Spatial context and visual perception for action

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In this paper, evidences that visuo-spatial perception in the peri-personal space is not an abstract, disembodied phenomenon but is rather shaped by action constraints are reviewed. Locating a visual target with the intention of reaching it requires that the relevant spatial information is considered in relation with the body-part that will be used to perform the task. This entails the selection of body-scaled visual information in regard to an action-dependent system of reference. In this regard, experimental data are presented which suggest that (1) what is visually perceived as reachable depends on anthropometrical and motor factors. (2) The location of what is visually reachable is defined according to body limbs, which serve as system of reference in the specification of the spatial dimensions that characterise the reachable object. (3) The system of reference is specified from a combination of visual and somatic information, what is accounted for by the notion of "allelocentric" system of reference. (4) The specification of the independent spatial dimensions determining the location of a visual object, i.e. distance and direction, is based on visual signals of different nature.

The function of vision is a question that has undoubtedly stimulated philosopher and scientist since the origin of the cogitation about the human thought. When questioned about the function of vision, individuals would generally answer that its function is to perceive the external world, but at the same time, one acknowledges that being aware of a wonderful landscape does not mean that every aspect of the landscape is perceived. The complexity of the visual system mainly results from the apparent unicity of the perceptual experience, which is in fact the consequence of the integration of a large amount of information accessible in different regions of the brain. One of the functions of vision is to provide information about distant objects so that living organism gifted with light sensitive cells can evaluate the intrinsic (size, colour, texture) and extrinsic (position, velocity) properties of nearby and far objects without the necessity to contact them directly. It was quite a common view in the past to consider that to identify those properties, information about

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the objects themselves was sufficient (Carpenter, 1988, Howard & Rogers 1995). Numerous psychophysical studies have indeed focussed on the discrimination power of the visual system when varying one or another particular object's property, but neglecting often the function of vision. The idea that I would like to defend is that the function of vision is to allow the identification of properties of distant stimuli that contribute to the organisation of adapted behaviour. This includes recognising (e.g. our parents' face) and locating (e.g. orientation and distance) the various stimuli of interest. But the perceptual process which enables face recognition is not the same than that which enables spatial localisation. Though an untold quantity of spatial information is available at any time in the visual input, the way that information is selected and used really depends on the purpose of the behaviour. Thus selection occurs within the visual system and the question that is addressed in this paper is how this selection occurs in the context of action.

Recently, it has been acknowledged that spatial context plays an important role in visual perception and visual control of active behaviour. It was for instance demonstrated that spatial context enhances visual location of target object. Biederman (1972) showed that visual search performance is better in the natural scenes than in jumbled scenes. In the same vein, a large body of data has suggested that attempts to reach visual object are more successful when the object is visible in a structured rather than a neutral visual context (Conti & Beaubaton, 1980; Foley, 1980, Coello & Rossetti, 2004). The aim of the present paper is thus to provide some insights about the kind of interaction that occurs between visual context, target properties and behavioural constraints when perceiving the external world with the purpose of performing goal directed actions in the near-body space.

Visual perception is constrained by action
Specifying the limit of what is reachable
Reaching a visual object necessitates beforehand to determine whether the object of interest is situated within the reaching space nearby the body or is beyond one's reach. Several studies have suggested that people are quite accurate in visually perceiving the critical limits of what is reachable. The critical test consists in placing individuals facing a horizontal surface and to present series of visual objects in successively nearer or further locations along the sagittal axis (method of limits). The task simply consists for the participant in giving an overt verbal response about whether the visual object is thought to be reachable or not with the hand. In such perceptual task, no movement is actually performed and the mobility of the trunk is generally restricted. When using this paradigm, the general agreement is that the decision to reach a target with the index finger depended on the distance of the target relative to the length of the arm (Carello et al. 1989, Bootsma et al. 1992, Rochat & Wraga 1997). Thus, determining whether a visual object is reachable or not is mainly a function of the observer's body capabilities. More precisely, estimation of one's own reaching capabilities slightly overestimates

actual arm length by about 10%. Such an overestimation was interpreted as originating from people's everyday experience of reaching, which naturally requires multiple skeletal degrees of freedom whereas they are generally tested in restricted postural situations that prevent natural body movement (Rochat & Wraga 1997). Indeed when evaluating the limit of the reaching space with no postural constraint, i.e. using the torso and the arm instead of merely the arm, the overestimation diminished (Carello et al. 1989). However, it is worth noting that such overestimation could also have a perceptual origin. In Carello's et al. (1989) experiment, participants were requested to evaluate the reachability of visual objects on an uninformative black background. And it is well acknowledged that the structure of the visual scene broadly influences the location at which visual objects are perceived (Coello et al., 2000, see below). In order to estimate the perceptual component of the inaccuracy when estimating the limit of what is reachable, we conducted an experiment aiming at analysing the accuracy of the subjective limit of what is reachable, but varying the visual context (Coello & Iwanow 2004). Eight participants were requested to judge whether the visual target presented on a horizontal surface (between ±50mm from the maximum reachable distance) is reachable or not with the right hand. The experimental device consisted of a rectangular box divided horizontally by an upward-facing reflecting mirror. With the head resting on the upper part of the box, only the top half of the box was visible to the participants (see Figure 1). A computer monitor was placed upside-down on the top surface of the apparatus and the image of the monitor screen projected on the bottom surface of the box, as a consequence of the optical properties of the mirror. The visual context varied so that the targets were presented along the sagittal axis on a dark or textured background made with dots randomly positioned over the whole workspace. In each visual context, the critical limit of what is reachable was determined using a least square iterative fit procedure to obtain the logistic function that best fitted the (yes or no) responses of the participant for the various positions of the target (see Coello et al. 2003 for details). We found that the subjective area comprising reachable stimuli corresponded to arm length in the most ecological situation (textured background, -1mm with respect to arm length), but extended in the dark condition (+15mm with respect to arm length, see Figure 1).

