983). *The modularity of mind. An essay on faculty psychology*. Cambridge, Mass: The MIT Press.
92. Fodor, J. A., & Pylyshyn, Z. (1981). How direct is visual perception? Some reflections on Gibson's ecological approach. *Cognition, 9*, 139-196.
93. Frisby, J. P. (1979). *Seeing*. New York: Oxford University Press.
94. Frisby, J. P., Davies, I. R. (1971). Is the haptic Mueller-Lyer a visual phenomenon? *Nature, 231*, 463-465.
95. Gibson, J. J. (1933). Adaptation, after-effect, and contrast in the perception of curved lines. *Journal of experimental psychology, 16*, 1-31.
96. Gibson, J. J. (1962). Observations on active touch. *Psychological Review, 69*(6).
97. Gibson, J. J. (1966). *The senses considered as perceptual systems*. Boston: Houghton Mifflin Company.
98. Gibson, J. J. (1979). *The ecological approach to visual perception*. Houghton Mifflin Co.
99. Goodale, M. A., Milner, A. D., Jakobson, L. S., Carey, D. P. A. (1991). A neurological dissociation between perceiving objects and grasping them. *Nature, 349*, 154-156.
100. Goodwin, G. M., McCloskey, D. I., Matthews, P. B. C. (1972). The contribution of muscle afferents to kinesthesia shown by vibration induced illusions of movement and by the effects of paralyzing joint afferents. *Brain, 95*, 705-748.
101. Goodwin, G. M., McCloskey, D. I., Matthews, P. B. C. (1972). The persistence of appreciable kinesthesia after paralyzing joint afferents but preserving muscle afferents. *Brain Research, 37*, 326-329.
102. Goodwin, G. M., McCloskey, D. I., Matthews, P. B. C. (1972). Proprioceptive illusions induced by muscle vibration: contributions by muscle spindles to perception? *Science, 175*, 1382-1384.
103. Goodwin, G. M., McCloskey, D. I., Matthews, P. B. C. (1972). A systematic distortion of position sense produced by muscle vibration. *Journal of physiology (London)*.
104. Gordon, A. M., Forssberg, H., Johansson, R. S., & Westling, G. (1991). Integration of sensory information during the programming of precision grip: comments on the contributions of size cues. *Experimental Brain Research, 85*, 226-229.
105. Gregory, R. L. (1962). Visual illusions in space. *New Scientist, 15*(446).
106. Gregory, R. L. (1963). Distortion of visual space as inappropriate constancy scaling. *Nature, 199*(678-91).
107. Gregory, R. L. (1963). Sensory Processes. In G. Humphrey (Ed.), *Psychology through Experiment*. London: Methuen.
108. Gregory, R. L. (1964). Reply to L.B Brown and L Houssiades (1966) "Illusory perception as a constancy phenomenon". *Nature, 204*(4955), 302-303.

