Effects of visual coherence on visuo-manual coordination

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Abstract

Strong relationships exist between goal directed action and visual perception, both at the behavioural and cortical level. However, the nature and specificity of these interactions remain poorly understood. Here, we study the interactions between visual motion processing and goal-directed motor control in two perceptual-motor tasks involving driving and tracking moving objects of varying coherence. Our results show that overt motor behaviour does not influence perceptual coherence. In contrast, perceptual motion coherence has a strong influence in the tracking task, but a weak effect in the driving task. These findings suggest that perception and action share at least common mechanisms and that motor control depends on the manual task under investigation.

1 Introduction

The seminal work of Gibson (1966, 1977) emphasised the role of motor activities on visual perception. Conversely, it is well known that vision plays an important role in both the control and learning of goal-directed movements,

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leading to a tight linkage of perception and action (Welch, 1978). Along with these ideas, based on behavioural studies, it is widely accepted that the brain processes perception and action along parallel cortical pathways: a ventral processing stream is more specifically involved in object recognition while a dorsal stream is more specialised in motion analysis and on-line visual control of action (Goodale & Humphrey, 1998; Goodale & Milner, 1992). Likewise, recent studies point to a distinction between a vision for perception and a vision devoted to action (Rossetti, 2000), although evidence for a parallel modulation of visual motion perception and oculomotor pursuit behavior also suggests that both share common mechanisms (van Donkelaar, Miall & Stein, 2000; Stone, Beutter & Lorenceau, 2000).

Visuo-manual control is but one task in which complex interactions occur between on-line sensory processing and motor planning, that requires the integration of visual and proprioceptive informations in order to carry out a relevant hand motor command. For example, visuo-motor adaptation studies have shown that delaying visual feedback (Foulkes & Miall, 2000; Smith & Bowen, 1980) or occluding/distorting the visual field through prismatic lenses (Prablanc, Echallier, Komilis & Jeannerod, 1979; Welch, 1978) plays a critical role in motor performance, thus highlighting the importance of spatial and temporal congruence of the available sensory signals for accurate motor control. Less attention has been paid to the influence of the reliability of visual stimulation in the execution of regular isotonic movements, in particular when precise control of trajectories is needed. Manipulating the reliability or coherence of visual inputs raises new issues that concern the extent to which perceptual coherence alter motor control. Reciprocally, one may wonder whether active movements, thought to be involved in the building-up of an unified sensorimotor space (Paillard, 1991), facilitate the interpretation of unreliable sparse visual signals and their perceptual integration into a single unified object. Shedding light on these issues would help determining the nature of the reciprocal interactions between perception and action, and could have important consequences for patients with visual loss, either due to impaired sensitivity or cortical lesions.

In the present study, we build upon psychophysical experiments demonstrating that moving visual shapes partially visible through apertures can be seen as rigid shapes moving as a coherent whole or as non rigid parts moving incoherently, depending on the visibility of the apertures (Lorenceau & Shiffrar, 1992, 1999). Perceived coherence also strongly depends on the shape themselves, with closed shapes (e.g. diamond) perceived as much more coherent than open shapes (e.g. cross and chevron; see Lorenceau & Alais, 2001). To test whether active movements influence perceived coherence, we used a dual perceptual-motor task in which subjects had to drive or to track 2-D geometrical shapes of varying coherence along conic trajectories, and to evaluate the perceived coherence of the visual stimulation. On the one hand, if perceived coherence judgements are different from those found in previous experiments without goal directed action, this would add support to the proposal of distinct visual processes for perception and action. On the other hand, if perceived coherence modulates motor performance (smoothness and accuracy), this would suggest either that motor processes depends on perceptual mechanisms or that both share common mechanisms. In addition, if the driving and tracking motor tasks yield different results, this would indicate that perception/action interactions are specific of the sensorimotor requirements. The rationale behind this last hypothesis is that the two tasks involve distinct sensorimotor loops: in the driving task, visual information, together with proprioceptive inputs, act as a sensory feedback of self-generated movements, whereas in the tracking task visual information can be viewed as the 'triggering' input of an open-loop controller.

