Technology and Perception : the Contribution of Sensory Substitution Systems

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The strong programme of research in the study and development of cognitive technologies today is based on the hypothesis that these technologies are not only technical means which enable us to enhance our calculating, memorising or perceptive abilities, but that they actually play a key role in the constitution of human experience. The aim of this article is to provide this hypothesis with experimental content through the study of a series of very specific technical devices usually referred to as "sensory substitution systems". After analysing some of the results achieved so far, we will describe several experiments on the construction of a three-dimensional perceptual space through technical means. We will then demonstrate the role of human action, and, therefore, of the "corps propre" (the body from the point of view of the subject), in the process of the construction of perception. These experiments will also enable us to discuss the conditions for conducting fundamental research in the field of technology, combining scientific method and phenomenological analysis. In conclusion we will suggest various possible lines of future research on this subject.

KEYWORDS: SPACE ; PERCEPTION ; PHENOMENOLOGY ; SENSORY SUBSTITUTION ; COGNITIVE TECHNOLOGY.

Technical artefacts should not merely be understood as means that allow human beings to achieve certain pre-set goals. On the contrary, the process of their development and integration by individuals and societies transforms, or invents, the very goals of human activity. This is the strong version of a research programme in cognitive technology. It consists in adopting the hypothesis that technologies actually constitute human experience, by generating new domains of what is possible with unexpected consequences. The aim of this article is to furnish this hypothesis with experimental content. We wish to show in particular that cognitive technologies are not only relevant for the creation of new calculating or memorising abilities, but that they can actually give rise to new modes of perception. This sort of study is made possible by a series of very particular technical devices which were initially developed to assist people with sensory handicaps.

I. Sensory substitution systems: presentation and results

Devices referred to as "sensory substitution systems" have been developed since the end of the 1960's for assisting the blind [6, 14]. These devices transform stimuli that are linked to one sensory mode (vision) into the stimuli of another mode (touch). In a classic situation (Tactile Vision Substitution Systems), a visual image captured by a video camera is converted into a tactile "image" made up of a surface of stimulators (generally a 20 / 20 matrix) placed on the subject's back, chest or forehead [8][1]. The only system which has been widely marketed is the Optacon, a device normally designed for reading: the image captured by a video camera placed on the text is reproduced on a matrix of micro-vibrators (with 6 columns of 24 rows), on which the blind subject places one finger of his/her free hand[2]. With the addition of a lens, the Optacon can be modified so as to capture light coming from the distal environment [5].

Such devices were developed for assisting persons affected by blindness (whether congenital or not); however, they may also be used by sighted subjects who have been blindfolded. The first applications of these devices have yielded three fundamental results which we now take as the starting point of our research.

[1] For a system that is currently marketed, see: UNITECH RESEARCH, INC., 582 Grand Canyon Drive, Madison, WI 53719. http://www.execpc.com/~unitech
[2] Optacon - Telesensory Systems, Palo Alto, California, USA

i) First, forms that are shown to an immobile camera enable only limited discrimination of the stimuli received, and these are perceived as being situated on the surface of the skin. Thus, the mere substitution of an input through the optic nerve by a tactile input does not, as such, enable a spatial type of perception.

ii) However, if the user is given the possibility to manipulate the camera (e.g. to perform right-to-left and up-and-down movements, forward and backward zooming, focussing changes), he/she develops spectacular abilities to recognise forms. The user first learns how the variations in his sensations are linked to his own actions: when he moves the camera from left to right, the stimuli on his skin move from left to right; when he zooms forward, the stimuli spread out; etc. After having learned how to direct the camera towards a specific target, he begins to distinguish lines and volumes; later he recognises familiar objects of increasing complexity; eventually he is able to discriminate human faces.

Moreover, this ability to recognize forms is accompanied by an *exteriorisation*, a projection of the percepts which become objects located in space. At first the user only senses a series of stimulations on his skin. But as he progresses in his perceptive learning, he gradually comes to forget these tactile sensations and to perceive stable objects at a certain distance, "out there in the world" in front of him. Thus, according to users' declarations, the proximal irritation caused by the tactile matrix is clearly distinguished from the perception itself. This subjective locating of objects in space occurs rapidly (after 5 to 15 hours of training). The blind subject thus discovers perceptive concepts which are new for him, such as parallax, shadows, object interposition, etc. Some classic visual illusions are reproduced spontaneously [3, 13]. Such experiments can be performed just as well by a sighted person who has been blindfolded as by a visually handicapped person.