109. Gregory, R. L. (1965). Seeing in depth. *Nature, 207*(4992), 116-117.
110. Gregory, R. L. (1966). Visual Illusions. In B. Foss (Ed.), *New Horizons in Psychology* (pp. 68-96). Harmondsworth: Pelican.
111. Gregory, R. L. (1967). Comments on the inappropriate constancy scaling theory of illusions and its implications. *Quarterly Journal of experimental Psychology, 19*(3).
112. Gregory, R. L. (1968). Perceptual illusions and Brain models. *Proceedings of the Royal Society, B 171*, 179-296.
113. Gregory, R. L. (1968). Visual Illusions. *Scientific American, 4*, 66-76.
114. Gregory, R. L. (1973). The confounded eye. In R. L. Gregory & E. H. Gombrich (Eds.), *Illusion in Nature and Art*. London: Duckworth.
115. Gregory, R. L. (1973). A discussion of G.H. Fisher's 'Towards a new explanation for the geometrical illusions: Apparent depth or contour proximity' and the inappropriate constancy-scaling theory. *British Journal of Psychology, 64*, 623-626.
116. Gregory, R. L. (1978). Illusions and Hallucinations. In E. C. Carterette, M. P. Friedman (Eds.), *Handbook of Perception 9*. New York: Academic Press.
117. Gregory, R. L. (1983). Visual perceptions and illusions. In J. Miller (Ed.), *States of Mind* (pp. 42-64): BBC.
118. Gregory, R. L. (1997). Knowledge in perception and illusion. *Philosophical Transactions of the Royal Society of London, B 352*, 1121-1128.
119. Gregory, R. L. (1997). Visual Illusions Classified. *Trends in Cognitive Sciences, 1*(5), 190 -194.
120. Gregory, R. L. (1998). Brainy mind. *British Medical Journal, 317*, 1693-1695.
121. Gregory, R. L., & Harris, J. P. (1975). Illusion-destruction by appropriate scaling. *Perception, 4*, 203-220.
122. Grice, H. P. (1962). Some Remarks About the Senses. In R. J. Butler (Ed.), *Analytical Philosophy, First Series.* (pp. 133-153). Oxford: Basil Blackwell.
123. Harper, R. S., Stevens, S. S. (1948). A psychological scale of weight and a formula for its derivation. *American journal of psychology, 61*(343-351).
124. Harshfield, S. P., De Hardt, D. C. (1970). Weight judgement as a function of apparent density of objects. *Psychonomic science, 20*, 365-366.
125. Hay, J. C., Pick, H. L., Ikeda, K. (1965). Visual capture produced by prism spectacles. *Psychonomic science, 2*, 215-216.
126. Heller, M. A. (1982). Visual and tactual texture perception: intersensory cooperation. *Perception & psychophysics, 31*(4), 339-344.
127. Heller, M. A., Joyner, T. D., Dan Fodio, L. H. (1993). Laterality effects in the haptic horizontal vertical illusion. *Bulletin of the psychonomic society, 31*(440 442).
128. Heller, M. A., Joyner, T. D. (1993). Mechanisms in the haptic horizontal-vertical illusion: evidence from sighted and blind subjects. *Perception & Psychopshysics, 53*(4), 422-428.
129. Heller, M. A., Calcaterra, J. A., Burson, L. L., Green, S. L. (1997). The tactual horizontal-vertical illusion depends on radial motion of the entire arm. *Perception and psychophysics, 59*(8), 1297-1311.
130. Heller, M. A., Calcaterra, J. A., Green, S. L., Brown, L. (1999). Intersensory conflict between vision and touch: the response modality