2 Method

2.1 Apparatus

Stimuli consisted of outlines of a diamond, a cross and a chevron sharing the same properties (length of 10.15 degrees of visual angle, dva, luminance of 59.52 cd.m^{-}2), viewed on a 21" screen (1024 $\times$ 768 pixels $\times$ 8 bits) located at 57 cm of the head of the subjects. Visual coherence was manipulated by presenting either the entire shapes (high coherence) or by presenting them through static visible (medium coherence) or invisible (low coherence) vertical apertures (18.08 $\times$ 3.01 dva) that masked their vertices (Fig. 1; see Lorenceau & Alais, 2001 for additional technical description). The manual interface was a joystick (2 degrees of freedom), sampled at the same frequency as the refresh rate of the screen (100 Hz). Movements were recorded on-line with the help of a dedicated software.

2.2 Experimental procedure

The experiment comprised two sessions, a 'Tracking' task and a 'Driving' task, runned in four alternate and successive blocks of 81 trials each. Each subject performed all the blocks with the dominant hand. Movements could be either clockwise or counterclokwise. Before taking part in the experiment, subjects were familiarized with the joystick manipulation and performed

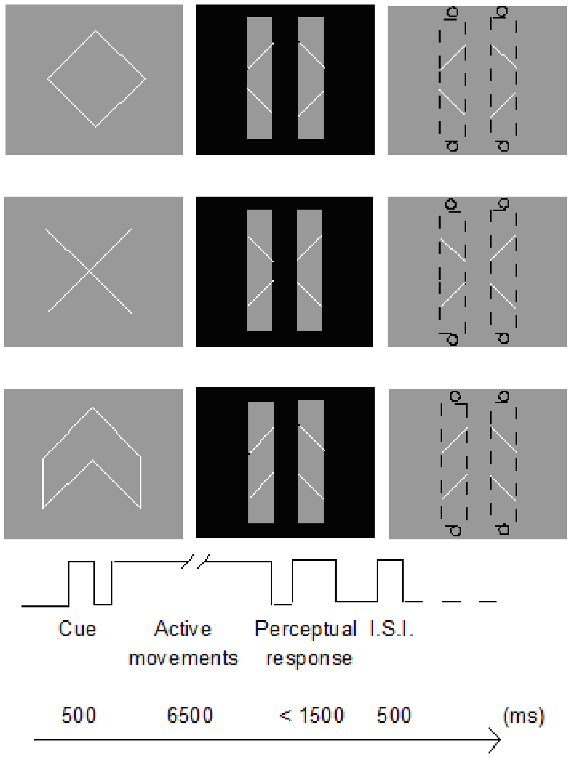


Fig. 1: Illustration of the experimental method. The top panel shows the stimuli used (from top to bottom: diamond, cross and chevron) and the coherence levels manipulated (from left to right: no apertures, visible and invisible apertures), while the bottom panel illustrates the experimental setup for one trial in the 'Driving' task.

smooth closed movements with visual feedback of the position of the joystick on the screen for a period that lasted for 3-6 min.

In the 'Tracking' task, subjects were asked to follow as precisely as possible with the joystick the centre of the stimuli translating at a constant angular frequency (0.83 Hz) along a circular (radius, 0.75 dva) or an elliptic trajectory (min/max radius, 0.75/1.51 dva). No visual feedback of the active hand was provided, nor of the position of the joystick on the screen. Manual tracking began after after a 500 ms preparatory period and lasted for 6.5 seconds (see Fig. 1). In the 'Driving' task, subjects had to drive the same stimuli with the joystick along similar conic trajectories, previously cued during 500 ms by a red symbol (outline of a circle or an ellipse). Movements were performed at an approximately constant speed (see below), and were constrained to a small virtual workspace on the screen such that stimuli disappeared when driving movements exceeded a surface of 2.26 $\times$ 2.26 dva. A the end of each 7 s trial, subjects were asked to evaluate the perceptual coherence of visual stimuli on a 3-points numerical scale (0: no coherence, 1: medium coherence, 2: high coherence), apart from their motor performance.