The process of perceptive learning prompted by such a device highlights the surprising plasticity of the central nervous system, which is made to undergo vast functional reorganisation. The tactile sensory input has nothing to do with the visual one, no more than the controlling of the camera with one's hands has any connection with the commands of the ocular muscles. And yet, the brain proves capable of organising a perceptive world whose forms and events coincide with those given to us in visual perception. Moreover, when, in the case of a trained subject, one moves the tactile stimulator matrix from the chest to the back, or if one replaces the camera which was held in the subject's hands with a miniature camera fixed to the frame of a pair of glasses, the subject adapts almost immediately. In a few seconds, he recovers a distal perception in front of him.

The fact that the subject needs to perform an action upon the sensory captors in order to build a perception makes the term "sensory substitution systems" inadequate. It appears indeed that what the technical device must provide is not only access to new sensory data, but also the power to act upon the receptor system. It is therefore more appropriate to refer to these systems as "sensori-motor coupling devices". As a matter of fact, the same is true for natural vision - it requires both a functional eye and the activity of the ocular muscles which determine saccadic movements of the eye (of 10 to 20 milliseconds). In cases where the eye is perfectly immobilised, no vision seems to be possible. The image that was perceived vanishes in a few seconds [9, 19].

This essential role of action in the gradual emergence of structured representations shows that what is perceived, or recognised, are not strictly speaking the invariants of the sensation, but the invariants of sensori-motor loops that are inseparable from the subject's own activity [11, 12, 22, 21]. We depart here from the classic idea of perception, in which the system received input data passively, then performed a calculation in order to identify objects, events, etc., and produced representations within an internal space. On the contrary, it is by his/her action that the subject seeks and builds rules about constant relations between action and sensation. These rules, which enable the subject to anticipate the effects of actions upon sensations, correspond to the perception of forms and of their spatial position. The perception of an object consists in isolating what remains constant in the relation between a varying action (i.e. the mobility of the perceptive organ) and a varying sensation (caused by the subject's action). The richness of the perception must therefore depend as much upon the characteristics of the action (mobility, speed, zooming, etc.) as upon those of the sensation (width of the spectrum, number of sensors, etc.).

iii)- Nevertheless, the first spectacular achievements of systems developed for handicapped people also brought with them an unexpected disappointment: blind users rejected the devices, calling them unsatisfactory and depressing. These technologies were developed in the 1960's, the first successful experiments have been described and known since the 1970's, and yet they have not come to pervade our daily life, or at least that of non-sighted people [4]. Indeed what these systems can offer to a blind person is not the vision of which sighted people talk to him so much. There are no colours, few points, and a camera with awkward and limited movements, which causes great slowness in recognising a situation. This sensori-motor coupling resembles, in some ways, that of our vision, but it does not replace it. Its performance is more of an additional kind: it is a new mode of perception that opens an unprecedented space for a coupling between the subject and his/her environment. A sighted and blindfolded person, or a blind person having lost sight at a late stage, is perfectly able to tell the difference: what the device shows them is not at all what they know about vision. It is simply "information" about forms and their positions, but the quality of the experience is incomparable. What is most badly missing, according to users' declarations, are the subjective values of perceptions (for example, subjects discover their own face, or faces of their close relatives, without attributing any emotion to them) [1, 7]. But the contrary would have been surprising. The emotional value of a form is not simply data which must be captured. It has to be built up through a specific learning process. The question, raised by the first users, of the subjective meaning that is, or is not, attributed to these new perceptions, therefore leads to the problem of the relation between representations and affects.

These are two areas of research which should not be separated: perception as a process of acquiring and composing sensori-motor invariants of increasing levels, and the building of a value system attributed to these invariants. In Kantian terms, what should be done here is to establish a relationship between the aesthetics of perception (The Critique of Pure Reason) and the aesthetics of judgement (The Critique of Judgement). But in this article we will only be able to describe experiments concerning the first of these points.

The spectacular results achieved by these perception devices highlight an original research method for studying the cognitive effects of technologies: providing a subject with a novel sensori-motor coupling device gives us a means for studying empirically how his/her way of perceiving and acting is transformed. Such a study requires, therefore, a combination of two types of approaches.

