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INFLUENCE OF VISUAL CONTEXT ON POINTING MOVEMENT ACCURACY

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Résumé :

Dans une tâche de pointage visuo-manuel chez l'homme, deux types d'informations visuelles, habituellement confondues, ont été expérimentalement dissociées : les réafférences visuelles concernant la main elle-même et les indices visuels relatifs à l'environnement dans lequel la main se déplace. Le mouvement pouvait être effectué avec ou sans réafférences visuelles et dans chacune de ces deux situations les sujets pouvaient bénéficier, à certains moments du pointage, de la présence d'un champ visuel structuré. Les résultats confirment que la suppression de la vision du membre pendant le mouvement diminue la précision du pointage. Ils indiquent d'autre part que la détérioration peut être partiellement attribuée à la suppression des indices visuels environnementaux. En effet, lorsque la main seule est visible, sans aucun repère externe, des erreurs concernant l'amplitude des mouvements sont observées. De plus, même en absence de vision de la main, la présence d'un cadre visuel permet une amélioration de la direction et de l'amplitude des pointages. Lorsque le membre est visible, le contexte visuel dans lequel se déroule l'activité interviendrait essentiellement sur le contrôle du mouvement en cours, alors qu'il serait plutôt utilisé au moment de la planification du mouvement lorsque le membre ne peut être vu.

Key words: visual context, pointing movement, spatial coordinates, visual reafferents.
Mots clés : contexte visuel, mouvement de pointage, coordonnées spatiales, réafférences visuelles.

INTRODUCTION

The accomplishment of fast and accurate hand movements directed towards visual targets requires the forming of a spatial relationship between points located in physical space, and a limb extremity. The construction of this relationship involves several functional stages, among which the following have been distinguished: visual location of the target; proprioceptive and/or visual localization of the hand; and finally the mapping of both types of spatial information within a common reference system (Paillard and Beaubaton, 1978). Organization and control of a goal-directed movement can thus be considered to be a series of hierarchical operations occurring at distinct functional levels and involving spatial coordinate transformations (Pellionitz and Llinas, 1980). The question of trajectory specification either in terms of intrinsic coordinates, i.e. in joint angles, or extrinsic ones in extrapersonal space is still a matter of controversy (Morasso, 1981; Soechting and Lacquaniti, 1981). It can be postulated that the target may be established in physical space by means of extrinsic coordinates. From a theoretical point of view, a distinction between two sub-systems of extrinsic coordinates, differing as to the origin used in the location process, can nevertheless be envisaged: an *egocentric* system where an object is located with respect to the subject who is himself the reference; and an *exocentric* system where subject and object are situated in relation to some external reference within physical space.

The visual environment surrounding the target is probably of major importance. Matin et al. (1982) have clearly shown the effect of a structured visual field on the magnitude of what they have called the "oculoparalytic illusion". Under partial extraocular muscle paralysis, observers made large errors in visually localizing and in pointing at a light that appeared in total darkness whereas, in an illuminated visual field, both visual localization and pointing were accurate. They concluded that the use of extraretinal eye position information (of either inflow or outflow origin) could be limited to instances where the target is viewed in total darkness and that its utilization is suppressed in a normally illuminated visual field in which localization depends on purely visual signals. These findings strongly suggested that the processes and even the structures involved in a visual pointing task might depend on whether the target is seen in darkness or in a structured frame of reference (Paillard, 1986).

In this framework, the visual cues available during performance of a visually directed movement could be of primary importance for the selection of the spatial coordinate system in which the action is planned. Now, most of the studies devoted to the organization and control of directed movements have focused principally on visual feed-back concerning the limb itself and they have tended to neglect the associated contextual visual cues. This is the reason why the exclusion of visual reafferents generally causes the suppression of all spatial information provided by the ambient field. This is typically the case when, to prevent subjects from having any sight of

their limb, experiments are conducted in a totally darkened room. In this "visual open-loop" situation it has been known for a long time that the accuracy of movement considerably decreases in comparison with that achieved under the "visual closed-loop" condition. It could be of interest however, to distinguish the reafferents relating to the hand itself from those concerning the environmental landmarks. In a previous study in which this experimental dissociation was made, the results indicated that vision of environmental cues might contribute to the accomplishment of a pointing movement (Conti and Beaubaton, 1980).