The factorial design adopted was composed of four main experimental factors used in the statistical analysis: coherence level (no apertures, visible and invisible apertures), stimuli (diamond, cross and chevron), trajectories (circular, horizontal and vertical ellipses) and direction of motion (clockwise and counter-clockwise). Stimuli and trajectories were randomized across trials. An additional 2-level session factor was considered for comparisons between the 'Driving' and 'Tracking' tasks.

2.3 Participants

Ten right and left-handed paid observers (5 males and 5 females ; mean age, 28.5), with no known visual and motor deficits, participated in the experiment. Manual dominance was assessed through a modified version of Edinburgh Handedness test (Oldfield, 1971). Informal consent was obtained from all participants who were naive as to the goal of the experiment.

2.4 Data processing

Raw data analyses were performed with Matlab (Matlab Software Inc.) custom routines. For the 'Tracking' task, mean amplitude ratio (also referred as gain) and mean phase lag of movement were computed from the spatial positions of the joystick and the target (expressed in polar coordinates). For the 'Driving' task, two analyses were undertaken: first, the global geometrical aspect of the trajectory was evaluated through a least mean square fitting procedure from which we derived mean eccentricity of the closed pattern; second, we calculated the mean variation of cyclical path length in a single trajectory. Additionally, we computed the mean angular frequency of movements.

3 Results

Perceptual coherence judgments are shown in Fig. 2 as their associated ranks averaged across trials, direction and subjects, for each experimental coherence level.

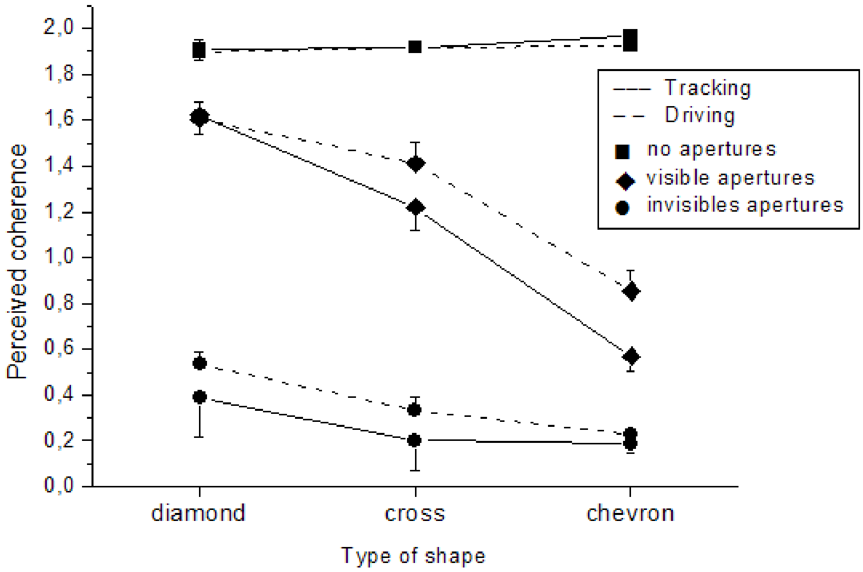


Fig. 2: Mean perceived coherence judgements as a function of stimuli, for the two tasks and coherence levels. Data are averaged over all participants and across all other conditions.

As expected from previous experiments (Lorenceau & Shiffrar, 1992) the results show a strong general effect of the presence of apertures on perceived visual coherence, especially for invisible apertures ($F(2,16)=304.91$, $p < .001$). In addition, this effect is modulated by the stimuli used as we observed a significant 2-way interaction (coherence level $\times$ type of shape, $F(4,32)=37.35$, $p < .001$) indicating that the effect of coherence level is more important for a cross and a chevron. Finally, this effect does not differ across the two sessions ($F(1,8)=.88$, ns), suggesting that the two motor tasks had no effect on perceived coherence.

