The Constitution of Spatiality in Relation to the Lived Body : a Study based on Prosthetic Perception

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Abstract

Studies using the sensory substitution devices designed for visually impaired persons reveal that perceptive activity itself is embodied in a lived body capable of movement and possessing its own spatial dimensions. We have used these prosthetic devices, based on the substitution of the visual sensory input by a tactile sensory input, in order to carry out a systematic study of perception, and in particular of spatial depth. We show that the spatial localisation of a target requires dynamic sensori-motor coupling, and that this activity involves the spatial dimensions of the lived body of the perceiving subject.

Introduction

We have been engaged for several years in a fundamental research programme on the functioning and appropriation of technical devices for supplementing perceptive capacities (Lenay, 1997 ; 2000 ; Hanneton, 1999). This programme is based on an extension of pioneering work of Bach-y-Rita on "sensory substitution" systems. These devices have been developed, since the end of the 60's, in order to help persons with congenital or acquired visual impairment (Bach y Rita, 1994 ; Kaczmarek, 1995). The first "Tactile Vision Substitution System" (TVSS) converted a visual image captured by a video camera into a tactile "image" composed of a 20 x 20 array of stimulators placed either on the back or on the chest (Collins, 1973). The initial studies with this device produced three results which are quite fundamental, and whose validity and relevance has only been confirmed and amplified by subsequent research :

i) Firstly, the presentation of shapes to an immobile camera only permits a very limited discrimination of the received stimuli, and the latter are perceived as being situated on the surface of the skin. Thus, the simple substitution of an entry via the optic nerve by a tactile entry does not, in itself, give access to spatial perception.

ii) However, if the subject disposes of the capacity to actively manipulate the camera (movements from left to right, up and down, zoom), he or she develops a spectacular capacity to recognize shapes. The first step is learning how variations in sensation follow from actions : when the camera is moved from left to right, the stimuli on the skin shift from right to left; when zooming in, the stimuli expand, etc. When the subject has learned to aim the camera at a target, he or she begins to discriminate lines and surfaces, and then to recognize familiar objects of increasing complexity to the point of being able to discriminate faces.

iii) Thirdly, this recognition is accompanied by a "projection" of the percepts into objects with external spatial localisation. Initially, the subject feels the successive stimulations on the surface of the skin. However, as perceptual learning proceeds, these sensations of touch fade from consciousness, and are replaced by the perception of stable objects, situated "out there" in front of the subject. Thus, according to the testimony of the subjects, the proximal irritations produced by the tactile display unit are quite distinct from the perception itself. This subjective localisation of objects in space comes about quite rapidly, after 5 - 15 hours of familiarisation and learning. Congenitally blind subjects discover perceptual concepts which are radically new for them, such as parallax, shadows, the interposition of objects, etc. Certain classical optical illusions are spontaneously reproduced (Bach y Rita, 1982 ; Guarniero 1977). These experiments can be performed not only with visually impaired subjects, but also by blindfolded normal subjects.

The perceptual learning involved in these studies reveals the astonishing plasticity of the central nervous system, which undergoes vast functional reorganisation. The tactile sensory input has no intrinsic relation to the retinal input of the visual system, and the motor control of the camera by the hands has no intrinsic relation to the motor command of the ocular muscles. Nevertheless, the brain exhibits the capacity to constitute a perceptual world composed of forms and events which correspond to those given to us by visual perception. In addition, if the tactile display unit is displaced form the chest to the back, and the hand-held camera is replaced by a miniature camera attached to the frame of a pair of "spectacles", a practised subject is able to adapt almost immediately. In a few seconds, the subject recovers a distal perception "out there" in front of him.