dominates when precise, attention-riveting judgments are required. *Perception & psychophysics, 61*(7), 1384-1398.
131. Hinton, J. (1973). *Experiences*. Oxford: Clarendon Press.
132. Hollins, M., Favorov, O. (1994). The tactile movement aftereffect. *Somatosensory and motor research, 11*(2), 153-162.
133. Holway, A. H., Hurvich, L. M. (1937). On the discrimination of minimal differencies in weight: 1. A theory of differential sensitivity. *Journal of psychology, 4*, 309-332.
134. Huang, I. (1945). The size-weight illusion in relation to perceptual constancies. *Journal of general psychology, 33*,,43-63.
135. Humphrey, N. K., Morgan, M. J., Gregory, R. L. (1965). [Reply to Humphrey and Morgan] (1965) "Constancy and the geometrical illusions". *Nature, 206*(4985), 744-745.
136. Husserl, E. (1973). *Logical Investigations*. London: Routledge. Original work published 1900-1901. Second revised edition 1913.
137. Husserl, E. (1990). *Ideas Pertaining to a Pure Phenomenology and to a Phenomenological Philosophy. Second Book: Studies in the Phenomenology of Constitution*: Kluwer Academic Publishers. Original work published 1952.
138. Jacob, P. (1997). *Pourquoi les choses ont-elles un sens?* Paris: O. Jacob.
139. Jacob, P., Jeannerod, M. (2003). *Ways of seeing. The scope and limits of visual cognition*. Oxford: Oxford University Press.
140. Jones, L. A. (1986). Perception of force and weight: theory and research. *Psychological Bullettin, 100*(1), 29-42.
141. Kandel, E. R., Schwartz, J. H., Hessel, T. M. (2000). *Principles of neural science*: McGraw-Hill.
142. Katz, D. (1989). *The World of Touch*. Hillsdale: L. Erlbaum Associates Publishers. Original work published 1925.
143. Kawai, S. (2002). Heaviness perception II. Contributions of object weight, haptic size, and density to the accurate perception of heaviness or lightness. *Experimental Brain Research, 147*(1), 23-28.
144. Kirkham, R. L. (1992). *Theories of truth*. Cambridge, Mass.: MIT Press.
145. Kirsh, D., Maglio, P. (1995). On distinguishing epistemic from pragmatic actions. *Cognitive Science,* 18, 513-549.
146. Klatzky, R., Lederman, S. (1987). There's more to touch than meets the eye: the salience of object attributes for haptics with and without vision. *Journal of experimental psychology: general, 116*(4), 356-369.
147. Klatzky, R. L., Lederman, S. J., Metzger, V. A. (1985). Identifying objects by touch: An "expert system". *Perception & Psychophysics, 37*(4), 299-302.
148. Knill, D. C., Richards, W. (1996). *Perception as Bayesian inference*. Cambridge: Cambridge University Press.
149. Koseleff, P. (1957). Studies in the perception of heaviness. *Acta psychologica, 13*, 242-252.
150. Lederman, S., Abbott, S. G. (1981). Texture perception: studies of intersensory organization using a discrepancy paradigm and visual versus tactual psychophysics. *Journal of experimental psychology: human perception & performance, 7*(4), 902-915.
151. Lederman, S., Klatzky, R. (1993). Extracting object properties by haptic exploration. *Acta Psychologica, 84*, 29-40.
152. Lederman, S. J., Thorne, G., Jones, B. (1986). Perception of Texture by Vision and Touch: Multidimensionality and Intersensory Integration.

Journal of experimental psychology: Learning, memory and cognition, 12(2), 169-180.
153. Lederman, S. J., Klatzky, R. L. (1987). Hand movements: A window into haptic object recognition. *Cognitive Psychology, 19*(3), 342-368.
154. Lewis, D. (1980). Veridical hallucinations and prosthetic vision. *Australasian journal of philosophy, 58*, 239-249.
155. Loomis, J. M., Lederman, S. J. (1986). Tactual perception. In K. Boff, Kaufman, L., Thomas, J. (Ed.), *Handbook of perception and human performance*. New York: Wiley.
156. MacKay, D. M. (1951-1952). Mindlike behaviour in artefacts. *Brithish Journal of Philosophy of Science, 2*, 105-121.
157. Marr, D. (1982). *Vision*. New York: W. H. Freeman and Co.
158. Masin, S. C., Crestoni, L. (1988). Experimental demonstration of the sensory basis of the size-weight illusion. *Perception & Psychophysics, 44*(4), 309-312.
159. McCulloch, W. S., & Pitts, W. (1943). A logical calculus of the ideas immanent in nervous activity. *Bull. math. biophys., 5*, 115-133
160. McDowell, J. (1982). Criteria, defeasibility and knowledge. *Proceedings of the British Academy, 68*, 455-479.
161. McDowell, J. (1986). Singular thought and the extent of inner space. In P. Petit & J. McDowell (Eds.), *Subject, thought and context*. Oxford: Oxford University Press.
162. McDowell, J. (1998). *Meaning, knowledge and reality*. Cambridge, Mass.: Harvard University press.
163. Mellor, D. H. (1988). Crane's Waterfall illusion. *Analysis, 48*(147-150).
164. Merleau-Ponty, M. (1945). *Phénoménologie de la perception*. Paris: Gallimard.
165. Merleau-Ponty, M. (1964). *Le visible et l'invisible*. Paris: Gallimard.
166. Mfa Koert van Mensvoort, I. (2002). *What you see is what you feel: exploiting the dominance of the visual over the haptic domain to simulate force-feedback with cursor displacements.* Proceedings of the conference on Designing interactive systems: processes, practices, methods, and techniques table of contents, London, England.
167. Millar, S., Al-Attar, Z. (2000). Vertical and bisection bias in active touch. *Perception & Psychophysics, 29*(4), 481-500.
168. Millikan, R. (1984). *Language, thoughts and other biological categories*. Cambridge, Mass.: MIT Press.
169. Millikan, R. (1993). *White Queen Psychology and Other Essays for Alice*. Cambridge, MA: MIT Press.
170. Milner, A. D., Goodale, M. A. (1995). *The Visual Brain in Action*. Oxford: Oxford University Press.
171. Moore, G. E. (1922). The refutation of idealism, *Philosophical studies*. London: Routledge and Kegan Paul.
172. Murray, D., Ellis, R., Bandomir, C., Ross, H. (1999). Charpentier (1891) on the size-weight illusion. *Percept Psychophys., 61*(8), 1681-1685.
173. Nagel, T. (1974). What is it like to be a bat? *Philosophical Review, 82*, 435-456.
174. Nelkin, N. (1990). Categorizing the Senses. *Mind and Language, 5*(2), 149-164.
175. Nielsen, T. I. (1963). Volition: a new experimental approach. *Scandinavian journal of psychology, 4*, 225-230.
176. Noë, A. (1999). Thought and experience. *American Philosophical Quarterly, 36*(3), 257-265.