On the basis of these results, two conclusions were formulated. First, the perception of whether a visual object is reachable or not is body-scaled and leans upon arm length. Second, the fact that the critical limit of what is reachable recedes in darkness about 15mm farther than the maximum distance the hand could reach suggests that the perception of what is reachable strongly depends on the vision condition. An accurate estimation of what is reachable requires a precise estimation of distance, which necessitates a structured visual space. In the reported experiment, the variations of performance when varying vision condition resulted obviously from the fact that the visual space shrinks egocentrically in impoverished visual condition.
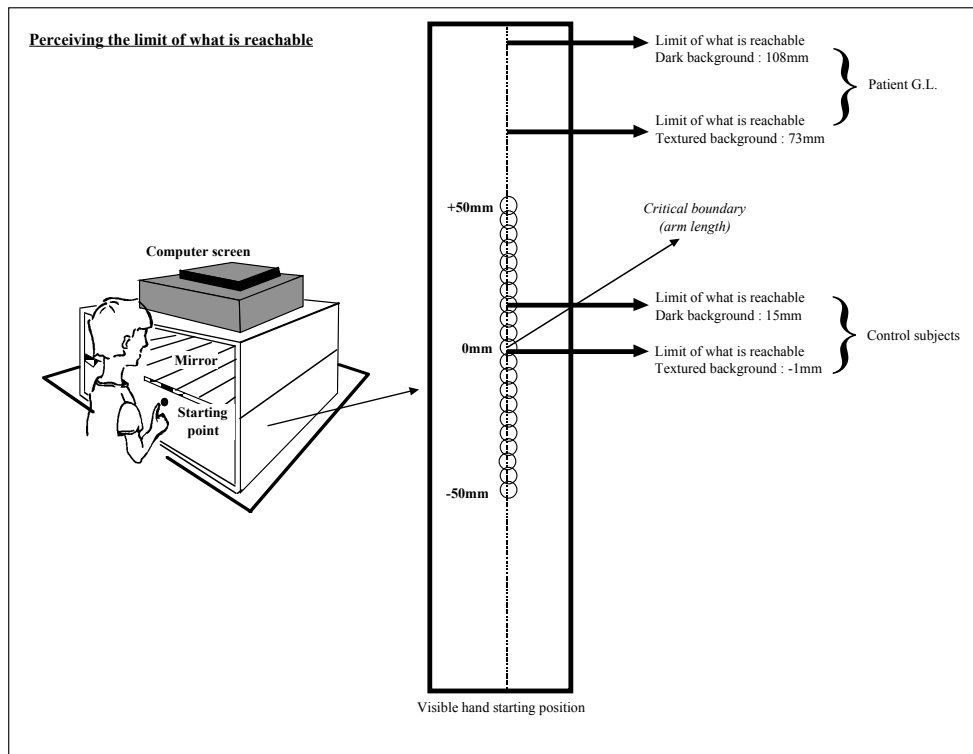
Figure 1. Schematic representation of the experimental apparatus and the layout of the visual targets used to estimate the limit of what is reachable in darkness or with a textured background. The critical boundary corresponded to maximum arm length measured individually. Performances shown are those of the control participants and the patient G.L. (adapted from Coello et Iwanow 2004)

Sources of information to specify reachability

In a recent study, we were interested in establishing whether the subjective limit of what is reachable involved the perceptual system only or included also some information related to the motor system. Indeed, there are clear evidences that perception of visual objects that have the property of being reachable and graspable involved brain structures that are known to be part of the motor system (Jeannerod, 1997). In this respect, activations of premotor areas during observation of reachable objects have been highlighted in humans and animals studies. Research on monkeys for instance have shown that in addition to their motor discharge, some premotor neurons (canonical neurons) respond also to the presentation of graspable objects (Gentilucci et al. 1983, 1988, Rizzolatti et al. 1981, 1988, Fadiga & Craighero 2003). Direct evidence for an activation of premotor areas during observation of reachable

objects was also provided in humans by PET[1] studies. Grafton et al. (1997) reported for instance that premotor cortex became active during simple observation of tools but not during observation of bidimensional meaningless pictures. Moreover, this premotor activation was further augmented when the task consisted in naming the tool use. Interpretation of this result was that the perception of some objects automatically affords actions that can be made towards them (Gibson 1979). Evidences for affordances directing action have also been observed in the context of neurological pathologies. Humphrey and Riddoch (2001) for instance reported the case of the patient M.P. showing aspects of unilateral spatial neglect as a consequence of a stroke in the right parietal lobule. The performances were characterised by a constant failure in detecting visual stimuli presented on his left side. This neglect patient was however able to detect targets in multi-objects displays on the neglected space when cued with an action (find the object to drink from) but not when cued with a semantic information (find the cup). This cueing-by-action was successful when the objects were oriented with their handle pointing towards the patient, not otherwise.