On one hand, from an external point of view, it is possible to study the ways in which the device is used and the new abilities it brings to the subject. This type of observation will be of interest for a whole range of different scientific approaches, from sociology to psychology and classical psycho-physiology (for instance, measuring the speed of solving specific tasks). But to limit oneself to such studies would be insufficient. Indeed, the fact that the user is offered an opportunity to acquire a new mode of perception makes it important to follow, from an inside point of view, the way in which the world appears to the subject.

It is therefore necessary, on the other hand, to study from an internal point of view the way in which technical devices transform the subject's modes of perception, of reasoning or of action. This requires us to resort to a phenomenological type of method. Indeed, since Husserl, this philosophical approach consists in a "return to the things themselves", as they appear in consciousness. It therefore focusses on the way in which phenomena appear, independent of the existence of any particular thing as such which might cause these phenomena to occur, and independent of any scientific theory which would claim to explain it. The phenomenological approach therefore consists in putting in parentheses the theory of the existence of an outside world (this is the phenomenological reduction). In the framework of an experimental type of research, such internal knowledge is accessible only through the direct implication of the researcher, or by creating the conditions for a sufficiently comprehensive verbalisation of the private thoughts of the subject of the experiment. We will return, in our conclusion, to the apparently paradoxical conditions required for such "experimental phenomenology".

But first I would like to describe a few experiments and some very preliminary results, which will enable us to justify the above statements and will give an outline of a research programme in which empirical studies are combined with philosophical analyses.

II. Research on the construction of space

The success of artificial perception devices shows that it is possible to give empirical content to certain aspects of the question of intentionality, i.e., in the present case, of the subject's awareness of something existing "outside" (the appearing of a phenomenon in a spatial perceptive field), since these devices allow one to follow and to reproduce the genesis of such awareness in adults. Our aim is to define the minimal technical conditions required for the emergence of the sense of exteriority of an object in a perceptive space where it can be located. To do this, we use a sensory substitution device which has been simplified to the extreme, so as to enable us to identify the limit where this spatialisation becomes possible.

We have chosen a simple photo-electric cell fixed to a finger of the subject's right hand and connected to a tactile stimulator (a vibrator) which is held in the other hand. The vibrator reacts in all-or-none fashion to the crossing of a threshold of activation of the photo-electric cell, which captures a fairly wide ray of incidental light (approximatively 20 °). Thus there is only one point of stimulation, corresponding to one receptor field (by contrast, the TVSS has 400 stimulation points corresponding to the same number of distinct receptor fields on the camera's sensitive surface). One might also use for the same purpose an Optacon modified for capturing distal light and on which one would keep only one of the 144 possible tactile stimulation points.

II.1. Free exploration.

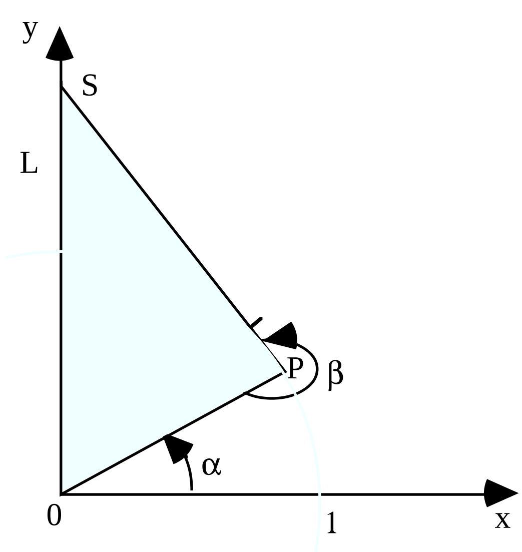
In the first experiment, a luminous target is placed at a distance from the subject in a dark room. The subject is blindfolded and can move freely his arm and his hand which is holding the receptor.

- Results from the point of view of the outside observer: after a few minutes of exploration, the subject proves able to locate the target, i.e. to indicate its direction and its approximate distance. He can also make a rough evaluation of the target's volume (It will be the subject of a further study to determine the effects of learning on the user's locating speed.)