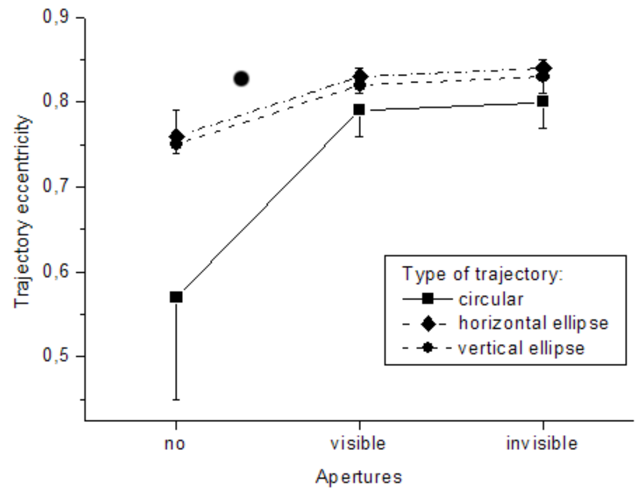
Motor accuracy (phase and gain) in the 'Tracking' task (Fig. 3) is affected by the presence of the apertures: for all three shapes, mean phase lag increases (+ $21° \pm 2$ between low and high coherence levels) as coherence level decreases ($F(2,18)=9.14$, $p < .01$). This effect is more pronounced for the cross and chevron stimuli, as can be seen with the larger slope of phase lag vs. coherence level, in comparison to the diamond (see Fig. 3). In addition, gain is always higher than 1, regardless of the experimental condition (1.67 ± 0.25, averaged across conditions). Analysis of pure tracking errors (i.e. tracking in the wrong direction) reveals that the number of 'opposite' tracking movement increase with decreasing coherence level (+ 8% ± 3 of total trials, between low and high coherence levels).

In the 'Driving' task, the effect of coherence on motor performance (Fig. 4) is less than in the 'Tracking' task, although coherence level has a significant effect on the fitted trajectory eccentricity for the three trajectories, with a higher mean eccentricity of movement, especially for the circular trajectory (+ 0.20 between low and high coherence levels), at low coherence level ($F(2,18)=113.05$, $p < .001$). This is associated with an increase of 1.53 dva (± 0.4) in mean cyclical path length between low and high coherence levels ($F(2,18)=12.73$, $p < .001$). In summary, on-line adjustments tend to be more variable and movements are distorded toward elongated trajectories at a low coherence level. Angular frequency of movements (0.81 Hz ± 0.12, averaged across conditions) is near the constant target frequency used in the 'Tracking' task (0.83 Hz), and certainly reflects the well-known isochrony principle (Viviani & McCollum, 1983).

4 General discussion

Perceived coherence judgements are comparable to those reported in previous psychophysical experiments (Lorenceau & Alais, 2001; Stone et al., 2000): occlusion of the vertices of the objects strongly impairs visual motion perception, and cross and chevron stimuli lead to more incoherent motion percepts when presented through apertures, in comparison to diamond. These observations suggest that active movements do not facilitate a coherent interpretation of visual shapes' motion, although in this study, perceived coherence has not been measured in passive viewing condition that would allow direct comparisons. However, the fact that perceived coherence was similar in both the driving and tracking tasks indicate that the specific motor requirements did not influenced perceived coherence.

As expected, motor performance were degraded at a low coherence level. Visual coherence affects more strongly the tracking behavior in comparison to the driving behavior. In manual tracking, the predictability of target trajectory has been shown to play a critical role in spatial and temporal accuracy, which can be accounted for by the inability of the observers to anticipate the future position of the target. It is also generally agreed that phase lag reflects lack of such predictive mechanisms. Thus, the observation