In the same vein, we analysed the performance of the patient G.L. who is a deafferented patient with a complete loss of sense of movement and postural changes. G.L. suffered a permanent and specific loss of the large sensory myelinated fibers in the four limbs following two episodes of sensory polyneuropathy, which affected her whole body below the nose. The illness resulted in total loss of sense of touch, vibration, pressure and kinaesthesia. G.L. is confined to a wheelchair, but she does most of the daily manual activity under constant visual guidance. Of course G.L. has no visual deficit and she shows normal behaviour when required to describe, identify or locate visual object. When tested with our paradigm, the performance of G.L. was different in some aspects from that of the control subjects when estimating the limit of what is reachable. The distance at which she thought she would be able to reach visual targets was weakly related to body characteristics as she judged as reachable in a structured visual environment target 108mm further than her arm extremity. However, the perceptual contraction of the visual space was also experienced by G.L. as the limit of what is reachable receded by about 35mm in darkness. This indicates that the perception of whether a visual object is reachable or not reposes on two independent factors. On the one hand, the perception of reachability depends on pure visual factors since the structure of the visual environment determined the distance at which visual objects are perceived. On the other hand, the subjective estimation of reachability rests on an interaction between the visual system and the motor system.

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[1] Tomography using positron emission (PET) is a functional imaging technique for a better knowledge of brain activity in the conscious person. PET measures the emission of positrons from the brain after a small amount of radioactive isotopes, or tracers,! have been injected into the blood stream.! A common example is a glucose-relative with embedded fluor-18.!! With this molecule, the activity of different regions of the brain can be measured.! The result is a three-dimensional map with the brain activity represented by colours.

It is interesting to mention the fact that the idea that visual perception is shaped by action has also received favouring argument coming from recent neuropsychological works. For example, Berti & Frassinetti (2000) reported the case of the patient P.P. suffering a cerebral vascular accident, which mainly impaired the right parietal cortex. One consequence of the stroke was a severe spatial neglect for the left-side stimuli that stabilised even after several months. Surprisingly, neglect syndrome was found to affect perception in near (50cm) but not far space (100cm). The opposite pattern has been found by Ackroyd et al. (2002), who reported a patient with neglect of far but not near left space. Thus visual space is not isomorphic and appears divided as a function of action contingencies, even when perceiving without the intent of acting.

Visual information is functionally used
Combining multiple visual signals

Once a visual object has been perceived as reachable in the peri-personal space, its absolute position must be specified in a format that is accessible to the motor system so that reaching attempts and objects manipulations can be considered. Though it is well acknowledged that the perception of a visual target rests on the combination (or integration) of retinal, extra-retinal and somatic signals[2] (Wade 1996, Blouin et al. 1996, Magne & Coello 2002, Carrozzo et al. 2002), I will refer in what follows to the endpoint of the process, that is the location of visual targets in relation with the position of the motor effector that is going to be used to reach it. The gap separating the effector from the target delimitates action space, and we assume that this is what needs to be perceptually assessed (Tipper et al., 1992, Gordon et al. 1994, Vindras & Viviani 1998, Coello & Rossetti 2001). As was claimed by the mathematician Henry Poincaré a century ago (1902): "When we say that we locate an object, … this simply means that we represent the movements that are required to reach this object…". Taking this viewpoint for granted, the question that remains to properly address is how we perceive the effector-to-visual target gap. As this will become obvious in the next section, there is no general agreement concerning this issue though many experimental data are available. Controversial arguments are mainly associated with the underlying notions of system of reference and spatial dimensions, which are two unavoidable notions necessary to clarify position coding. The notion of system of reference accounts for the fact that determining the location of an

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[2] Extraretinal signals refer to the position of the eyes obtained from non-retinal sources, including oculomotor command to displace the fovea towards a visual target (copy of motor efference), and proprioceptive cues transmitted from anatomical structures in the eye muscles (e.g. vergence information). Retinal signals are independent of eye position and refer mainly to physical aspects of the image that stem from the optical projection of the external world. Somatic signals refer to stable and changing body postures.

object in space implies an arbitrary coordinate system that has itself an origin, an orientation in space and a spatial metric. The idea that I would like to argue for is that the system of reference used to locate a visual target is a function of (1) the action constraints and (2) the sources of spatial information that are available about the body limb used to act. The notion of spatial dimension refers to the fact that assuming that position coding takes place in regard to an action centred-system of reference (Tipper et al. 1992), distance and direction are two independent parameters that are specified through the combination of different visual signals. For the sake of clarification, I will focus in what follows on visuomanual activities, i.e. the simple situation in which a target is visually located to be reached with the hand.

Specifying the system of reference

Previous studies on perception for action have suggested that the system of reference used to locate a visual target can be inferred from end-point constant and variable error of hand displacement towards this target (i.e. average terminal location and variability, Soechting & Flanders 1989, Gordon et al. 1994, McIntyre et al. 2000). Based on the underlying assumption that the longest axis of variable error ellipsoid (i.e. the ellipse encompassing 95% of the data) points towards the origin of the system of reference, different outcome was obtained depending on the test condition. With a continuously visible or memorised target, the axis of maximum variability converges towards the mid-point between the eyes, suggesting a viewer-centred system of reference when responding with vision of the hand (McIntyre et al. 1997, Carrozzo et al. 1999). When vision of the hand is prevented, the axis of maximum variability is rather organised around an arm-related axis (McIntyre et al. 1998, Carrozzo et al. 1999). The fact that the variability depends on the starting hand location (McIntyre et al. 1998) and was generally greater along the movement direction when displacing the hand on an horizontal plane (Gordon et al. 1994) as been generally used as arguments in favour of the vectorial coding theory of target location. According to this theory, target related signals are combined with hand related signals to form a simplified hand-centred vectorial representation of target location (Bock & Eckmiller 1986, De Graaf et al. 1996, Redding & Wallace 1997, Gordon et al. 1994, Rossetti et al. 1995, Vindras & Viviani 1998, Krakauer et al. 2000). Evidence for vectorial coding came with the observation that hand displacement is generally linear and terminal errors are greater when the hand is located out the visual scene (Bock et al. 1990, De Graaf et al. 1996, Gordon et al. 1994, Vindras & Viviani 1998), with the consequence that the error main axis pointed collinear to the vector expressing proprioceptive mislocation of hand starting position (Vindras et al. 1998). Thus, making the hand-to-target gap visually available ensures more accurate target location, obviously because the visual system offers a better spatial resolution than the proprioceptive system contributing to the perception of hand location.