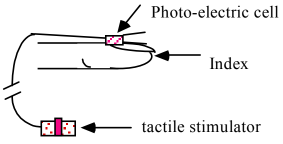
The essential role of action in the progressive emergence of structured percepts lends support to the hypotheses of active perception. In this perspective, we abandon the conception of perception as a process in which the system passively receives an input in the form of "information", and then performs computational operations in order identify objects and events in the form of internal representations. On the contrary, it is by means of his own actions that the subject seeks and constructs the regularities in the relations between action and sensation. What is perceived and recognized is not so much invariants of sensation, but rather invariants in the circular sensori-motor loops that are inseparable from the activity of the subject (Gibson, 1966 ; 1986 ; Paillard, 1991 ; Varela, 1979 ; Turvey, 1995 ; Edelman, 1987 ; O'Regan, 2001). It follows that richness of perception depends as much (if not more) on the qualities of action (mobility, rapidity, and indeed the whole range of actions that are qualitatively possible) than on the qualities of sensation (spectral range, the number of sensors, etc).

The requirement that the subject should be able to actively *manipulate* the sensory captors means that the phrase "sensory substitution" is, strictly speaking, inappropriate. It is not sufficient for a technical device to give access to novel sensory inputs; it must also provide opportunities for novel *actions,* with appropriate sensory consequences.

This type of prosthetic device, in addition to its purely practical import, offers an original experimental situation for the study of perceptive activity. It opens up the possibility of an empirical access to the consciousness of objects as situated externally in space. Specifically, it is possible to experimentally reproduce the *genesis* of depth perception in adult subjects, and hence to observe the processes involved.

Materials and methods

Our method of investigation consists of a deliberate *simplification* of the sensori-motor coupling, reducing it to the bare minimum that is still sufficient for a subject to perceive an object as localized in external space (Marque, 2000). The sensory input, in particular, is reduced to the simplest form possible, a single vibratory tactile stimulator that is either "on" or "off". The stimulator is held in one hand, and activated by a simple photoelectric cell fixed on the index finger of the other hand. The photoelectric cell captures incident light in a fairly wide angle (about 20°); it is activated (and hence activates the tactile stimulator) when the light intensity is greater than a certain threshold.



A luminous target is placed at a certain distance from the subject in a dark room. Subject are blindfolded, and can freely move their arm, hand and finger to which the photoelectric cell is attached. After several minutes exploration, the subjects (20 sighted and 10 unsighted) are able to localize the target. There is two experimental conditions, distance and direction, of 6 target's position for a pointing task. We take the average distance between finger's pointing and target's position. Subjects were able to distinguish between the six targets as it is shown by the confidence ellipses or by verbalisation (on the basis of a series of reference positions previously learned) (Hardy 2000).

To sum up: when the subject has succeeded in "latching on" to the target, he is rapidly able to indicate its position, both in respect to direction and in depth.

It will be noted that under these conditions, with just a single point of tactile stimulation, corresponding to a single receptive field, the sensory input is reduced to a binary temporal sequence: "off....... on.. off... on... off" etc; in other words, the sensory input as such contains absolutely no *possible* reference to any spatiality. We may recall that in the TVSS, there were 400 points of stimulation, arranged in a 20 x 20 array that corresponded to the receptive fields of the video camera. Under those conditions, it was not possible to exclude that the input information already contained a certain amount of characteristically spatial information. The present experimental set-up is designed specifically to totally exclude such an eventuality; if the target is localized, it *can* only be due to active exploration. We may say that the set-up *forces a spatial and temporal deployment of the perceptive activity*; and consequently, this activity takes the form of observable movements that can be studied in a purely behaviourist manner.

Analysis of the results

It is not difficult to understand how localization of the target is possible. In fact, localization is still possible even if the movements are themselves simplified, and we reduce them just to movements of the arm around the shoulder articulation, and movements of the wrist (ie the elbow is blocked in a straight-arm position). For convenience, in the following diagrams we consider movements only in a 2-D horizontal plane (we recover 3-dimensional space, as in the actual experiments, if we consider also up-and-down movements). In Figure 1, we represent the situation in (x, y) coordinates. The subject is situated at the origin, (0,0), which we designate as point O. The target is a point source, S, situated at a distance L from the subject with co-ordinates (0,L). Point P represents the wrist of the subject; the co-ordinates are ($b.\cos\alpha$, $b.\sin\alpha$), where b is length of the arm, and α = (Ox, OP) indicates the direction of the arm. The angle at the wrist, between the arm and the hand, is designated by β = (PO, PS).