The purpose of this study was to define the extent to which a structured visual framework contributes to the accuracy of goal-directed movements and to determine the moment at which this framework may be used. It was therefore decided to control the experimental environment in which the target appeared, separately from the hand visibility parameter. Sight of the moving limb could be removed and visual field maintained or, conversely, the field could be suppressed while allowing the subjects to see their hand moving against a completely dark background. Furthermore, intermediate situations were tested in which information concerning the visual environment was available only during the static phase (before and after the movement, when the hand was motionless) or during the dynamic, executive, phase. We assumed that this field factor would make it possible to establish more clearly the role of visual feed-back.

METHODS

Apparatus.

The main characteristics of the apparatus used have been described elsewhere (Conti and Beaubaton, 1980). The subjects sat in front of a vertical panel, the bottom of which was fitted with a small starting platform and the top with a grid-patterned printed circuit (32 x 32 cm). This circuit automatically supplied the rectangular coordinates of the point on the panel first contacted by the finger. The visual target was one among four red light-emitting diodes (5 mm in diameter) symmetrically arranged 7.5 cm above, below, right and left of the grid-center. The pseudo-random order in which the targets were illuminated could not be predicted.

The small plate used as the starting point of the movement was situated 45 cm beneath the grid-center. The pointing thus consisted of a vertical movement, from bottom to top, mainly involving shoulder and elbow. A second panel was located horizontally above the vertical one. When vision of the limb was prevented, the target lit up on this horizontal panel and was reflected by a 45 deg angled mirror. The subjects then pointed, under the mirror, at the virtual image of the target. When the limb could be seen, the mirror was replaced by a glass, allowing vision of the hand during the movement. The initial position of the hand was not visible and only the second half of the movement was under visual control.

Whatever the limb vision conditions, when visual field information was available, the panel on which the targets appeared was totally illuminated, whereas in cases involving suppression of all field information, the targets were presented in total darkness. When the moving hand alone had to be visible in the dark, subjects wore a phosphorescent glove. Since the two panels were absolutely equivalent, the visual environment was rigorously identical in situations where the hand was visible and in those where it was not. This visual field was kept constant for all the subjects; it consisted of the vertical and horizontal framework of the apparatus and of the pointing grid which looked like black points, regularly distributed every 5 mm on a white background. The four basic experimental situations are shown in figure 1.

Figure 1. The 4 basic experimental situations.

(A,B: with limb vision; C,D: without limb vision; A,C: with visual context; B,D: without visual context)