Thus, several scenarios have to be considered according to whether action is entirely under visual control or not. As noticed above, when a visual

target is immersed in an otherwise neutral or empty space with no visual information about the body or body-parts, target position is specified in reference to the motor effector that is located proprioceptively (egocentric system of reference). This entails the necessity of an intermodal combination of visual and somatic information for specifying target location. By contrast, when the motor effector belongs to the visual scene, visual target-to-effector gap can be directly identified on the retina and somatic information becomes optional (allocentric system of reference). This latter point is nicely illustrated by the performances of patients suffering from proprioceptive deafferentation, which do not differed from that of healthy individuals when full vision of the workspace is provided, while deteriorating rapidly in the case of partial visual information leading to obliterated upper limbs (Ghez et al. 1990, 1995, Blouin et al. 1993). In visuomanual tasks, the general agreement is that though target coding in a hand-centred system of reference can be achieved whatever the vision condition (Vindras & Viviani 1998, 2002), many evidences indicate that a full vision condition enhances spatial performance by reducing constant (Prablanc et al. 1979, Elliott 1988, Proteau 1992, Blouin et al. 1993, Ghilardi et al. 1995, Carrozzo et al. 1999) and variable localisation errors (Desmurget et al. 1995, Rossetti et al. 1994, Ghez et al. 1990, 1995, Carrozzo et al. 1999). Furthermore, if action space is embedded in a geometrically structured space, effector-to-target gap is more accurately perceived than if the two positions are evaluated in an empty space (Coello & Magne, 2000, Magne & Coello 2002, Grealy et al. 2003), thus favouring an allocentric system of reference for an accurate target location.

So far, few experiments have focussed on the dissociation between these two potential systems of reference, i.e. allocentric and egocentric, to locate a visual target for action. In this regard, the work carried out by Redding and Wallace (1996, 1997) is worth mentioning. Studying the effect of altering the egocentric direction of the whole visual scene by the way of wedge-prism spectacles on visuomotor performance, they found that target location can be coded very accurately providing that the hand and the target are simultaneously visible before responding. A broad misperception of target location was observed otherwise. Such performance is expected only if one assumes that retinal signal is used to determine target location in the form of a Cartesian vector in a hand-centred system of reference (Redding & Wallace 1996, 1997). Other data are in agreement with this interpretation. Goodbody and Wolpert (1999) observed for instance that when decoupling the actual and perceived hand location by a translation of the visual feedback during horizontal pointing movements, target was located according to the visual hand only. Though convincing, the idea of a distinction between an uni-(allocentric) versus multimodal (egocentric) coding of the hand-to-target gap has been challenged by other experimental works. Rossetti et al. (1995) observed for instance that introducing a sensory conflict between hand related visual and proprioceptive signals, but leaving the visual location of the target unchanged by using half-prisms affecting the lower visual field only, resulted in mislocating the target in the direction opposite to the visual shift. Though the hand was viewed when estimating the location of the target, the magnitude

of the error concurred perfectly with the expectancy considering a balanced contribution of visual and proprioceptive signals related to the hand. These data indicate that an allocentric coding is not systematically operating in the context of action despite the complete vision condition and suggest rather that a sort of combination between an allocentric and egocentric coding might be at work. The controversy between the aforementioned studies might be though related to the magnitude of the discrepancy experimentally introduced between visual and proprioceptive information. One way to gain better insight about the possibility to refer to different systems of reference to locate a visual target consists in dissociating the visual space from action space, as this is the case in video-controlled tasks.

Directional coding in video-controlled situation

Locating a visual target on the basis of information provided by a vertical display to perform actions on a horizontal surface seems a straightforward situation for anyone who is familiar with computers. However, studies in that area have pinpointed that space perception becomes problematic as soon as the visual display is oriented differently than the workspace, and the underlying difficulty is obviously related to the question of systems of reference (Wade 1996, Pennel et al. 2002). Considering the geometrical aspects of a video-controlled task, identifying the direction of a visual target requires the use of adequate reference axes, whereas identifying the distance of a visual target imposes the evaluation of the changing visual context in terms of scaling factor (Krakauer et al. 2000). Thus, changing the orientation of the visual scene affects primarily direction coding (see Figure 2).

