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Fast random motion biases judgments of visible and occluded motion speed

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ABSTRACT

Human sensitivity to speed differences is very high, and relatively high when one has to compare the speed of an object that disappears behind an occluder with a standard. Nevertheless, different speed illusions (by contrast, adaptation, dynamic visual noise) affect proper speed judgment for both visible and occluded moving objects. In the present study, we asked whether an illusion due to non-directional motion noise (random dynamic visual noise, rDVN) intervenes at the level of speed encoding, thus affecting speed discrimination, or at the level of speed decoding by non-sensory decision-making mechanisms, indexed by speed overestimation of visible and invisible motion. In Experiment 1, participants performing a temporal two-Alternative Forced Choice task, judged the speed of a target moving in front of the rDVN or a static visual noise (SVN). In Experiment 2 and 3, the target disappeared behind the rDVN/SVN, and participants reported whether the target reappeared early or late (Experiment 2), or the time to contact (TTC) with the end of the occluded trajectory (Experiment 3). In Experiment 1 and 2, we found that rDVN affected the point of subjective equality (*pse*) of the individual's psychometric function in a way indicating speed overestimation, while not affecting speed discrimination threshold (just noticeable differences, *jnd*). In Experiment 3 the rDVN reduced the TTC.

Though not entirely consistent, our results suggest that a similar speed decoding mechanism, which read-out motion information to form a perceptual decision, operates regarding of whether motion is visible or invisible.

1. Introduction

Humans often have to judge the speed of objects in order to move safely in their environment and avoid collisions. Psychophysical studies reported that observers can judge the speed of a single stimulus against an *implicit* standard with high precision, and can detect speed differences as low as 5% (McKee, 1981), despite random variation of temporal frequency (McKee, Silverman & Nakayama, 1986). The ability to judge relative speeds is maintained even when the trajectory is occluded so that the judgment has to rely on past visual experience acquired during visible trajectory before occlusion (DeLucia & Liddell, 1998). The Weber fraction for invisible motion can be, in appropriate conditions, relatively low (15%), indicating sufficiently good sensitivity in detecting small accelerations or decelerations of occluded motion (as inferred from when the target reappears) relative to pre-occluded speeds (DeLucia & Liddell, 1998; Battaglini, Campana & Casco, 2013). The evidence that the speed of invisible motion can be discriminated, leads to the question of whether speed judgments during visible and invisible motion rely on similar mechanisms.

Evidence that seems to support this hypothesis comes from findings that, despite the high capability of judging speed differences in optimal conditions, misperceptions of speed are still common phenomena both when motion is visible and when it is not. For example, Smith (1985) found that perceived speed of a low spatial frequency grating was consistently underestimated after adaptation to a homogeneous field flickering at temporal frequencies ranging from 0.8 to 12.8 Hz. Moreover, Treue, Snowden & Andersen (1993) showed that the perceived speed of a unidirectional moving random-dot pattern can be biased by adding briefly presented stationary points, which activate transient channels responding to high temporal frequencies. Misjudgments of speed can be also caused also by dynamic noise: random dynamic noise, not possessing directionality, may lead to speed misperception of visible motion (Edwards & Grainger, 2006).

The intriguing result that speed misperceptions are produced by temporal energy or motion noise without directionality, has been taken as evidence that misperceptions do not reflect the activation of early filters encoding direction and speed of motion on the basis of oriented spatiotemporal energy computation. Indeed, the response of these

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filters does not distinguish variations of spatial frequency, temporal frequency or contrast from variations of speed (Adelson & Bergen, 1985; Burr, Ross & Morrone, 1986; Treue et al., 1993; Smith, 1985). Speed misperception may be reflected onto the output of successive speed encoding mechanism (as indexed by *jnd*), based on the ratio of spatiotemporal energy computations (McKee et al., 1986). Alternatively, speed misperception by noise may result from decoding of speed, which requires a higher level computation based on the comparison between the activity of filters tuned to the same spatial frequency but differing in temporal frequency preference (Grzywacz & Yuille, 1990). Speed misperception by noise with no directionality was interpreted as depending on the activation of these higher order temporal frequency analyzers (Treue et al., 1993; Smith & Edgar, 1994; Castet, 1995), operating at the level at which the target's encoded speed is decoded into a speed representation to form a perceptual decision.

Both seminal (McKee et al., 1986) and recent studies (Gold & Ding, 2013; Carandini & Churchland, 2013) provide methodological insights in order to distinguish the level of processing at which noise interferes with speed judgments. McKee et al. (1986) suggested that the efficiency in encoding velocity per se is reflected in the Weber fraction, that is, by the speed discrimination threshold (just noticeable difference, *jnd*). On the other hand, the efficiency of decoding speed in order to make a perceptual decision on the magnitude of a test speed in comparison to a specific standard, is reflected into the point of subjective equality (*pse*) (Klein, 2001; Gold & Ding, 2013). Interestingly, most of the studies on speed misperceptions evaluated *pse* but not *jnd*, so that the interpretation can not exclude that their effects reflected an encoding operation.

Jnd and *pse* can be derived by psychometric functions generated by the percentage of trials in which the observer judges the comparison stimulus (CS) faster than the standard stimulus (SS) as a function of the difference in speed between two stimuli (Δspeed), in a two-interval forced-choice task. This effect of speed bias due to decoding would be reflected onto the position of the psychometric function on the x-axis (without affecting its slope) (Klein, 2001; Gold & Ding, 2013). This effect can be decoupled from the effect of sensitivity to speed (*jnd*), which would instead produce variations of the slope of the psychometric function (without affecting the position).