- Results from the point of view of the subject: after an initial period searching for any activation of the vibrator, he perceives those first tactile stimulations as located on his skin. But very soon, as he gains better control over the production of such stimulations, he senses the presence of an object located in space outside of him. The succession in time of the sensations he receives seems to point to different "contacts" with a single distal object. It should also be noted that the vibrator can be moved towards a different area of the skin without interrupting the perception. In fact the subject actually comes to forget the place in which the sensations occur (except when paying specific attention to this) and to perceive an object in space. Conversely, stimuli that are sent artificially, regardless of the movements of the finger on which the photo-sensitive cell is fixed, are not associated with any distal perception but remain perceived as proximal sensations on the skin.

It is quite easy to understand how it is possible for the subject to locate the target. The conditions set by this ultra-simplified coupling device for his exploration are sufficient. For greater simplicity, let us consider only the movements of the extended arm, and of the hand in relation to the arm (excluding the elbow and the many articulations of the fingers and hand). We assume that the subject's position is fixed, his chest always turned in the same direction. We consider only those movements which are in a horizontal plane (a three-dimensional space can be retrieved by also integrating up-and-down movements). We consider that the target is a point-source, S, with coordinates (0, L). It is in front of the subject, who is placed in O. The angle indicating the direction of the arm is α = (Ox, OP); the angle between the arm and the hand is β = (PO, PS). Point P ($\cos\alpha$, $\sin\alpha$) represents the subject's wrist. If two pairs of values (α, β) are known in the subject's reference frame, they are sufficient for the subject to locate the light source S.

Experiment No. 1:



The arm (with the forearm) has a length of 1. The distance from the target, L (0S), can then be obtained by a trigonometrical relation, according to the following formula:

$$L = \sin\alpha - \cos\alpha \tan(\alpha+\beta) \qquad (1)$$

where α : [0, π/2] and β :]3π/2-a, 2π[

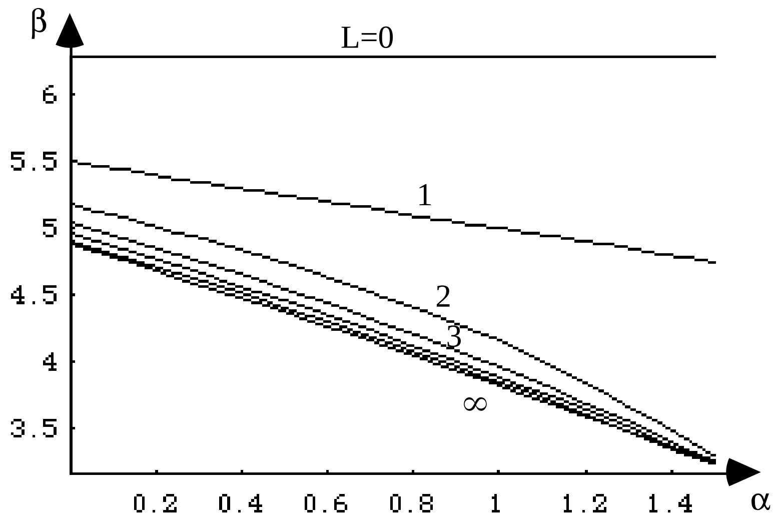
We observe experimentally, however, that in practice two "contacts" with the target are not sufficient to give rise to an actual subjective experience of a distal object. First, proprioception alone offers only very imperfect access to the values of α and β; secondly, and more importantly, if the movements cease, the spatialisation disappears. In cases where the subject remains still, the tactile stimulation may be either absent or present, but nothing suggests that its source might be external and distal. Thus, by its extreme simplicity, our sensori-motor coupling device shows that the performance of an action is an absolute necessity for making perception possible. Perception requires permanent activity: it is necessary to tilt the hand and to change the position of the wrist, so that the stimulation may constantly appear and disappear.

How then shall we characterise the way in which a spatial perception is built from the subject's point of view? The problem is not so much to understand the way in which the notion of space is generated as such. The subjects already have general notions of exteriority, space and time. What we are looking at is the process of constructing the spatialisation of an object which will thereafter be thought of as the source of the subject's sensations. The question of whether any perception is possible in space is in fact the problem of whether it is possible to conceive of separate events as being simultaneous. But how can the diversity of sensations that are perceived by the subject as successive in time be thought of as referring to simultaneous objects? This requires an activity whereby the succession of different sensations over time is synthesised, according to a certain rule. This rule, as Kant has shown, is the rule of reversibility:

> "Things are simultaneous when, in empirical intuition, the perception of one thing can follow the perception of the other, and conversely (...)." (Kant, E. (1787) *The critique of pure reason*, [14] The analogies of experience, third analogy. The principle of simultaneity.)