Because of the discrepancy between the visual and action space, one may expect the location of a visual target to depend principally on the *modus operandi*, that is how spatial information is extracted from the visual display. Indeed, evaluating target location in relation with the location and orientation of the hand in the visual scene represents the simplest way to perform an accurate spatial coding (Krakauer et al 2000). Experimental data showed that this simple visual coding is extremely difficult to achieve, in particular if the visual display is at different orientation to the workspace. Target location is broadly misperceived in the remote visual scene, as shown in Figure 3a. In the figure is depicted the mean trajectory (N=8) while pointing for the very first time a visual target with the visual scene oriented at 40° and with no vision of the movement (notice the inter-individual variations). This seems to indicate that the specific orientation of the visual display is not accurately anticipated (Pennel et al. 2003). Then the obvious conflict between visual and proprioceptive information relating to the arm prevented seemingly the ability to locate accurately the visual target in relation to the visual hand, despite the fact that this corresponded to the relevant solution for an accurate spatial coding (allocentric system of reference). Nevertheless, individuals can adapt to the unfamiliar situation (Figure 3b). Pennel et al. (2002, 2003) reported directional errors of target location grouped around 23° and 40° for a difference in orientation between the visual space and the workspace of 40°

(Figure 3a, see also Coello et al. 2004). The fact that the directional errors grouped around 23° or 40° suggested different types of interaction between proprioceptive and visual signals. Based on movement vector analysis, Pennel et al. (2002) showed that the visual target was located according to the location and orientation of the proprioceptive hand (egocentric system of reference, including the corresponding projection in the remote visual scene), or according to the location of the visual hand but the orientation of the proprioceptive hand (coined allelocentric system of reference). The term "allelocentric" was preferred because the Greek word allelos means "one another" and thus an allelocentric system of reference specifies a system of reference derived from both the visual and proprioceptive signals relating to the effector. To summarise, visual target was located in a hand-centred system of reference. But though individuals oriented all their system of reference according to the proprioceptive hand, they differed according to where they positioned its origin. The reason for prevailing one type of information in determining the origin of the system of reference was obviously related to the accuracy with which the proprioceptive system informed about arm posture. Indeed, when comparing the error in coding target location with the accuracy with which proprioceptive system informs about arm posture, a well-defined correlation was observed. Thus, when requested to proprioceptively estimate the location of their acting hand at the starting position, performances were more variable and less accurate for individuals using an allelocentric system of reference (Figure 3c, see Coello et al. 2004). From these data, one may speculate that the decision to favour one or another sensory signal in spatial coding depends on the spatial resolution of the sensory systems. One obstacle in mastering video-controlled task results thus from the persistent influence of proprioceptive information in the spatial coding of visual goals for action. The assumption that visual information can be enough to code target-to-effector gap (allocentric system of reference), as suggested by the Redding and Wallace's study is thus incorrect. When a visual target is coded according to a body limb, the latter seems necessarily defined on the basis of a combination of visual and proprioceptive signals (allelocentric system of reference), but with the particularity that the combination must be accounted for by including inter-individual differences.

Distance coding in a structured environment

Determining the actual distance of a visual target from a body part supposes that relevant 3D information is perceived. In this regard, both retinal and extra-retinal signals can fulfil the task. Indeed, information about the state of extra-ocular muscle can, in principle, provide the central nervous system with an estimate of the angle of binocular vergence, from which the radial distance to the point of fixation can be estimated (Tresilian et al. 1999). However, a visual target is generally embedded in a geometrically structured space that also provides 3D information by the mean of the retina (Gibson, 1979). Though the multiple sources of 3D information, studies questioning sensory integration in the context of visuomanual tasks have in general acknowledged extra-retinal signals as a prevailing source of distance

information (Jeannerod 1988, Desmurget et al. 1998) at least with regard to the near space (Treisilian et al. 1999). The main arguments were that shifts in the perceptual estimate of target location are observed in presence of pathology weakening eye muscles (Matin et al. 1982), or when deviating one eye mechanically (Bridgeman 1986) or optically using wedge-prism spectacles (Treisilian et al. 1999) in healthy subjects. The interpretation of such perceptual effects induced by abnormality in eye movement control was that locating a visual target relies primarily on extra-retinal signals (in its inflow (Sherrington 1897) or outflow (Helmholtz 1866) form) that inform about eyes position.
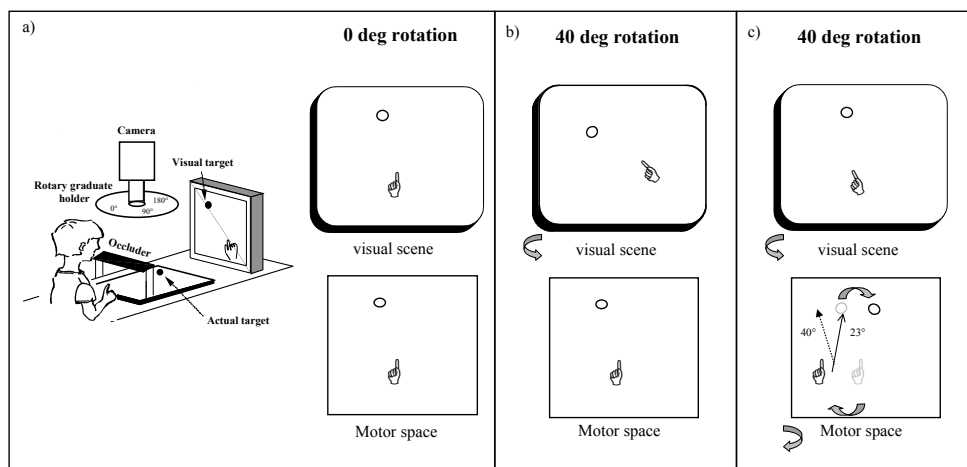