In order to establish whether visible and invisible motion share similar speed processing mechanisms, either devoted to encoding or decoding speed, we asked whether non-directional motion noise (rDVN) similarly affected speed discrimination, as indexed by *jnd* and reflecting common encoding mechanisms, or speed overestimation by decision-making mechanisms, as indexed by *pse* and reflecting similarity in decoding processes for the two motion types.

2. Experiment 1

In Experiment 1, we compared the interference effects of rDVN as compared to SVN on the perceived speed of a disk moving in front of the texture. We asked whether rDVN produced a speed bias and/or whether it affected the capability of discriminating speed differences between two sequentially presented disks moving at a constant speed. Observers judged directly the speed of the comparison stimulus ("is CS faster?"), which varied from trial to trial, relatively to the speed of the standard stimulus (SS) which was the same in every trial (Fig. 1).

2.1. Method

2.1.1. Participants

Twenty one students of the University of Padova (5 females, aged 23–26 years) took part in this experiment. Participants had normal or corrected-to-normal vision and were naive to the purpose of the experiment; they gave written informed consent prior to their inclusion in the experiment. The study was conducted in accordance with the Declaration of Helsinki (1964) and received ethical approval from the University of Padova (protocol 1901).

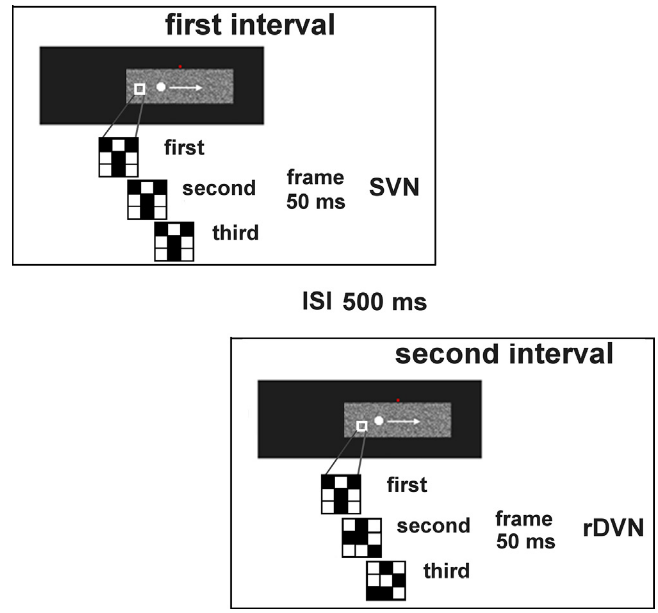

Fig. 1. Illustration of a trial. In the first interval there is an example of static visual noise (SVN) where the pixels do not change their grey value, whereas in the second interval the noise is dynamic (rDVN) in which the gray level of the pixels changes randomly every 50 ms. Participants were asked to report in which interval the target is faster.

2.1.2. Apparatus

Participants seated in a dark room 57 cm from the screen. Viewing was binocular; stimuli were generated with MATLAB PsychoToolbox (Brainard, 1997; Pelli, 1997) and were displayed on a 19-in. CTX CRT Trinitron monitor (refresh rate: 100 Hz). A gamma-correction was applied so that the luminance was a linear function of the digital representation of the image. The screen resolution was 1024 × 768 pixels. Each pixel subtended ~1.9 arcmin. Target and background luminance, measured using a Minolta LS-100 photometer, was 125 cd/m^2 and 0.9 cd/m^2 respectively.

2.1.3. Stimuli

Target. The target was a white disk (0.5 deg in diameter, luminance 125 cd/m^2) appearing on a rDVN/SVN 4 deg to the left or to the right in respect to the center of the texture, with equal probability. The target disk moved horizontally frame-to-frame in constant steps towards the opposite side. Target speed was fixed (3 deg/s) for SS, and varied across trials for CS, along seven levels: 2.7, 2.8, 2.9, 3, 3.1, 3.2, 3.3 deg/s. The target disappeared after 8 deg. Being the trajectory of fixed length, the stimulus durations were: 2.96, 2.86, 2.76, 2.67, 2.58, 2.5, 2.42 sec.

Background texture. A central textured area of either SVN or rDVN, 8 deg long and 2.5 deg wide, was created by assigning to each pixel a random gray value from 1 to 255 levels of grey (Battaglini, Contemori, Maniglia & Casco, 2016). The mean luminance was ~68 cd/m^2. A red dot (0.1 deg in diameter, 24 cd/m^2) placed 0.2 deg above the center of the texture was the fixation mark. In the SVN, pixel values remained unchanged whereas in the rDVN it changed randomly every 50 ms, producing an effect similar to a detuned TV (Fig. 1).

2.1.4. Experimental procedure

In Experiment 1, each trial consisted of two intervals separated by a 500 ms inter-stimulus interval (ISI) randomly interleaved, with SS and CS randomly presented in either interval. Participants performed two counterbalanced blocks of 112 trials each (16 repetition × 7 speed levels). In one of the two blocks, the SVN was presented in both intervals. In the other block, the CS moved against the rDVN, whereas the SS moved against the SVN. All participants were instructed to maintain