Vision Research 50 (2010) 1035–1040

Contents lists available at ScienceDirect

Vision Research

journal homepage: www.elsevier.com/locate/visres

Detection of radial motion depends on spatial displacement

Cristina de la Malla [a], Joan López-Moliner [a,b,*]

[a] Vision and control of action (VISCA) lab, Departament de Psicologia Bàsica, Universitat de Barcelona, Catalonia, Spain
[b] Institute for Brain, Cognition and Behaviour (IR3C), Catalonia, Spain

ARTICLE INFO

Article history:
Received 29 October 2009
Received in revised form 10 February 2010

Keywords:
Motion detection
Radial motion

ABSTRACT

Nakayama and Tyler (1981) disentangled the use of pure motion (speed) information from spatial displacement information for the detection of lateral motion. They showed that when positional cues were removed the contribution of motion or spatial information was dependent on the temporal frequency: for temporal frequencies lower than 1 Hz the mechanism used to detect motion relied on speed information while for higher temporal frequencies a mechanism based on displacement information was used. Here we test whether the same dependency is also revealed in radial motion. In order to do so, we adapted the paradigm previously used by Nakayama and Tyler to obtain detection thresholds for lateral and radial motion by using a 2-IFC procedure. Subjects had to report which of the intervals contained the signal stimulus (33% coherent motion). We replicated the temporal frequency dependency for lateral motion but results indicate, however, that the detection of radial is always consistent with detecting a spatial displacement amplitude.

1. Introduction

Radial motion is the retinal flow pattern that is caused when objects approach (expansion) or move away from (contraction) an observer along the line of sight. Its detection, therefore, subserves relevant responses in daily life situations (e.g. avoiding collisions, intercepting objects). Perceiving the direction of motion in depth (MID) has attracted the attention of many studies (e.g. Gray & Regan, 2006; Portfors-Yeomans & Regan, 1996, 1997; Regan & Kaushal, 1994; Sumnall & Harris, 2002), as well as the relevance of radial flow in different tasks. However, less attention has been devoted to characterizing the mechanisms that allow us to detect radial motion itself. In this study we try to characterize the mechanisms involved in the detection of radial motion. To do so, we rely on a previous paradigm that has been used to identify the mechanisms of low-level motion detectors in lateral motion (Nakayama & Tyler, 1981) and in second-order motion (Seiffert & Cavanagh, 1998). Basically these paradigms allow us to test whether motion detection is based on spatial information or motion signals.

Neurophysiological evidence in monkeys points to area MST as the site for radial motion processing as well as circular motion (Duffy & Wurtz, 1991). Some studies with humans, however, have also found that MT neurons can sometimes be activated by radial patterns but not always (Ptito, Kupers, Faubert, & Gjedde, 2001). Alternatively, it has been shown that parietal visual neurons are sensitive to the direction of motion but not to its speed and their large receptive fields would make them especially sensitive to optic flow (Motter, Steinmetz, Duffy, & Mountcastle, 1987; Steinmetz, Motter, Duffy, & Mountcastle, 1987). Area V6 appears to contribute to processing radial flow in humans with direction and speed selective neurons like those in MSTd but smaller receptive fields (Pitzalis et al., 2009) resulting in a local analysis of coherent motion before MT. Finally, the VIP area and the cingulated sulcus visual area could provide motion cues to MST (Wall & Smith, 2008) for obtaining egomotion from radial flow.

Psychophysical and behavioural studies have addressed diverse questions related to radial motion as well. For example, global radial motion has shown to override local radial motion in time to contact (TTC) tasks (Harris & Giachritsis, 2000) even in conditions in which local motion analysis were more favourable (Giachritsis & Harris, 2005). Another issue has been the differential sensitivity to comparable radial motion when corresponds to objects that move in depth or is self-generated (Lappe, Bremmer, & van den Berg, 1999; Rushton, Bradshaw, & Warren, 2007; Rushton & Warren, 2005; Warren & Rushton, 2004, 2007). Rushton and Warren (2005) propose that processing in cortical areas sensitive to optic flow might solve this ambiguity. The perception of speed of radial motion has also received attention in Bex and Makous (1997). They showed that speed of radial patterns is usually overestimated when compared to rotational or translational patterns. These authors suggested that radial motion would be processed after a previous stage in which local direction and speed of motion would be encoded (Bex, Metha, & Makous, 1998, 1999). Global motion would be left for a second stage which would probably rely on spatial linear summation of local signals obtained in the first phase

* Corresponding author.
E-mail address: j.lopezmoliner@ub.edu (J. López-Moliner).

0042-6989/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.visres.2010.03.014

(Morrone, Burr, & Vaina, 1995). Consistent with this two-stage idea, Burr and Santoro (2001) showed that perception of radial motion needed more integration time than lateral motion.

If we want to characterize a mechanism of motion detection we have to keep in mind that visual motion implies an ubiquitous confound: the movement of a visual target always involves a change of position (if lateral motion is involved) or size (e.g. the approach of a non-rotating object). These two sources of information are physically related but can be dealt with differently by the visual system. For example, one can easily ascertain a change of position without experiencing no motion at all (e.g. a clock hand or the shade projected by a stick) and alternatively, one can perceive motion without experiencing a clear concomitant change in spatial position (e.g. motion after-effects). Let us suppose that an object moves towards you for half a second at a given constant velocity and then stops. You may have detected the motion because the projected image was isotropically enlarged by a minimal increment of size (spatial information) irrespective of the speed at which this change of size took place. Alternatively, you could have detected the motion because the image expansion reached a velocity threshold (motion information) independently of the actual increment in size. We further know that these two sources of information can be dissociated (Regan & Hamstra, 1993) or combined when estimating the TTC (López-Moliner & Bonnet, 2002; López-Moliner, Field, & Wann, 2007; Smith, Flach, Dittman, & Stanard, 2001). Regan and Beverley (1978, 1979) and Beverley and Regan (1979) suggested the existence of neural mechanisms for perceiving MID that would be specifically sensitive to changing size. They showed (Regan & Beverley, 1978, Fig 1) that adaptation to oscillating size only depressed visual sensitivity to detecting changes of size but not to the detection of oscillatory motion stimuli that implied the same radial motion components without changing their size. These differences suggest that different channels than those processing motion process the change of size.

