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Detection of colour changes in a moving object

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Abstract

The colour-changing stimulus paradigm is based on a tacit assumption that kinematic attributes (velocity, movement direction) do not affect the detection of colour change (Moutoussis & Zeki, 1997). In this study three experiments are reported that clearly demonstrate that the time needed to detect changes in colouration of a moving stimulus becomes shorter with its velocity. The reduction of reaction time with increase of velocity is a purely kinematic effect independent on the reduction of reaction time caused by the stimulus uncertainty effects. It is concluded that colour coding mechanisms are not totally ignorant about movement parameters.

Keywords: Motion; Velocity; Reaction time; Probability; Colour change

1. Introduction

Semir Zeki with colleagues introduced an elegant colour-changing stimulus paradigm to determine the relative speed of processing different stimulus attributes (Moutoussis & Zeki, 1997). When moving objects are repeatedly changing colour (between red and green, for example) and alternating their motion direction (upward and downward) with the same frequency, then colour change must occur approximately 80 ms after changes in direction to be perceived as synchronous. They proposed that this asynchrony is due to the fact that the colour and motion analysing systems occupy geographically distinct locations in the visual cortex and these two systems have different perceptual latencies: we become conscious of colour before we become conscious of motion (Zeki et al., 1991). This spectacular demonstration has served as a crucial evidence for a generalisation that there are many consciousnesses distributed in time instead of a single unitary consciousness (Zeki, 2003).

This interpretation of the results of the colour-and-direction-changing experiments is highly controversial because it disagrees with many observations including neurophysiological data showing that cortical areas MT and MST, the most relevant for motion processing, have substantially shorter latencies than the area V4 known as the prime site for colour analysis (Schmolesky et al., 1998). Beside other similar observations (e.g., Berry, Brivanlou, Jordan, & Meister, 1999; Livingstone & Hubel, 1988), there is a group of psychophysical findings which can be interpreted as latency differences indicating that a moving object is processed faster and reaches consciousness earlier than a stationary one (e.g., Nijhawan, 1994; Whitney & Murakami, 1998; however, for an opposite result see Nijhawan, Watanabe, Khurana, & Shimojo, 2004).

On the other hand, several studies have questioned Zeki's interpretation on the ground that perceptual judgements are not directly interpretable in terms of perceptual latencies, at least not without an explicit model of the psychophysical decisions. It appears, for example, that about 80 ms delay occurs only for relatively high frequencies of oscillation. As the change rate slows down, the perceived asynchrony between colour and motion changes disappears (Nishida & Johnston, 2002). The perceptual delay of 80 ms observed in the colour correspondence task (Moutoussis & Zeki, 1997) is replaced with almost perfect synchrony in the temporal order task where the observer's task was to indicate whether a change in colour occurred before or after a

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change in motion (Bedell, Chung, Ogmen, & Patel, 2003; Nishida & Johnston, 2002). There was also no difference when observers were asked to make button press responses to a particular colour or motion direction—responses to changes of these two attributes were identical (Nishida & Johnston, 2002). Thus, these studies show that latencies in the perceptual system are task-specific and can vary according to the immediate stimulus context (cf. Adams & Mamassian, 2004; Allik & Kreegipuu, 1998; Arnold & Clifford, 2001). For example, it has been shown that an apparent temporal ordering of two simultaneous events depends on preceding stimulus events (Collyer, 1976).

Beside establishing limits in which the colour-motion asynchrony could be observed, there is a more fundamental problem with the colour-changing paradigm that to our knowledge has never been discussed. The colour-changing stimulus paradigm seems to be based on a tacit assumption that kinematic attributes (velocity and acceleration) do not affect the detection of the colour change. It is assumed that the colour-change of a moving object is detected identically irrespective of the velocity of the moving target. Trying to reveal ideas behind the silent assumption, it seems that the proponents of this paradigm assume the existence of two types of colour detectors (coding red and green respectively) which switch on as soon as one of them has detected the presence of the colour they are turned to. It does not matter whether this colour belongs to a moving or stationary object—colour-coding units are movement-blind and they just measure presence of radiation with a particular wavelength.

In the present study, we present evidence that the detection of changes in colour depends on the velocity of moving targets that seriously undermine the whole logic of chronometrisation of the perceptual delay by the colour-changing stimulus paradigm. To test the influence that movement speed has on the ability to notice changes in the moving object colouration, we designed three experiments. In the first experiment, an object moving with a uniform speed across the screen changed its appearance once during the movement. The observer was instructed to react as fast as possible when the moving object changed either its colour or contrast in relation to the starting value. In the second experiment, we made the place where the colour-change took place constant but manipulated the probability of the occurrence of the colour-change. Finally, in the third experiment we studied how the size of the stimulus and the luminance gradient affected the detection of the colour change. All three experiments demonstrated that the time needed to detect changes in colouration becomes shorter with velocity.

2. Experiment 1

The purpose of the experiment was to study simple reaction times (RTs) to unpredictable changes of an object that moves with different constant velocities and to compare them with the time required to detect similar changes of a stationary object. There were two types of experimental sessions dependent of the changing attribute: in one type of sessions the chromatic object changed its colour from red to green or green to red; in the second type of sessions the achromatic object changed incrementally or decrementally its contrast. The observer's task was to indicate, as fast as possible, when the object changed its colour or contrast.

2.1. Methods

2.1.1. Observers

Seven observers, four women (20, 21, 22, and 30 years) and three men (20, 21, and 22 years), with normal or corrected-to-normal vision participated in the experiment. Four observers were unaware of the purposes of this experiment.

2.1.2. Apparatus and stimuli

Stimuli were generated on the HP 19″ monitor screen (approximately 22.08° × 17°) with the help of a Cambridge Research Systems VSG 2/3. In order to achieve a better temporal resolution (200 Hz frame rate) the spatial resolution was reduced to 186 vertical lines and 752 horizontal positions. Reaction time was measured using an external clock of VSG 2/3 card providing the precision of at least 1 ms. The background luminance of the screen was 1.92 cd/m^2. The colour stimuli were red or green rectangular bars (1.96° × 0.25°) with approximately equal luminance of 12.7 cd/m^2. The achromatic stimulus was a white bar with two possible luminance values either 5.09 or 20.2 cd/m^2. These two values around the luminance of the colour bar were chosen to obtain approximately comparable perceptual salience of the change. Observers sat at a 90 cm viewing distance from the screen and were instructed to fixate a small cross in the centre of the screen. The order of sessions (colour or luminance change) was randomised.

2.1.3. Procedure

Each trial started with the appearance of either a moving or stationary rectangular bar. The bar appeared at the left or right edge of the screen and started immediately to move horizontally across the screen with one of five constant velocities: $v = 5.9$, 11.7, 17.6, 23.4 or 35°/s that were chosen randomly within a single block. The central part of the trajectory (one third of the screen width) was divided into 10 equally spaced positions (7.4; 8.2; 9.0; 9.8; 10.6; 11.5; 12.3; 13.1; 13.9 or 14.7° from the starting edge), the possible switch-points, where colour or luminance of the moving object could change. The (luminance or colour) change could happen with equal probability in one of these 10 positions and the movement lasted from 211 to 2509 ms, depending on the colour-change location and movement velocity, before the change occurred. The stationary bar ($v = 0$°/s) appeared randomly in one of these 10 positions and changed unpredictably its colour or luminance within the time window of 317–2509 ms after its appearance on the screen (corresponding temporally to the relevant interval