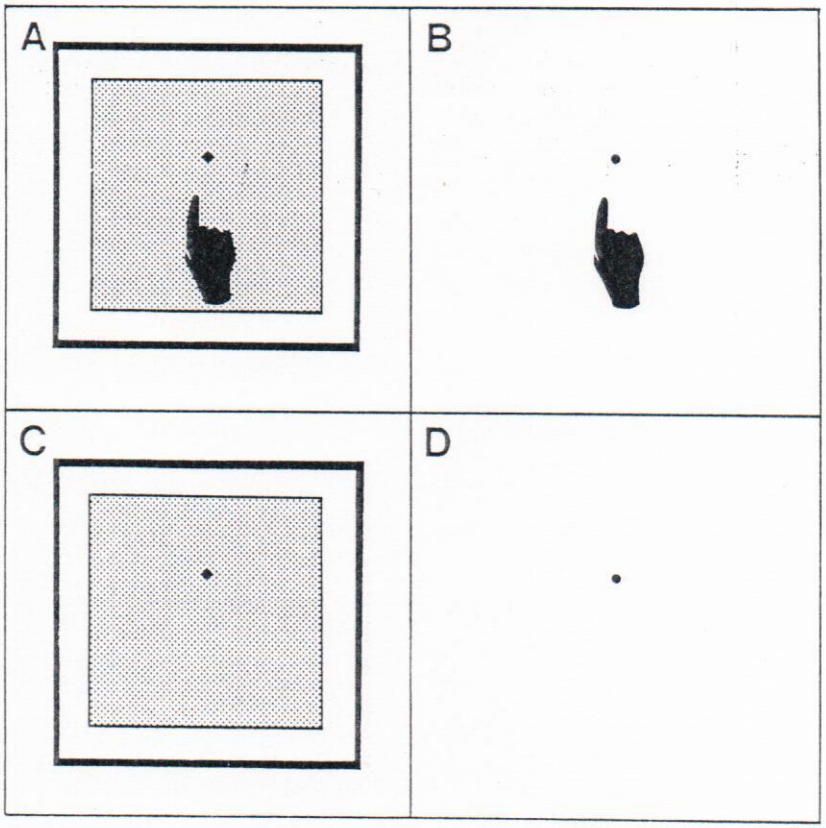


Figure 1. Les 4 situations expérimentales de base.

(A,B : avec vision du membre ; C,D : sans vision du membre ; A,C : avec contexte visuel ; B,D : sans contexte visuel)

Experimental conditions.

Two factors were studied in this experiment.

a) Visibility of movement:

Two conditions were compared: "limb vision" (LV), in which the subjects could see their hand trajectory throughout the pointing movement and "no limb vision" (NLV), in which vision of the hand displacement towards the target was suppressed.

b) Visibility of field:

Each movement visibility condition was divided into four sub-conditions depending upon the moment when environmental cues were available:
- *"no field"* condition (NF): the whole response was carried out in the dark.
- *"no on-going field"* condition (NOGF): the experimental environment was lit up until the hand left the starting point; it was unlit during the movement then lit up again when the finger contacted the grid.
- *"on-going field"* condition (OGF): the experimental environment was visible only during the movement. The field was lit up when the subject's hand left the starting platform and the lighting was switched off again when the hand reached the experimental panel.
- *"complete field"* (CF): the subjects could see the environment before, during and after the performance of the pointing movement.

In all, the subjects were confronted with 8 experimental situations, the order of which was varied across subjects. A series of 64 trials was performed in each situation.

Subjects.

Sixteen adult subjects, ten males and six females ranging from 20 to 43 years of age, participated in the experiment. All were right handed and spontaneously used their dominant hand to perform the task. They had either normal or corrected to normal vision.

Procedure.

The subjects had to point their index finger at a luminous target. A trial was started by placing the finger on the starting platform; this triggered the lighting up of one target on the panel, after a foreperiod of unpredictable duration (0.5 sec or 1 sec). Subjects were required to respond by releasing the platform and pointing as accurately as possible at the target. The release of the starting switch caused the lighting of the visual context to go on or off, depending on the experimental situation. When the moving hand alone needed to be visible in the dark, the subjects wore a phosphorescent glove.

Spatial accuracy was determined in each trial using 2 variables:
- *The directional error,* which was the angle between the optimal trajectory and the actual trajectory. It could be either positive, if on the right of the target, or negative, if on the left.
- *The amplitude error,* which was the difference between the actual and the optimal amplitude of the movement, from the starting point to the target. The amplitude error was taken to be positive when the movement was too wide.

At the same time we recorded, for control purposes, two temporal variables, namely the reaction time, i.e. the time between the target lighting going on and the starting point release, and the movement time separating the release from the contact with the grid. We used 4 targets to avoid too great standardization of the pointing, and the spatial variables were computed independently for each target. However, a previous analysis failed to reveal any significant differences related to target positions, so we neutralized this experimental factor by computing the mean accuracy for the 4 targets. These means were subjected to a two way 2 x 4 (feedback x field condition) analysis of variance.

RESULTS

All in all, performance clearly decreased when sight of the hand was prevented. Indeed, subjects were hypometric and more widely dispersed under the NLV condition, although direction error did not differ between the two limb vision conditions. The presence of a structured visual field exerted a noticeable influence on pointing accuracy but the effects were different depending upon whether or not subjects were able to see their hand during the movement (figure 2).