Figure 2. a/ Experimental apparatus, visual display and workspace. b/ A clockwise rotation of the camera entails a counter-clockwise rotation of the visual scene. c/ The rotation can be visually cancelled following a clockwise rotation of the hand-to-target vector in the opposite direction (thick line: hand and target visual actual location, thin line: projection of hand and target visual location in the workspace). Dashed and plain line arrows in the workspace indicate expected movement path according to the Allelocentric and Egocentric system of reference. (adapted from Coello et al. 2004)

However, some data argue against such a radical view. In fact, mislocation resulting from weakened eye muscles or mechanical perturbation of eye position was found to virtually vanish in presence of a structured visual context (Bridgeman & Graziano 1989, Matin et al. 1966). Furthermore, other studies have shown that the accurate determination of target position in a visuomanual task requires a wide and textured workspace, particularly when targets at different distances need to be discriminated (Coello & Magne 2000). As a consequence, a substantial underestimation of target location (generally 10% of the distance) was observed when the retinal signals were

impoverished due to a reduction in the size of the visual scene (Coello & Grealy 1997), or when the target was presented in a dark and unstructured environment (Foley & Held 1972; Prablanc et al. 1979, Bock & Eckmiller 1986, Berthier et al. 1996, Van der Heidjen et al. 1999). The fact that similar pattern of results was obtained when both the hand and the target were visually available (Coello & Magne 2000) suggests two commentaries. On the one hand, significant distance underestimation in darkness indicates that extra-retinal signals do not carry an accurate distance information. On the other hand, this shows that distance perception cannot be accounted for by the simple comparison of two distant positions, namely the hand and the target. More precisely, spatial information filling in the hand-to-target gap obviously plays a crucial role in distance estimation. Surely visual elements or surfaces structuring the gap between two distant objects may provide some metric information that enables the accurate quantification of the inter-object gap.

We tested this assumption by comparing distance performance in a visuomanual task when the action surface was structured or not (Magne & Coello 2002), the hand and the target being always visible. The task consisted in performing 120 non-visually controlled movements in darkness, then in presence of a textured background and finally in a dark condition again. The interesting aspect of the task was that participants could not anticipate the change from one visual condition to another. The underlying working hypothesis was that if retinal signals provide accurate distance information, performance should improve from the first trial following the provision of a textured background. As shown in Figure 4a, the main findings agreed with the expected behaviour. Distance was underestimated in darkness, confirming previous observations. The underestimation was worse when viewing monocularly than binocularly, which confers nevertheless some advantage of having two eyes and related vergence information. However, underestimation nearly disappeared following the provision of a textured background and this from the first performance in the monocular as in the binocular vision condition. Consequently, retinal information about the whole action space is necessary for an accurate coding of the hand-to-target gap. Kinematic analysis of the motor performance showed that early parameters such as the peak velocity mimicked the variations observed for the distance performance, indicating that variations of distance performance have to be explained by factors arising within the sensory component of the task (Figure 4b). Interesting is the variation of distance performance when lowering unexpectedly the quality of retinal signals in the post-exposure condition. Distance perception was accurate but only during the few first motor productions. This contrasting influence of adding or removing texture information seems to indicate that in addition to supplying distance information, retinal signals contribute to the calibration of extra-retinal signals. Indeed, the fact that the performance drift occurred during four blocks of 10 trials on average (which corresponds to about 4 minutes of practice) is very reminiscent of the proprioceptive drift reported for the sensation of arm position following visual occlusion (Wann & Ibrahim 1992).
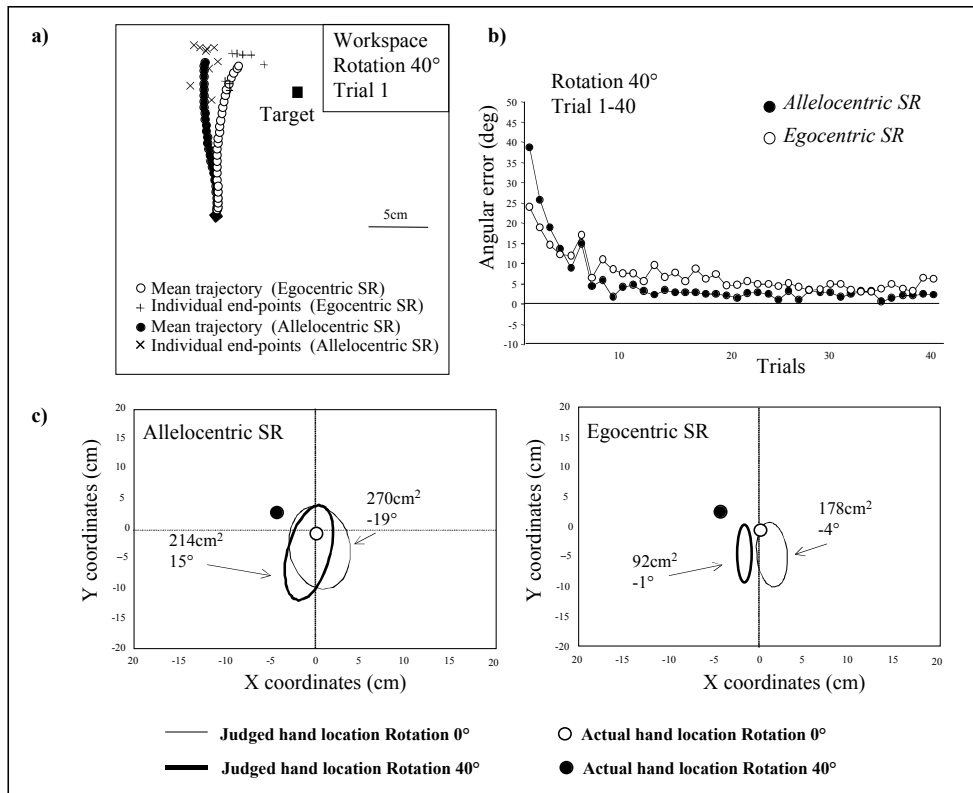
Figure 3. a/ Mean trajectories and individual end-points and b/ variation of angular error as a function of the trial with an orientation of the visual display at 40° when using an Allelocentric or Egocentric system of reference (the experimental situation is that described in Figure 2c). c/ Confident ellipses (surface in cm² and orientation in deg) of proprioceptive estimation of hand starting position in the 0° or 40° condition (Figure 2a and 2c) as a function of the frame of reference used (the white and black dot indicates respectively the actual hand position for the conditions 0° and 40° respectively, adapted from Coello et al. 2004).