177. Noë, A. (2000). *Perception, action and non conceptual content*. A Field Guide to Philosophy of Mind. Available: http://host.uniroma3.it/progetti/kant/field/hurleysymp.htm.
178. Noë, A. (2002). Is perspectival self-consciousness non conceptual? *The Philosophical Quarterly, 52*(207), 185-194.
179. Noë, A. (2003). Causation and perception. *Analysis, 63.2*, 93-100.
180. Noë, A. (2004). *Action in perception*. Cambridge, MA: MIT Press.
181. Noë, A. (2004). *The enactive approach to perceptual consciousness*. Available: http://www.interdisciplines.org/enaction/papers/1.
182. Noë, A. (Forthcoming). Experience without the head. In T. S. Gendler & J. Hawthorne (Eds.), *Perceptual Experience*.: OUP.
183. Noë, A. (In press). Direct perception, *The Macmillan Encyclopedia of Cognitive Science*.
184. Noë, A. (Commissioned). Enactive consciousness. In J. Prinz (Ed.), *Handbook of the philosophy of psychology*. Oxford: Oxford University Press.
185. Noë, A. (2003). *Art as enaction*. Available: http://www.interdisciplines.org/artcog/papers/8/10.
186. O'Regan, K., Noë, A. (2000). *Experience is not something we feel but something we do: a principled way of explaining sensory phenomenology, with Change Blindness and other empirical consequences.* Paper presented at the ASSC Conference: The unity of consciousness: binding, integration and dissociation, Brussels.
187. O'Regan, K., Noë, A. (2001). A sensorimotor account of vision and visual consciousness. *Behavioral and Brain Sciences, 24*(5), 939-1011.
188. Pagano, C. C., G., S., Turvey, M. T. (1996). Is limb proprioception a function of the limbs' eigenvectors? *Ecological psychology, 8*(43-69).
189. Pagano, C. C., Carello, C., Turvey, M. T. (1996). Exteroception and exproprioception by dynamic touch are different functions of the inertia tensor. *Perception & psychophysics, 58*(8), 1191-1202.
190. Pagano, C. C., Fitzpatrick, P., Turvey, M. T. (1993). Tensorial basis to the constancy of perceived object extent over variations of dynamic touch, Perception and psychophysics. *Perception and psychophysics, 54*, 43-54.
191. Pagano, C. C., Kinsella-Shaw, J. M., Cassidy, P., Turvey, M. T. (1994). Role of the inertia tensor in haptically perceiving where an object is grasped. *Journal of experimental psychology: human perception and performance, 20*(276-285).
192. Pagano, C. C., Turvey, M. T. (1992). Eigenvectors of the inertia tensor and perceiving the orientation of a hand-held object by dynamic touch. *Perception & Psychophysics, 52*(617-624).
193. Pagano, C. C., Turvey, M. T. (1993). Perceiving by dynamic touch the distance reachable with irregular objects. *Ecological psychology, 5*(125-151).
194. Pagano, C. C., Turvey, M. T. (1995). The inertia tensor as a basis for the perception of limb orientation. *Journal of experimental psychology: Human perception and performance, 21*(5), 1070-1087.
195. Pasquinelli, E. (2003). Aux Frontières du Toucher. *Voir Barré, 26-27*, 74-86.
196. Ponzo, M. (1910). Intorno ad alcune illusioni nel campo delle sensazioni tattili, sull'illusione di Aristotele e fenomeni analoghi. *Archive für die Gesamte Psychologie, 16*, 307-345.
197. Purves, D., Augustine, G. J., Fitzpatrick, D., Katz, L. C., La Mambia, A. S., McNamara, J. O. (1997). *Neurosciences*.: Sinauer Associates.