Under the "limb vision" (LV) condition, the visual context only affected the amplitude error, and the pointing direction remained unchanged in all four visual field situations. Amplitude error was minimal in two situations, "complete field" (CF) and "on-going field" (OGF), in which the field was present during the movement; these did not differ statistically ($F(1,15) = 1.0$, n.s.). The "non on-going field" (NOGF) situation was intermediate since error was greater than in CF ($F(1,15) = 5.67$, $p<.05$) and greater, but not significantly, than in OGF. Finally, when the whole task was performed in darkness (NF) subjects made greater errors than in the three remaining conditions.

The factor "field visibility" had a rather different effect under the "no limb vision" condition (figure 2); the overall effect of the visual field was significant with regard to both amplitude ($F(3,45) = 4.31$, $p<.01$) and direction ($F(3,45) = 4.37$, $p<.01$). But, with both variables, only one situation, "complete field" (CF) was statistically different from the three others, which did not differ significantly. In other words, when the task was entirely (NF) or even partly (OGF and NOGF) performed in darkness, a shift in pointing seems to have occurred towards the right and the bottom, in relation to the situation in which a structured visual field was continuously available.

Figure 2. Amplitude and direction errors in the 2 situations "limb vision" (LV) and "no limb vision" (NLV) under the 4 visual context conditions. (CF: context always present; NOGF: context during the static phases only; OGF: context during the dynamic phase only; NF: no context)

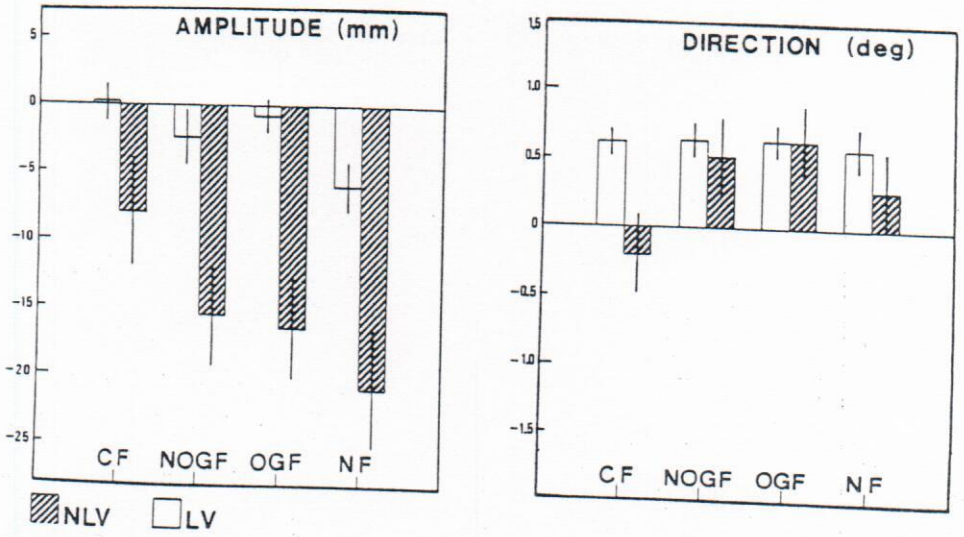


Figure 2. Erreurs d'amplitude et de direction dans les deux situations "avec vision du membre" (LV) et "sans vision du membre" (NLV) pour les quatre conditions de contexte visuel.
(CF : contexte constamment présent ; NOGF : contexte en phases statiques; OGF : contexte en phase dynamique ; NF : absence de contexte)

It should be noted that, in both situations LV and NLV, the observed modifications associated with the changes in the environmental conditions did not result from any variations in the temporal characteristics of the task. Indeed, neither reaction times nor movement times were statistically modified when the visual environment changed.

DISCUSSION

As the results show, the presence of a structured visual field influenced the results of the visuo-manual pointing task. This effect varied somewhat, however, depending on whether or not vision of the moving limb was possible.

In the classical "visual closed-loop" procedure, two kinds of visual information are both available: vision of the hand itself, and vision of the environment in which both target and hand are located. The latter type of information seems to play an important role, since

its suppression brought about a decrease in accuracy. Furthermore, when contextual information was available only before and after the movement (NOGF), when the hand was motionless, accuracy was increased relative to a completely lacking visual context. This result suggests that the context might be used before the movement begins, for instance to localize the target. However, contextual cues were found to be more efficient when they were given during the executive phase of the movement (OGF) since in this case maximal accuracy was achieved. Moreover, the accuracy increased in the amplitude error only, suggesting that the structured visual field may play a role in movement control and perhaps more specifically in the fine adjustment of the braking processes when the hand is in the vicinity of the target.