Complementary experimental works have also convinced us that the contribution of retinal information is also very dependent on how the visual scene is structured (Coello et al. 2000, Coello 2002, Grealy et al. 2003). Indeed, the superior performance in presence of a textured background was observed only when the textured surface coincided with action plan (i.e. the part of the visual scene where action occurs). When this was not the case, the

condition with a textured background was strictly equivalent to the dark condition[3] (see Figure 4c).

The last point that I would like to emphasize in the present paper concerns whether there is some reason to admit that the texture influence mentioned above is perceptual in nature. Indeed, in all the experimental works presented up to now, spatial perception was inferred from manual reaching response. Consequently, it is fair admitting that spatial performance can be influenced by the motor component of the task, as well as by the visual characteristics of the situation. In order to unravel this issue, the influence of context information (in the form of a textured background) was investigated in two tasks, a pure perceptual task and a visuomotor task. The two tasks focussed on the estimation of the egocentric distance of a visual target (Coello & Iwanow 2004). In the perceptual task, participants had to provide an overt judgement about whether the visual target was perceived as reachable with the hand or not, but with no actual movement being performed. In the visuomotor task, participants carried out non-visually controlled pointing movements towards visual targets located at various distances along the sagittal axis. As shown in Figure 5a, the effect of providing a textured background on distance performance had the same magnitude in the perceptual and visuomotor task, but opposite in direction. In the visuomotor task, target location was underestimated by 46mm in absence of the textured background, but by only 29mm when it was available. By contrast, in the perceptual task the critical limit of what is reachable in darkness was situated 15mm beyond the critical boundary established from arm length, but 16mm nearer in presence of the textured background. The effect of structuring the workspace was thus of same magnitude in the two tasks but opposite in direction. This opposite effect can be accounted for by the simple fact that presenting a visual target in absence of meaningful visual context brings about a perceptual constriction of the whole visual space that induces misperception of target location. Being perceived nearer that its actual location, a visual target that is too far to be reached was nonetheless perceived as belonging to the reaching space, with the consequence that reaching movements towards it were hypometric. The assumption that structuring the workspace influenced in a similar way target location in the perceptual and visuomotor tasks was supported by the highly significant linear relationship that we found when plotting the individual percentages of context influence in the perceptual task against those obtained in the visuomotor task (Figure 5b and 5c). This indicates that, in the visuomotor task, the influence of the textured background was highly predictable from that observed in the perceptual task, and thus established that this influence occurs mainly at the perceptual level.