Space emerges only as a result of its reversible exploration, i.e. of the possibility of finding again the same sensations by looking "back" at a previous "position". Thus, the perception of the target as located in space is obtained only if one has access to the rule of dependent variation between movements α and β, which maintain the tactile stimulation.

Let us note here one of the advantages of the experimental method we have chosen: one could suppose that the general dynamics described by such curves is already inscribed in our brain as a faculty to "point our finger" at any point in space. It is that sensori-motor scheme which we use (only reversing it) for "perceiving with our finger". If, then, this general scheme is pre-established, perception as such corresponds only to the selection of one particular line of covariation between α and β. This selection must occur very rapidly, as soon as the target is "caught". However, the solution which we have chosen for the problem of spatialisation is clearly



Curve representing angle β in relation to angle α (both expressed in radians) for the following values of L = 0,1,...,7. α varies from 0 to $\pi/2$. According to (1) one can determine β for any given L and α:

$$\beta = 2\pi - \alpha + \mathrm{Atan}((\sin\alpha - L)/\cos\alpha) \qquad (2)$$

different from that suggested by Kant. Indeed, for Kant, space emerges from a process of synthesis, spread over time, which focusses exclusively on a succession of sensations. In other words, this synthesis works according to a rule which links together only sensations. Action has no other function than to open access to this diversity of sensations. It does not play any constitutive role. The solution we suggest, in contrast, is a rule that links together actions and sensations (i.e. the law of covariation between α and β which determines a sensation); this rule is also, at the same time, a structure for anticipation, since perceiving an object is in fact being able to anticipate the sensation which will be received, given certain actions. As Maurice Merleau-Ponty wrote: "My body has a hold on the world [...] when my motor intentions, being put into action, receive from the world the responses which they had expected." [17: *289-290*].

The crucial role of action in perception becomes clear when we begin to seek the borderline conditions required to make the sense of spatialisation disappear, either by complicating the task (for example, by displaying moving targets or targets which switch on for only short periods of time), or, precisely, by limiting the subject's range of possible actions. This last line of investigation is the one which we describe here.

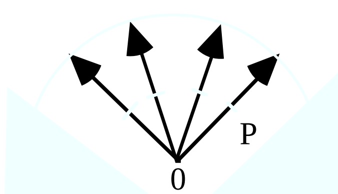
II.2. Exploration by rotation

In the second experiment, the subject is asked to limit his movements to a sweeping gesture with his arm extended (or to a sweeping gesture of the hand, with the arm remaining still) (see figure).

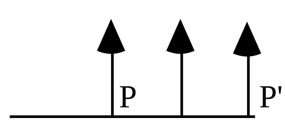
- Results from the point of view of the outside observer: the subject can indicate the direction of the target and roughly evaluate an angle "width", but he cannot tell the distance of the target [10].

- Results from the internal point of view: the subject declares that he has access to only two dimensions in space, "width" and "height". There is no "depth". However, once the target is "caught", the succession of sensations is indeed linked to an outside, immobile object in this two-dimensional space.

Access to a third dimension of space requires one additional action, as in the first experiment where the subject could move both his arm and his hand. But what are the specific characteristics of the movement that enables to perceive depth? In order to understand it, one must consider the way in which the subject locates himself in relation to the space that he perceives. In the first experiment, the subject perceived himself inside the space of the perception which he was building. From the moment when the object was perceived, the hand was simultaneously, at every moment, located in relation to that object (on the side to the right, or in front and above, etc.). As a matter of fact, this sense of belonging to the perceived space was reinforced if the whole body was allowed to move. What the subject senses as his location is the place where he is in action, i.e., in the perception experiments described here, the place where the receptor device is moving (not where the sensation is received). By contrast, in the second experiment, the subject does not think of himself as located in the two-dimensional space in which he perceives the target: he feels as if placed in front of the space which he perceives (even if this space can be perceived as being in contact with him). The decisive condition giving rise to depth would therefore seem to be that the action which makes it possible is a movement *in* the perceived space. Depth is the result of a form of commitment by the subject, of a relocation of the point of view of perception, i.e. of the spatial position from which the sensations are captured. The hand must move forward in the perceived space. Depth can, therefore, in no case be understood as a simple rule linking together different sensations; it requires that actions be integrated. We can find a relation here with the results of Maurice Merleau-Ponty's analysis of the phenomenology of perception. Perception depends on the subject's own "body image" ("corps propre"), i.e. not on the body as a perceived object, but on the body from the point of view of the subject, as a set of possible actions .