198. Raj, V., Ingty, K., Devanandan, M. S. (1985). Weight appreciation in the hand in normal subjects and in patient with leprous neuropathy. *Brain, 108*, 95-102.
199. Ramachandran, V. S., Hirstein, W. (1998). The perception of phantom limbs. *Brain, 121*, 1603-1630.
200. Ramachandran, V. S. (2002). The neurological basis of artistic universals.
201. Ramachandran, V. S., Rogers-Ramachandran, D. (1996). Synesthesia in phantom limb induced with mirrors. *Proceedings of the Royal Society of London, 263*, 377-386.
202. Révész, G. (1950). *The psychology and the art of the blind*. London: Longmans Green.
203. Rizzolatti, G., Fadiga, L., Gallese, V., Fogassi, L. (1996). Premotor cortex and the recognition of motor actions. *Cognitive brain research, 3*, 131-141.
204. Rizzolatti, G., Fogassi, L., Gallese, V. (2001). Neurophysiological mechanisms underlying the understanding and imitation of action. *Nature Reviews Neuroscience*(2), 661-670.
205. Rock, I., Victor, J. (1964). Vision and touch; an experimentally created conflict between the senses. *Science, 143*, 594-596.
206. Roskies, A. L. (1999). The binding problem. *Neuron, 24*, 7-9.
207. Ross, H. E. (1969). When is a weight not illusory? *Quarterly Journal of Experimental Psychology, 21*, 346-355.
208. Ross, H. E., DiLollo, V. (1970). Differences in the heaviness in relation to density and weight. *Perception & Psychophysics, 7*, 161-162.
209. Ross, H. E., Gregory, R. L. (1970). Weight illusions and weight discrimination. A revisited hypothesis. *Quarterly Journal of experimental psychology, 22*, 318-328.
210. Ross, H. E., Brodie, E., Benmson, A. (1984). Mass evaluation during prolonged weightlessness. *Science, 225*, 219-221.
211. Rule, S. J., Curtis, D. W. (1976). Converging power functions as a description of the size-weight illusion: a control experiment. *Bulletin of psychonomic society, 8*, 16-18.
212. Rule, S. J., Curtis, D. W. (1977). The influence of the interaction of weight and volume on subjective heaviness. *Perception & Psychophysics, 22*, 159-164.
213. Russell, B. (1912). *The problems of philosophy*. London: Williams and Norgate; New York: Henry Holt and Company.
214. Searle, J. (1983). *Intentionality: An Essay in the Philosophy of Mind*. Cambridge: Cambridge University Press.
215. Sellars, W. (1956). Empiricism and the philosophy of mind. In H. Feigl & M. Scriven (Eds.), *Minnesota Studies in the Philosphy of Science*. Minneapolis, MN: University of Minnesota Press.
216. Sellars, W. (1968). *Science and metaphysics*. London: Ridgeview.
217. Singer, G. (1968). The influence of two varieties of proprioceptive information on judgments on the spatial position of an object while the visual input is transformed. *Psychonomic science, 11*, 295-296.
218. Singer, G., Day, R. H. (1965). Kinesthetic figural aftereffects. *Journal of experimental psychology: Human perception and performance, 69*, 343.
219. Singer, G., Day, R. H. (1966). The effect of spatial judgment on the perceptual aftereffect resulting from transformed vision. *Australian journal of psychology, 18*, 63-70.