Even if the hand itself cannot be viewed in the visual environment, the presence of a structured visual field improves the performance of the pointing task. The greater accuracy observed in situation CF as compared with NF is consistent with a previous finding (Conti and Beaubaton, 1980) made in two analoguous situations. The main difference between those two situations concerns the conditions under which the target had to be localized, which were either a structured spatial frame or total darkness; in this connection, some previous studies have suggested that distinct mechanisms might be involved in each case (Matin et al., 1982).

The existence of double mode for locating a target in space has often been suggested: the first, egocentric or subject-related mode, seems to be used in darkness or in the absence of external landmarks, i.e. in instances when the target can be located purely in relation to the subject's body, and require the use of an extraretinal signal. The second, exocentric of object-related mode, seems to be used in a structured visual environment and to be more dependent on purely retinal inputs. In this case the target might be located in relation to other points in the environment, the position of which is unambiguously known.

Our results could be interpreted along these lines. Depending upon the visual cues available when it appears, the target might be located using either the first or the second reference system and the results appear to indicate that the exocentric location is the more accurate.

Nevertheless, if the visual context affects only the target mapping processes, the results obtained in situation NOGF, where the target was viewed in an illuminated context, should be quite identical to those measured in situation CF. Now this was not the case and in fact, the results in NOGF were no better than in NF. It seems necessary that contextual cues be present both for the preparation and for the performance of the movement, at least during the initial phase of the movement.

Indeed, if the movement trajectory is really planned, it seems theoretically necessary that the final state, i.e. the position of the target, but equally the initial state, namely the location from which the hand has to be displaced, both be specified. Prablanc et al. (1979) have shown that in a visuo-manual pointing task, the sight of initial hand position before the movement was sufficient to improve the pointing accuracy.

The position of the hand in body space is known on the basis of proprioceptive information signalling the angles formed by the various arm parts. To locate the hand in body space, the CNS must somehow be capable of transforming these angular values into extrinsic coordinates (Velay, 1984). The voluntary mobilization of the limb has been shown to improve the localization of the hand (Paillard and Brouchon, 1974; Velay, 1984), probably because the proprioceptive afferents are more complete when a certain level of muscular activation is achieved. It is thus conceivable that the operations underlying hand localization may partly overlap the initial phase of the movement, during which some further modulations of motor program are still possible (Megaw, 1974; Glencross, 1977). In our opinion, a common spatial coordinate system is required to locate both the visual target and the hand and then to plan the movement trajectory.

When the target appears in total darkness, it can be located exclusively within an egocentric system of reference and the movement must then also be planned within this body centered coordinate system. Conversely, when the target appears in a structured environment it might be simultaneously located with respect to the body and to some external landmark. However the use of an exocentric system implies that the hand be located relative to the environment. Now, if at the moment the hand is located the visual context suddenly disappears, the CNS might be forced to use an egocentric reference system, which is probably more archaic and less accurate but at least represents a reliable means of remaining independent of environmental vicissitudes.

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ABSTRACT:

In a visual pointing task performed by humans, two kinds of visual information which are not usually separated were experimentally dissociated: first, the visual feed-back concerning hand position; and secondly, the visual cues relating to the surrounding environment. The movement was executed both with and without vision of the hand. In both situations, subjects could take advantage of a structured visual field. Results confirm that suppression of vision of the hand decreases accuracy. Furthermore, this decrease may be partly attributable to suppression of environmental visual cues. Indeed, when the hand alone was visible but no visual landmarks were available, errors in movement amplitude were observed. In addition, even when the hand could not be seen, an improvement in both amplitude and direction of pointing was still possible when a

visual context was provided. When the hand could be seen, the visual context in which the task was performed seems to have mainly influenced control of the ongoing movement; and conversely, when the hand could not be seen, the context seems to have been used primarily for movement planning. We suggest that the visual field in which pointing takes place may determine the spatial coordinate system used to organize the movement before its execution.

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