Experiment 2 : angular scanning



Experiment 3 : linear scanning

> "What is important for the general orientation of the performance is not my body as it is in fact, as a thing in objective space, but my body as a system of possible actions, a virtual body whose phenomenal <location> is defined by its task and by its situation. My body is there where there is something to do" [16: 289]

If depth were to be captured by a synthesis limited to sensations alone, the subject would have to use various characteristics of the three-dimensional space projected onto the two dimensions perceived. For example, one could imagine that the effects of perspective and of constant size might give, as such, access to a three-dimensional spatialisation. A target that would gradually diminish in width could be thought of as receding. But, as Merleau-Ponty has also shown, apparent size can only serve as an indication of depth, not as a means for constructing it. A synthesis of that type would require the possibility of assuming from the outset an objective movement over there in front, in depth - a depth which we could not have since, precisely, it has yet to be constituted.

But, some will say, our solution of integrating action is based on a three-dimensional movement of the subject. We are therefore assuming, here too, what we are trying to construct. Indeed, this seems to be an impassable origin in the constructing of spatial perceptions: we have to admit that we already have, prior to perception, an original form of access to depth - the action of entering into the unknown, that is also the hallmark of our finiteness.

> "Thus depth cannot be understood as the thought of an a-cosmic subject, but as a possibility for a committed subject."[17: *309*].

The perception of space is characterised by a commitment of the perceiving subject, which is the movement of the subject of this perception in the subject's perceived space. But must we conclude from these reflections on action that the experience of depth is distinguished by this absolute unfathomable originality? In fact, no. There already is, even in the process of constructing width (and height), a commitment of the subject of the same nature as with depth. This is well demonstrated by a third experiment, which is based on another limitation of the subject's movements.

II.3. Exploration by translation

In the third experiment, the subject is asked to move his hand while maintaining his finger constantly pointed in a single direction, opposite him (see figure). The movements of the shoulder, elbow and hand articulations are complex, but the movement of the photo-sensitive cell remains simple, since it moves by translation along a plane which is perpendicular to the direction of the body (with the receptor field always facing ahead).

- Results from the outside point of view: as in the second experiment, there is no evaluation of the target's distance, but the subject can indicate the direction of the target and give a rough estimate of its width and height (however, in this case these values are given according to a linear type of measurement);

- Results from the internal point of view: the subject again declares that he can only conceive of two dimensions of the object, its "width" and its "height". There is still no "depth"; the succession of stimulations is, here too, linked to an external, immobile object located inside that two-dimensional space. However, this time the subject feels more involved in the perceived space, even though the latter remains flat. Here indeed, like in the first experiment, there is clearly a relocation of the place of action into the perceived space: the hand moves in the plane of perception. It is located in relation to the perceived object (to its right, left, above or under). This movement is close to that of a haptic exploration of the environment by touch (as in the case of stroking). Thus, width and height too result from a minimal commitment of the subject. The case of depth only enabled us to stress the more general importance of the subject's action. Whatever the spatial dimension, it emerges from the power of capturing a reversibility, which requires the possibility to go away and come back, i.e. to leave one's present position and to risk going out into the unknown by taking a real action. Width and height also result from a commitment of the subject which is necessary to capture a reversibility. They are, however, dependent on the degree of this commitment. A linear movement (as in the third experiment), which implies a movement of the hand into the perceived space, gives access to a linear type of measurement; on the contrary, an angular movement implying no other movement of the point of view but for the changes in its orientation gives access exclusively to angular measurements.

It should be noted here that the movement required in the third experiment is exactly that which would be obtained in the first experiment if the subject perceived an object placed at an infinite distance: in this case, angles α and β would vary in such a way that the straight line PS (which indicates the direction of the finger) would remain parallel to Oy (the direction of the body):

$$\lim_{l \to \infty} \beta(\alpha,L) = 3\pi/2 - \alpha.$$

We have indeed no access to volume perception for objects that are placed sufficiently far from our power to act. This explains why, for example, ancient civilisations could for so long consider the starry sky as a spherical surface. In order to see the sky as an arrangement of suns at many different levels in depth, one has to imagine oneself moving among those stars.