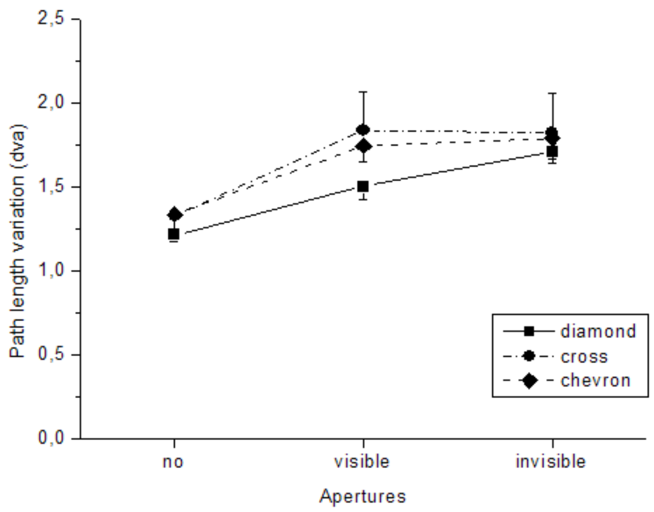


Fig. 3: *(top)* Mean trajectory eccentricity as a function of coherence levels in the 'Driving' task, for the three trajectories (circular, vertical and horizontal ellipse). *(bottom)* Mean path length variation as a function of coherence level, for the three stimuli (diamond, cross and chevron).

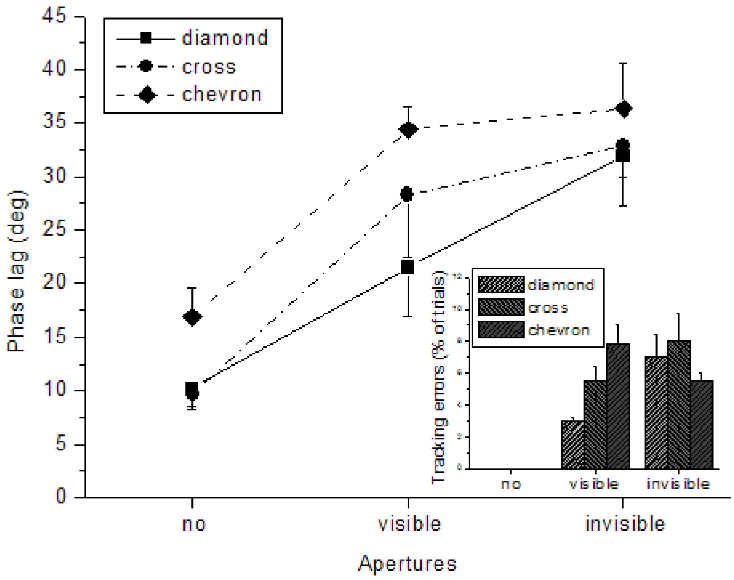


Fig. 4: Mean phase lag as a function of coherence level in the ‘Tracking’ task, for the three stimuli (diamond, cross and chevron). Pure tracking errors as a function of coherence levels are summarized in the insert on the bottom right of the figure.

of increasing phase lag in the tracking task with decreasing visual coherence suggests that subjects were unable to anticipate the future position of the target and, therefore, could not accurately adjust their overt tracking behavior to visual target motion. This point is further supported by the larger number of pure tracking errors in the low coherence condition. Both these effects are unlikely to reflect the change in the stimulus due to the presence of apertures, as they also depend on the visual shapes to be tracked. The larger mean phase lag for cross and chevron support the view that these effects reflect the poor representation of global coherent motion for these shapes, in agreement with previous psychophysical experiments (Lorenceau & Alais, 2001).

In the driving task, the fact that we observe significant variations of the global aspect ratio and mean cyclical length of the movements might reflect a potential influence of visual feedback on motor planning, although subjects could have decided not to take into account noisy visual information. A plausible explanation is that subjects relied on internal motoric rules, as proposed by Viviani & Stucchi (1992), which would allow them to correctly perform a regular smooth movement and discard the visual information when not reliable. This is also in agreement with computational studies of motor control involving adaptative planning of movements, which combine multisensory signals weighted according to their relative likelihood (van Beers, Baraduc & Wolpert, 2002). Faced with noisy visual information, subjects could have mainly relied on proprioceptive feedback and decide to switch to an open-loop mode of movement control. However, as observers were asked to judge perceived coherence at the end of each trial, and given that the subjects had to keep the shape in a small workspace, it is unlikely that visual information was always discarded. Although data suggest that under this driving condition, subjects could rely on an internalized motor program independently of visual inputs, thus supporting the notion of parallel processing streams for action and perception, additional experiments in which attention to the visual inputs would be experimentally manipulated would permit to be more conclusive on that point.

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