220. Singer, G., Day, R. H. (1969). Visual capture of haptically judged depth. *Perception & psychophysics, 5*, 315-316.
221. Snowdon, P. (1980-1981). Experience, vision and causation. *Proceedings of the Aristotelian Society, 81*, 175-192.
222. Solomon, H. Y. (1988). Movement produced invariants in haptic exploration: an example of a self-organizing, information-driven, intentional system. *Human movement science, 7*, 201-223.
223. Solomon, H. Y., Turvey, M. T. (1988). Haptically perceiving the distances reachable with hand-held objects. *Journal of experimental psychology: Human perception and performance, 14*(3), 404-427.
224. Solomon, H. Y., Turvey, M. T., Burton, G. (1989). Gravitational and muscular variables in perceiving extent by wielding. *Ecological Psychology, 1*, 265-300.
225. Solomon, H. Y., Turvey, M. T., Burton, G. (1989). Perceiving Extents of Rods by Wielding: Haptic Diagonalization and Decomposition of the Inertia Tensor. *Journal of Experimental Psychology: Human Perception and Performance, 15*(1), 58-68.
226. Sorensen, R. (2002). The art of the impossible. In T. Gender & J. Hawthorne (Eds.), *Imagination, conceivability, possibility*. Oxford: Oxford University Press.
227. Stein, B. E., Meredith, M. E. (1993). *The merging of the senses*. Cambridge, Mass.: MIT Press.
228. Stevens, J. C., Cain, W. S. (1970). Psychophysical scales of apparent heaviness in the size-weight illusion. *Perception and psychophysics, 8*, 225-230.
229. Stoffregen, T. A., Bardy, B. G. (2001). On Specification and the Senses. *Behavioral and Brain Sciences, 24*(1).
230. Strawson, P. F. (1979). Perception and its objects. In G. F. MAacDonald (Ed.), *Perception and identity*. London: Macmillian.
231. Suzuki, K., Arashida, R. (1992). Geometrical haptic illusion revisited: Haptic illusion compared with visual illusion. *Perception and Psychophysics, 52*(3), 329-335.
232. Tastevin, J. (1937). En partant de l'expérience d'Aristote. *Encéphale, 32*, 57-84
233. Taylor, C. M. (2001). Visual and haptic perception of the horizontal-vertical illusion. *Perceptual & motor skills, 92*(1), 167-170.
234. Thalman, W. A. (1922). The after-effect of movement in the sense of touch. *Am. J. Psychol., 33*, 268-276.
235. Thouless, R. H. (1931). Phenomenal regression to the real object. *British Journal of Psychology, 22*, 1-30.
236. Treisman, A. (1996). The binding problem. *Current opinion in neurobiology, 6*, 171-178.
237. Treisman, A., Schmidt, H. (1982). Illusory conjunctions in the perception of objects. *Cognitive Psychology, 14*, 107-141.
238. Turvey, M., Shaw, R. E., Reed, E. S., Mace, W. M. (1981). Ecological Laws of Perceiving and Acting: In Reply to Fodor and Pylyshyn. *Cognition, 9*, 237-304.
239. Turvey, M. T. (1992). Ecological foundations of cognition: invariants in perception and actionIn H. L. Pick & P. van den Broek & D. C. Knills (Eds.), *Cognition: Conceptual and methodological issues*. Washington, D. C.: American Psychological Association.
240. Turvey, M. T. (1996). Dynamic touch. *American Psychologist, 51*(11), 1134-1152.