A perception is not located inside a space of representation that is internal to the knowing subject, separate from a supposedly "external" space. It is built from the sensori-motor invariants of a coupling relation which implies the body as much as the medium in which the body is active. The space inside which perceptions are given is, at the same time, the space in which the subject moves. The subject lives inside the world which he perceives. Thus, space expresses our finiteness. It transcends the subject which inhabits it and is always a potential carrier of real risks, since the changes which take place in it can affect the subject who perceives it. We therefore understand that action is not a neutral movement that takes place outside of the knowing subject. It is always a relocation of the subject's capacity to act and to perceive which requires a real commitment from him.

II.4. The technical constitutivity of perception

We began by adopting a Kantian perspective, according to which an object in perception cannot be captured as the simple reflection of a thing as such which would be the cause of all phenomena (indeed, from the internal point of view of the subject, there is no other access to objects than the sensations which are given to him). Thus, the object must be understood as the result of an activity of human knowledge: it is a set of rules for synthesising sensations. Its objectivity is ensured by the universal and necessary character of these rules for all cognitive minds. For Kant, the origin of this necessity is linked to a universal, transcendental subject which must be assumed a priori.

However, in a spirit similar to the reflections of Maurice Merleau-Ponty, we have shown that the process of perceptive synthesis must bring actions and sensations together. Action is constitutive of perception. But the set of possible actions is defined by the powers of the subject's own "corps propre" (body image).

> "We must relate everything to the organic relations between subject and space, to this power of the subject over his world, which is the origin of space." [17: *291*]

The objects that are accessible through perceptive synthesis depend on the "corps propre" (body image), as do the possible actions of the perceiving subject. But our experiments clearly demonstrate that technical devices can be a kind of prostheses that change the body itself. They transform the system of possible actions and place restrictions on the links between those actions and the sensations. Thus, a technical device can set the rules of synthesis that are accessible to perceptive synthesis. This is what justifies our hypothesis that technical devices can be constitutive of new perceptive spaces, i.e. of spaces of representation and manipulation (real or potential) where the subject is distinguished from the objects on which he can perform actions[3]. At the same time, it also justifies the possibility of a paradoxical "experimental phenomenology", which opens a new, original line of research on the status of technology. We will therefore conclude with three theoretical and methodological remarks which define an area of research that we have only started to explore.

III. Methodological remarks and prospects for experimentation

III.1. Images and parallelism

In our experiments we chose borderline conditions for which the constructing of a space did not require the reception of a whole image, but only of a single pixel that reflected the presence or absence of a stimulus. As we have seen, such a device is sufficient to enable the thought of points with a location in space. In theory, by juxtaposing and composing these point perceptions, access to spatial forms should be possible. But in fact, the perception of forms is strongly restricted by the subject's memory abilities and speed of exploration. To solve this problem, we can gradually introduce a series of parallelisms in our system: we fix on the same finger several receptors which are photo-sensitive to parallel rays of incidental light, and each of which is connected to a different tactile stimulator. By doing this we obtain again classic systems of sensorial substitution. However, the genesis of our research places us in a slightly different perspective. A parallelism is considered here as formally equivalent to an increase of memory (for a situation which remains unchanged), or to an instantaneous "movement". Similarly, binocular vision, in which both eyes are involved in parallel and the distance of the perceived object is derived from their

[3] It should be noted here that Merleau-Ponty did not take up as a subject this role of technology in perception, whereas his demonstration is in great part based on the perceptive effects of various technical means, such as, for instance, prismatic glasses which reverse the visual field. This omission can be explained partly by the fact that the devices which he studied have only transient effects. The process of perceptive learning implied by the use of these glasses leads back, in the end, to natural vision. By contrast, with sensori-motor coupling devices, the user remains in a new perceptive mode even after having learned how to use them.

convergence, is formally equivalent to the use of one eye plus a slight movement of the head (this is what we do naturally when we want to assess the respective positions of two faraway objects).

Our approach, therefore, takes the opposite course to those research studies on vision that begin with an analysis of images already constituted on the retina, and only afterwards seek how representations can be derived from that information. In doing this one assumes at the outset at least two of the dimensions of perception and tends to forget about the subject's constructing activity, which in the end leads to a conception of representation as the internal reflection of a distinct external world. On the contrary, in our approach we will try to understand a received "image" as a composed set of sensori-motor cycles functioning simultaneously. We will thus preserve the subject's active commitment in the construction of the world in which he lives. This should enable a better understanding of the dynamic nature of perception, and also of the way in which we manage to extract the relevant components of a situation from among the massive flow of sensorial data [18].