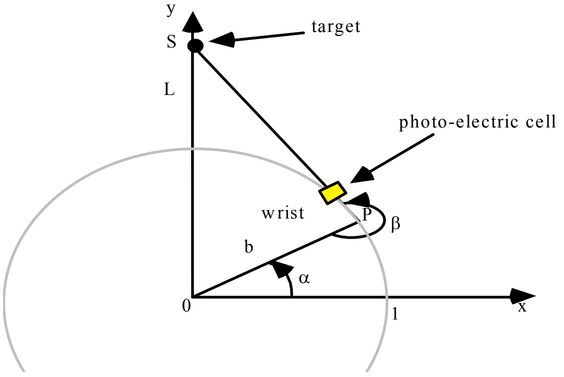


Figure 1: Specification of the variables L (distance of the target), b (length of the arm), α (direction of the arm) and β (angle at the wrist).

By trigonometry, from Figure 1 we obtain the following formula for L, the distance of the target :

$$L = b(\sin\alpha - \cos\alpha \tan(\alpha+\beta)) \qquad \text{Equation (1)}$$

We may suppose that the length of the arm, b, is known (we shall come back to this point in the discussion). It will be noted that for $\alpha = \pi/2$, β is necessarily 2π and the distance is indeterminate. We may suppose that this singular position (the arm straight out in front, the wrist and finger straight in line with the arm) is used to set the general orientation of the bust. Given this, from a purely mathematical point of view a single pair of values (α, β) could be sufficient to determine the distance.

The experimental observation, however, is that one or two "contacts" with the target are not sufficient for the subjects to succeed in localising the target. On the contrary, they perform regular oscillations around the target: small wrist movements (i.e. exploratory variation in β) in order to determine, for a given value of α, the precise value of β that is necessary to obtain the sensory feedback. Overall, it seems as though the subjects seek to identify the functional *relationship* between α and β which holds when sensory stimulation is present. It is indeed possible to rewrite Equation (1) to express α as a function of β :

$$\beta = 2\pi - \alpha + \mathrm{Atan}\left[(b \sin\alpha - L)/(b \cos\alpha)\right] \qquad \text{Equation (2)}$$

This function is shown in Figure 2, for different values of L, and it can be seen that the relationship between α and β is indeed characteristic of L. In particular, for small values of L, β increases sharply as a decreases from $\pi/2$; as L increases, the curve flattens out[1]. Thus, the proximity of the target is related to the rapidity with which β must be increased to compensate for a given decrease in α. We may also note at this point that if the subject makes a sudden, large movement of the arm, he becomes "lost", unable to rapidly discover an adequate wrist angle in order to point the finger at the target. This confirms that the basis of depth perception is not an isolated pair of values (α, β) but rather the *continuous* function in Figure 2.

It seems likely that the relative facility with which the experimental subjects succeed in this perceptive task stems from the fact that the relevant rule governing their movements, expressed mathematically by Equation (2), is already well know to them as the faculty of "pointing the finger" at any given point in space. The same sensor-motor scheme is used (in reverse) in order to "perceive with the finger". In other words, the perception of the spatial position of the target is neither more nor less than the "extraction" of a stable rule of pointing. It follows that depth perception does not occur in an abstract representational space, but rather in the concrete dynamic coupling between the subject and the environment. The position of the target in depth is constructed as a sensori-motor invariant[2].

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[1] It might be remarked that, from a purely mathematical point of view, one could equally well express α as a function of β. However, quite apart from the fact that the resulting expression is algebraically awkward, this would correspond to the subject cocking the wrist at a set angle β, and exploring the arm angles α to obtain a sensory stimulation; such behaviour is not observed in the experimental subjects.

[2] Space itself can thus be thought of as the group of transformations which make it possible to repeat the same succession of sensations via the same succession of actions. This is closely akin to the conception of the space of perceptions developed by Henri Poincaré (1905 ; 1907).