241. Turvey, M. T. (1998). Dynamics of effortful touch and interlimb coordination. *Journal of biomechanics, 31*, 873-882.
242. Turvey, M. T., Burton, G., Amazeen, E. L., Butwill, M., Carello, C. (1998). Perceiving the width and height of a hand held object by dynamic touch. *Journal of Experimental Psychology: Human Perception and Performance, 24*, 35-48.
243. Turvey, M. T., Burton, G., Pagano, C. C., Solomon, H. Y., Runeson, S. (1992). Role of the inertia tensor in perceiving object orientation by dynamic touch. *Journal of experimental psychology: Perception and human performance, 18*, 714-727.
244. Turvey, M. T., Carello, C. (1995). Dynamic touch. In W. E. S. Rogers (Ed.), *Handbook of perception and cognition* (pp. 401-490). San Diego: Academic Press.
245. Turvey, M. T., Carello, C., Fitzpatrick, P., Pagano, C., Kadar, E. (1996). Spinors and selective dynamic touch. *Journal of experimental psychology: Human perception and performance, 22*(5), 1113-1126.
246. Viviani, P. (1990). Motor-perceptual interactions: the evolution of an idea. In M. Piattelli Palmarini (Ed.), *Cognitive Sciences in Europe: Issues and trends* (pp. 11-39): Golem.
247. Viviani, P., Baud-Bovy, G., Redolfi, M. (1997). Perceiving and tracking kinesthetic stimuli: further evidence of motor-perceptual interactions. *Journal of experimental psychology: human perception & performance, 23*, 1232-1252.
248. Viviani, P., Stucchi, N. (1989). The effect of movement velocity on form perception geometric illusions in dynamic displays. *Perception & Psychophysics, 46*, 266-274.
249. Vogels, L. M., Kappers, A. M., Koenderink, J. J. (2001). Haptic after effect of successively touched curved surfaces. *Acta Psychologica, 106*(247 263).
250. Vogels, L. M. L. C., Kappers, A. M. L., Koenderink, J. J. (1996). Haptic after effect of curved surfaces. *Perception & Psychophysics, 25*, 109-119.
251. Vogels, L. M. L. C., Kappers, A. M. L., Koenderink, J. J. (1996). Influence of stimulus sequence on the haptic after effect. In A. M. L. Kappers & C. J. Overbeeke & G. J. F. Smets & P. J. Stappers (Eds.), *Studies in Ecological Psychology* (pp. 135-138). Delft: Delft University Press.
252. Vogels, L. M. L. C., Kappers, A. M. L., Koenderink, J. J. (1997). Investigation into the origin of the haptic after effect of curved surfaces. *Perception & Psychophysics, 26*(1), 101-117.
253. Watson, A., French, C. (1966). Mueller-Lyer haptic illusion and a confusion theory explanation. *Nature, 209*(26), 942.
254. Weber, E. H. (1978). *The sense of touch*. London: Academic Press. Original work published in 1934.
255. Welch, R. B., Warren, D. H. (1981). Immediate perceptual response to intersensory discordance. *Psychological bulletin, 88*, 638-667.
256. Wiener, N. (1948). *Cybernetics, or control and communication in the animal and the machine*. New York: Wiley.
257. Wittgenstein, L. (1958). *Philosophical investigations*. Oxford: Basil Blackwell.
258. Wolfe, H. K. (1898). Some effects of size on judgments of weight. *Psychological Review, 5*, 25-54.
259. Wong, T. S. (1975). A further examination of the developmental trend of the tactile horizontal vertical illusion. *Journal of Genet. Psychol., 127*, 149-150.