However, none of the studies so far have disentangled the use of spatial displacement from the use of motion when detecting radial motion. Nakayama and Tyler (1981) and Seiffert and Cavanagh (1998) did so for lateral and second-order motion respectively. Nakayama et al. when using a stimulus without a defined contour, found that for lateral motion that oscillates up to frequencies of 1 Hz observers use pure motion information instead of displacement. They concluded that speed or pure motion-sensitive mechanisms mediated the detection of motion when positional cues were removed and were dependent on the temporal frequency. However there was evidence for using spatial displacement mechanisms when positional cues were somehow available. The same paradigm used by Nakayama and Tyler allowed Seiffert and Cavanagh (1998) to conclude that displacement and not speed was the cue to detection of second-order motion stimuli. Their results indicate that first-order motion was determined by a pure motion system while the second-order motion stimuli were detected on the basis of a displacement-sensitive system. These two alternatives were also central to early motion detectors models: while Collewijn (1972) proposed a model based on the detection of a constant distance movement, van den Berg and van de Grind (1989) explained reaction times to motion by invoking a velocity model of bilocal detectors. These two mechanisms, velocity and distance models, have been later associated with relative and absolute motion respectively (Smeets & Brenner, 1994).

We here address whether the mechanisms that mediate the detection of radial motion are motion-sensitive or, on the contrary, rely on spatial information. In agreement with Nakayama & Tyler, our findings show that the mechanism used depends on the range of temporal frequencies for lateral motion, while the detection of radial motion always seems to rely on a spatial displacement.

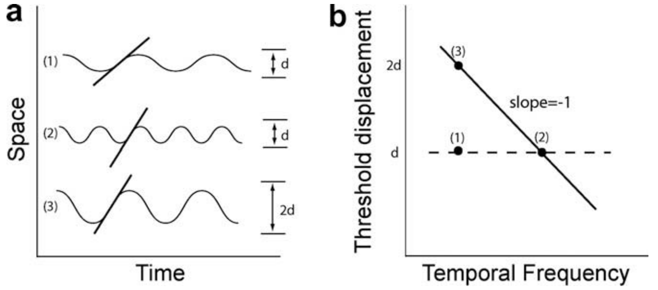

Fig. 1. (a) Different space–time plots that show how dot's position could vary across time. (1) and (2) have the same amplitude but different temporal frequency. (1) and (3) have the same temporal frequency but differ in their amplitudes. (2) and (3) have the same velocity (bold oblique lines) but differ in amplitude and temporal frequency. (b) Represents the different predictions in a log–log space for the examples plotted in 1(a) depending on whether speed (solid line) or displacement (dashed line) thresholds are used to detect motion.

1.1. The paradigm

Here we used the paradigm proposed by Nakayama and Tyler (1981) to dissociate pure motion and displacement information. A random dot pattern (see *stimuli* in Methods section for further details) oscillated sinusoidally from left to right in lateral conditions and expanding and contracting in radial ones. The oscillation was modulated by temporal frequency and displacement. Fig. 1a shows three different possibilities of how the position in space of a coherent dot of the stimulus is modulated across time. Examples (1) and (3) have the same temporal frequency but the displacement amplitude *d* of (3) is two times larger than the amplitude of (1) and (2). Dots in examples (1) and (2) have the same displacement amplitude *d* but the temporal frequency of (2) doubles that of (1). The slopes of the oriented lines in Fig. 1a denote the speed of the movement of coherent dots. In examples (2) and (3) the dots would move then at the same speed and when their displacement (thresholds) are represented as a function of temporal frequency (Fig. 1b) both points lie along a oriented line with a negative slope of -1 (in log–log coordinates, solid line in Fig. 1b). This reflects the fact that if a critical speed threshold is used, then dots oscillating at higher temporal frequencies will need smaller amplitudes (amplitude of 2 is smaller than 3) to reach the speed threshold. Alternatively, if a minimum displacement *d* is needed to detect motion, then obtained displacement thresholds will be flat with respect to temporal frequency (cases 1 and 2: same displacement with different oscillation frequencies).

2. Methods

2.1. Apparatus and stimuli

Stimuli were displayed on a Philips 22 inches CRT monitor (Brilliance 202P4) at a refresh rate of 118 Hz and screen resolution of 1154×864 pixels. Visual stimuli consisted of 150 random dots displayed within a circular window of 12 cm (163 pixels) of diameter that subtended 2°. Two stimuli were shown in each trial separated by a blank interval: one was made of noise only (all the dots moved in random directions) and the other contained signal (33% of coherent motion) plus noise. Stimuli were presented for 1500 ms. The viewing distance was 3.4 m and the minimum spatial displacement (1 pixel) at this distance subtended 0.37" of arc. Fig. 2 illustrates the stimuli used.

Dots always had a luminance of 46.8 cm/m^2 and were displayed on a grey background (10.24 cd/m^2). We used the same procedure as Shadlen and Newsome (2001) for controlling the dynamics of