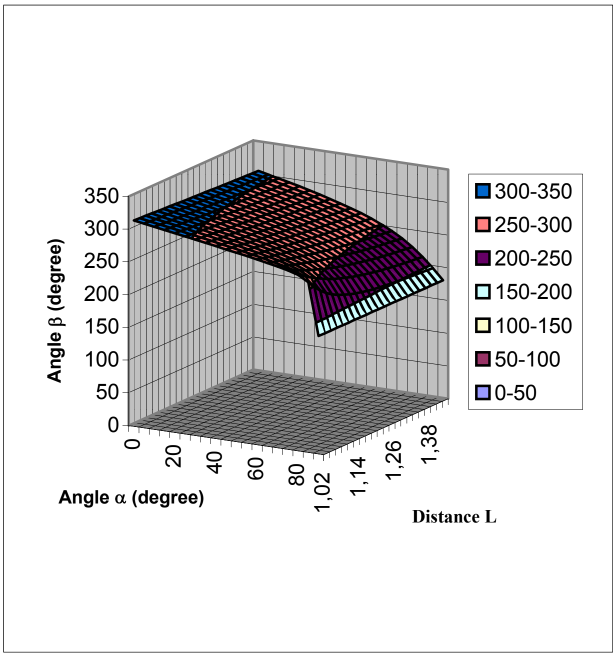

Figure 2. The curve expressing the angle β as a function of the angle α for values of L ranging from 1.02 to 1.42 (the length of the arm, b, is taken as unity).

In another series of experiments, we constrained the range of possible actions even further by requesting the subject to block the wrist movements, thus keeping the finger in a straight line with the arm. When the only movements allowed were rotation of the arm from the shoulder joint (i.e. variation in α but not β), the subject was still able to indicate the direction of the target, but depth perception was lost. Similarly, if movements at the wrist were allowed, but the arm was fixed (ie variation in β but not α), the subject was again able to indicate direction, but depth perception was again absent. In order for depth perception to arise, it was necessary that the wrist, with a possibility of action (variation in β), should itself be able to move in relation to the target. This requires, specifically, a concrete dimension of the arm which sweeps over the space. This is well expressed by equations (1) and (2), which include the parameter b, the length of the arm. This is not to say that the subject performs a trigonometrical computation based on an explicit value for b. In fact, one might just as well say that the length of the arm is constituted as a function of the distance of the target. This could be expressed by rewriting equation (1) in a mathematically equivalent form :

$$b = (\sin\alpha - \cos\alpha \tan(\alpha+\beta)) / L \qquad \text{Equation (3)}$$

The subject, as an organism in movement, belongs to the space in which he is situated with respect to the target. Perception is a form of *embodied* action, inseparable from a lived body which confers the possibility of acting in the world.

Conclusion

These experiments show clearly that there is no spatial perception without embodied action, no depth without a spatial dimension of the lived body which actually constitutes the "units" in terms of which "external" space can be perceived. In addition, we have seen how a technical device can function as a modification of the "lived body" which is constitutive of perceptual activity. We may generalize this approach by remarking that any tool, from the moment that it is correctly grasped, can be understood as an instrument of coupling which is integrated into the "lived body" of the perceiving subject. For example, the white cane of the blind person is an instrument of coupling which renders accessible a tactile perception *at the end of the cane* (i.e. where there are no nerve fibres at all). From the moment that the tool is integrated in the perceptive activity, it becomes "transparent" (i.e. it disappears from consciousness). To take another everyday example, an experienced driver "becomes one" with his car; he perceives the road-surface under "his" tires; it is "he" (and not the car) which grazes the kerb or runs over some rough gravel. The driver is not conscious of the vibrations in the car seat (as such), nor even of the relations between his proximal actions (turning the steering-wheel, stepping on the brake) and his sensations (visual or tactile); his attention is focussed on the outside, and on the events which occur in the "world" in which he is acting. We may conclude by saying that technical artefacts, by transforming our modes of acting and sensing, transform our "lived bodies" and are thus constitutive of our way of being in the world.

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