260. Wong, T. S. (1975). The respective role of limb and eye movements in the haptic and visual Muller-Lyer illusion. *Quarterly Journal of Expeprimental Psychology, 27*(4), 659-666.
261. Wong, T. S. (1977). Dynamic properties of radial and tangential movements as determinants of the haptic horizontal-vertical illusion with an L figure. *Journal of experimental psychology: Human perception and performance, 3*(1), 151-164.
262. Wong, T. S. (1979). Developmental study of a haptic illusion in relation to Piaget's centration theory. *Journal of experimental child psychology, 27*, 489-500.

Index of subjects and names

Index of boxes

Index of tables

Index of figures

Acknowledgements

I started my research for this thesis while I was working at PERCeptual Robotics Lab (PERCRO) of the Scuola Superiore Sant'Anna, Pisa, Italy. The idea of a thesis on illusions and the focus on haptics were strongly motivated by the first contacts with the lab director, Massimo Bergamasco. Subsequently, the daily exchanges with members of PERCRO have constituted an invaluable source of knowledge about the haptic interfaces, the existing research on haptics and the different aspects of Virtual Reality. The questions that the members of PERCRO have posed to me about the notions of illusion, sensory modality, conflict, coherence, expectation and the practical needs related to the realization of functional and efficient interfaces for the haptic sensory modality and intersensory perception have constituted the ground of my analysis of these notions and phenomena. I want to thank Massimo Bergamasco (who is also part of the commission of evaluation of this thesis) and all the friends at PERCRO, for an experience that has been both professionally and personally enriching.

While I was still collaborating with PERCRO I have been involved in another stimulating experience: the proposal and then the constitution of a European Network of Excellence on Enactive Interfaces (IST-2002-002114 enactive network of excellence). This project has financed part of the research for my thesis and has created a net of communication and exchanges with the most interesting researchers in Europe and beyond, including psychologists of different theoretical approaches to perception (ecological, sensorimotor, inferential), engineers, computer scientists, psychophysicists. I want to thank all of them for the inspiration they have provided in addition to the knowledge they have shared with the community of the Network. A special thanks to Benoit Bardy, who, in addition to the continuous motivation he has offered with his ideas and critical attitude, has also accepted to participate in the commission of evaluation of this thesis.

As to the philosophical development of the thesis I want to express my gratitude to the two institutions that have coordinated this work, the Dipartimento di Filosofia of the Università di Pisa and the Institut Jean Nicod of Ecole des Hautes Etudes en Sciences Sociales and Ecole Normale Supérieure.

Guglielmo Tamburrini, of the Dipartimento di Filosofia, has co-directed this thesis. It was he who suggested to me the direction of the studies on perception and who addressed me to Massimo Bergamasco, in order to find more pragmatic grounds for my research and to face the problems connected with the application of knowledge related to perception and illusions. It was also he who directed my very first steps in the domain of the epistemology of perception. Even if they have not taken part in the work for this thesis I cannot forget the role that other people of the Dipartimento di Filosofia have played in my philosophical passions and attitude. In particular I want to thank Paola Bora, who is also responsible for my going to Paris, and Aldo Giorgio Gargani, my guide since my first steps in the domain of philosophy and my source of inspiration since then.

Institut Jean Nicod is a wonderfully stimulating place. I want to thank the friends I have there and the people that have contributed to this thesis by their comments, views and works: Jérôme Dokic, Dario Taraborelli, Nicolas Bullot, Nivedita Gangopadhyay, Roberto Casati.

Jérôme Dokic, as well as Massimo Bergamasco and Roberto Casati have done a great work for me with their comments on the pre-final version of my thesis. Their suggestions have been the most precious.

Roberto Casati, my PhD advisor, deserves a particular place in these acknowledgements. He has read every line I have written in the last four years, and commented on each one of them. He has given me advice about every aspect of my research, sustained my professional activity and encouraged me. Over the years he has also become a dear friend and it is easy to me to thank him dearly.