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[3] The fact that action plan can contribute to shape perceptual space is known for some time in the field of research on visual attention. Tipper and colleagues (1992) for instance have provided evidences that visual attention can be locked to the position of the hand with respect to a target for action. If reaching with the hand directly out to an object then the irrelevant stimuli lying in front of the object are ignored. However, when moving the hand back to the object then same irrelevant stimuli are not ignored and interfere with target coding as shown by the increase of reaction time before action onset.
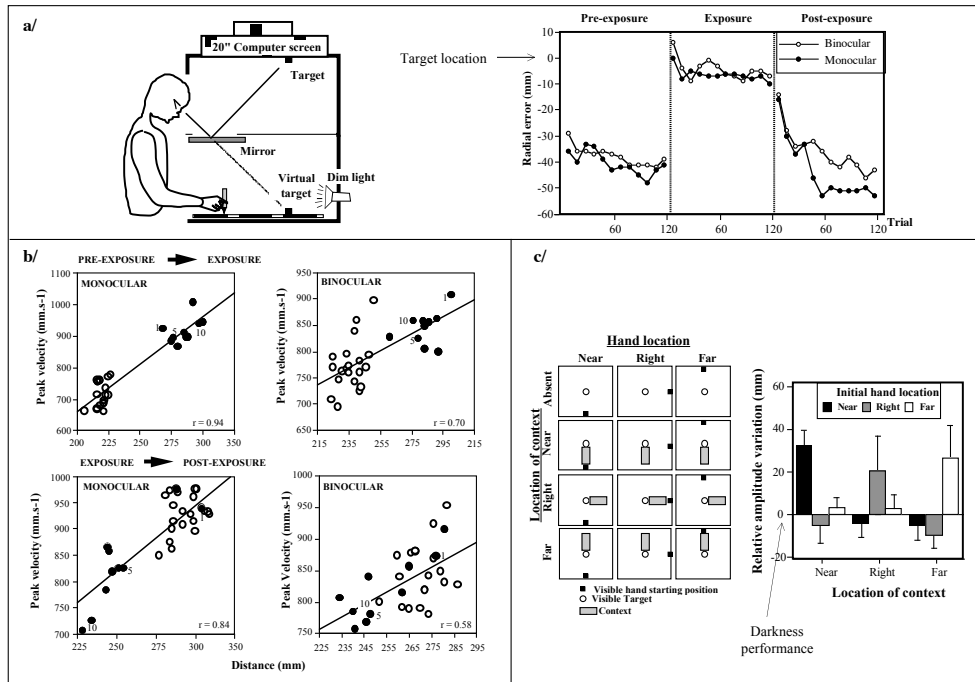
Figure 4. a/ Radial error over the successive blocks of 10 trials as a function of the vision condition (monocular or binocular) when pointing to visual targets in darkness (pre-exposure and post-exposure) or with a textured background (exposure). b/ Correlation between peak velocity and movement extent for a representative participant. The trials under consideration are the last 20 trials (open circle) of the pre-exposure condition and the first 10 trials (solid circle) of the exposure condition, or the last 20 trials (open circle) of the exposure condition and the 10 first trials (solid circle) of the post-exposure condition. Trials 1, 5 and 10 are indicated. c/ Experimental manipulation of the hand and context location and relative distance performance according to the dark condition in presence of a visual context as a function of the hand and context location (adapted from Magne & Coello 2002).
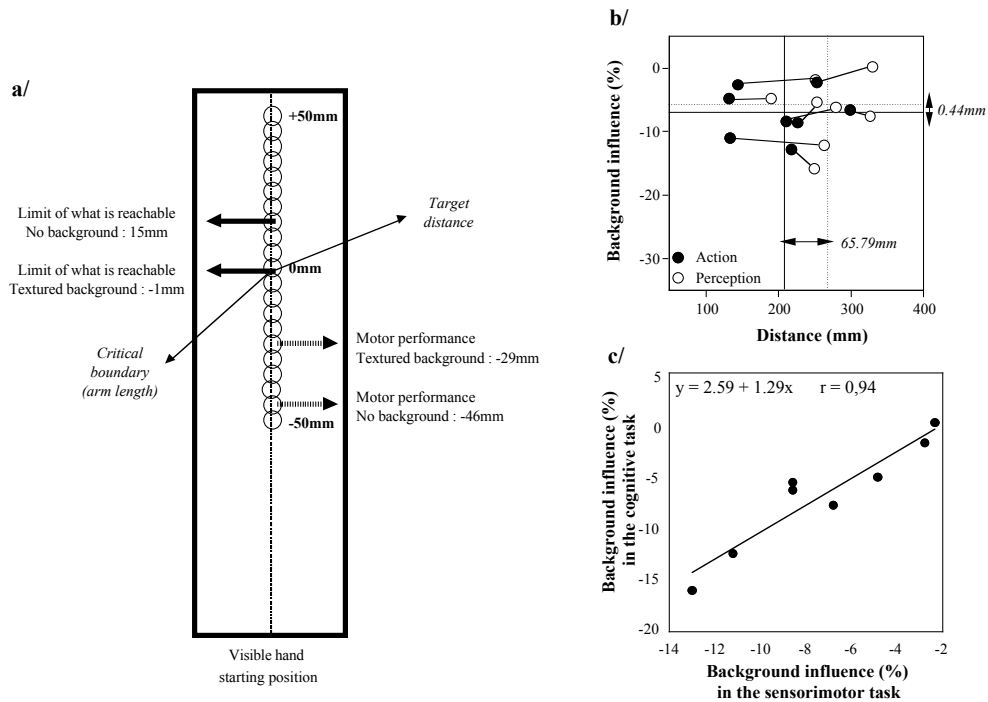
a/

b/

c/

Figure 5. a/ Perceptual and sensorimotor performances in darkness or with a textured background. b/ Individual percentages of background influence in the perceptual and sensorimotor task for the monocular and binocular vision condition. Individual results in the perceptual and sensorimotor task have been connected with a plain line. Horizontal plain line and horizontal dash line indicate the mean background influence in the sensorimotor task and the perceptual task respectively. Vertical plain line indicates the mean pointing distance whereas vertical dash line indicates the critical limit of what is reachable in presence of a textured background. c/ Correlation between background influence in the sensorimotor and the perceptual task (adapted from Coello et al. 2004).

Conclusion

The aim this paper was to provide evidences that visuospatial perception is not an abstract, disembodied phenomenon but rather is shaped by action constraints. The relevant visual information to reach a visual object is that enabling the location of that object in relation with the body part that is going to perform the task. This includes the selection of body-scaled information specifying object distance and direction in regard to an action-dependent system of reference. In order to modify the disposition of our sense organs in relation to the action constraints, the central nervous system must thus select just those inputs that are currently relevant, while simultaneously suppressing

irrelevant inputs. (Allport, 1989; Desimone & Duncan, 1995). In the context of action, the evidences reported here indicate that visuospatial perception is tuned to action plans and must thus be considered as satisfying principally to a functional criterion that enables adapted behaviour. Because the spatial resolution of the various visual signals differ, those signals that provide the most accurate (or the less variable, Ernst & Banks 2002) spatial estimation are selected. Finally since the specification of spatial location is multidimensional, the visual signals compete in a complementary manner. Whereas extra-retinal signals provide an accurate estimation of objects direction, they hardly inform about distance, for which structured retinal signals are essential.

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