III.2 - The observer's space and the subject's space

In the light of the approach to spatial perception which we have just outlined, what exactly were we doing in our experiments? First, we placed a luminous target, and a blindfolded subject equipped with the sensori-motor coupling device earlier described, in an "objective" and taken-for-granted space. Then, secondly, we put ourselves in the place of this subject and we tried actively to forget any prior knowledge about this external space. We adopted there Husserl's position of phenomenological reduction, putting aside the thesis of the world's existence and concentrating on the ways in which phenomena appear in perception. In particular, we examined the conditions in which the object appears as located in space. But, simultaneously, the experimentor was modifying the external conditions, for example moving the target, in order to verify that the subject was correctly identifying its direction. Does this mean, therefore, that we are accepting a naively empiristic solution according to which the subject's perceived space would be constructed as a correct reflection of the "real" space known to the external observer? Have we been using an experimental method that contradicts everything we sought to demonstrate in our discussion? In order to eliminate this contradiction, we only need to acknowledge that the "external" space, that in which we first placed the target and the subject, is itself actively constituted from the point of view of the experimentors. The question, then, is to determine the conditions that are required for different subjects to construct the same objectivity. And this question can, in turn, be submitted to experimentation: to do this, one can examine how several individuals, equipped with the same sensori-motor coupling devices, are able, through their interactions, to construct together shared representations[4].

III.3 - Future prospects for fundamental research on technology

Sensory substitution devices have disrupted the classical ways of defining the various sensory modes. If to "see" is no longer characterised by the use of the eye, nor even by the use of any particular area of the cortex, then we must redifine all the different senses in terms of the types of sensori-motor coupling relations which they establish between the body and the environment. And, conversely, any technical device, from the moment when it enables a reverse effect of the actions upon the sensations, transforms the modes of coupling between human beings and their environments, both at the level of sensation and at the level of action, and affects cognition by offering new invariants to perception. We must therefore consider that a hammer, an automobile, or a pair of skis can in this way give access to new perceptions. Cognitive technologies, i.e. the material and organised vehicles of human cognition [20], therefore include more than memorisation, transportation and data processing technologies.

We have seen, however, that the process of learning a coupling device leads to forgetting its presence (the place in which the device produces the sensations disappears from the subject's consciousness at the very moment when the perceptions which it enables are captured). The pair of glasses disappears from our perception at the moment when one uses them; when riding a bicycle one forgets about the vibrations of the handlebar in one's hands and perceives instead the road under the wheels; one forgets the joysticks of a video game and becomes the spaceship cruising the virtual space of the screen... The mastering of the tool makes it disappear from our consciousness. Perceptive learning consists in forgetting about the technical construction of the perception. This is where the lessons derived from the world of handicapped people and from the technological innovations which they produce can prove essential. They reveal to us, or remind us of, the possible constitutive role which technology can play in

[4] One might also hope that this type of study will yield information about the conditions which do or do not allow for the emergence of an emotional significance attached to the perceptive invariants. To achieve this, one should try to find the conditions required for the concerted constitution of a world of shared values.

human experience. But if we admit this constitutive role, technologies can no longer be conceived of as an application developed from the results of physical and biological research. On the contrary, by establishing new kinds of couplings between living beings and matter [16], technologies can be the bearers of unexpected existential and social consequences; they are the source of new powers, and at the same time they lead to the discovery of new problems. As a matter of fact, historically, a new technology often precedes the emergence of the scientific theories which are able to explain it. Writing preceded and made possible grammar, magnifying glasses and perspective techniques preceded and made possible Galileo's optics, etc. Thus, technologies cannot be understood only through the goals which preceded their development. They should be the subject of a fundamental type of research aimed, among other things, at understanding the mechanisms whereby technologies transform human experience. The understanding of tools as constitutive of specific perceptive worlds opens new prospects for technological development. On one hand, it should allow us to define the conditions required for an effective appropriation of the communication and calculation tools which are currently being developed. On the other hand, it should enable the production of a new family of technical devices aimed directly at adding new dimensions to our perception.

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