Perception, 2000, volume 29, pages 1203 – 1208

DOI:10.1068/p3047

Speed perception is affected by the Ebbinghaus – Titchener illusion

Marina Pavlova, Alexander Sokolov
Institut für Medizinische Psychologie und Verhaltensneurobiologie, MEG-Zentrum,
Eberhard-Karls-Universität Tübingen, Gartenstrasse 29, D 72074 Tübingen, Germany;
e-mail: marina.pavlova@uni-tuebingen.de
Received 15 February 2000, in revised form 28 June 2000

Abstract. We examined whether the apparent extent of motion affects speed perception. On the first presentation of each trial, a light dot travelled horizontally across a central circle of one of the Ebbinghaus configurations (with either small or large inducing elements). On the second presentation, observers adjusted the speed of a dot moving within the central circle alone so as to match the speed perceived in the first presentation. For all stimulus speeds (1.3, 2.1, and 5.5 deg s^{-1}), the matched speed with small inducing circles was systematically less than that with large inducing circles. The findings indicate that the perceived speed depends on the apparent extent of motion: the larger the apparent size of a frame, the slower the apparent speed. These results are consistent with the predictions of transposition effects in visual motion.

1 Introduction

Variations in the physical size of a spatial frame for motion cause misperception of actual speed: the larger the linear dimensions of a movement field, the lower the seen velocity. This velocity transposition principle (Brown 1931) receives empirical support from numerous psychophysical studies ranging from visual motion detection to extrapolation of moving targets. Our daily experience also follows the expectations based on velocity transposition. The smaller the car the quicker it is seen to travel. Similarly, an object appears to move faster when observed through a narrow slit than within a panoramic view.

For motion detection, increasing the linear dimensions of a spatial frame leads to an increase of the velocity thresholds (eg Bonnet 1982; Kinchla 1971). Yet, when a hierarchy of different-sized frames is simultaneously present, motion detection is determined by the most immediate frame (Linde and Sokolov 1986). Detection of abrupt changes in velocity of random-dot patterns that move across different-sized apertures also conforms to velocity transposition (Mateeff and Hohnsbein 1996). Snowden (1999) reported that speed discrimination thresholds for moving gratings are elevated with a randomly varying field size.

For speed estimations, the transposition effect has been replicated several times with different stimulus patterns and experimental paradigms (Mashhour 1964; Rock et al 1968; Zohary and Sittig 1993). Among other parameters, spatial frequency, size of a moving target, its contrast, and nonstationarity of a frame for motion alter the perceived speed (Blakemore and Snowden 1999; Chen et al 1998; Diener et al 1976; Gegenfurtner and Hawken 1996; McKee et al 1986; Norman et al 1996; Snowden et al 1998; Stone and Thompson 1992; Thompson 1982). The size of a physical frame, however, is likely to exert a stronger influence on the perceived speed. Even for motion extrapolation, we have found that the extent of visible motion produces much more pronounced effects on timing of occluded motion than, for example, the target size (Sokolov et al 1997).

Although the influence of the size of a physical frame on motion perception is well established, it still remains unclear how speed perception varies with the apparent size of a frame. One possible way to explore the issue is to employ geometric illusions that introduce changes in the perceived size of the immediate frame for motion while keeping physical parameters constant. Only a few early observations favour the conjecture that a target appears to move faster when travelling across subjectively shorter distances (Stucchi et al 1996). Here, using a matching paradigm we examine how the apparent size of a spatial frame for motion in the Ebbinghaus – Titchener illusion affects the perceived speed. Observers first saw a light dot moving horizontally across the central circle of one of the Ebbinghaus configurations with either small or large inducing circles. In the test presentation, they adjusted the speed of a dot traversing the central circle alone so as to match the speed perceived in the first presentation. We expected that an apparently larger immediate spatial frame for motion in the configuration with small inducing elements would result in a slowing down of perceived speed.

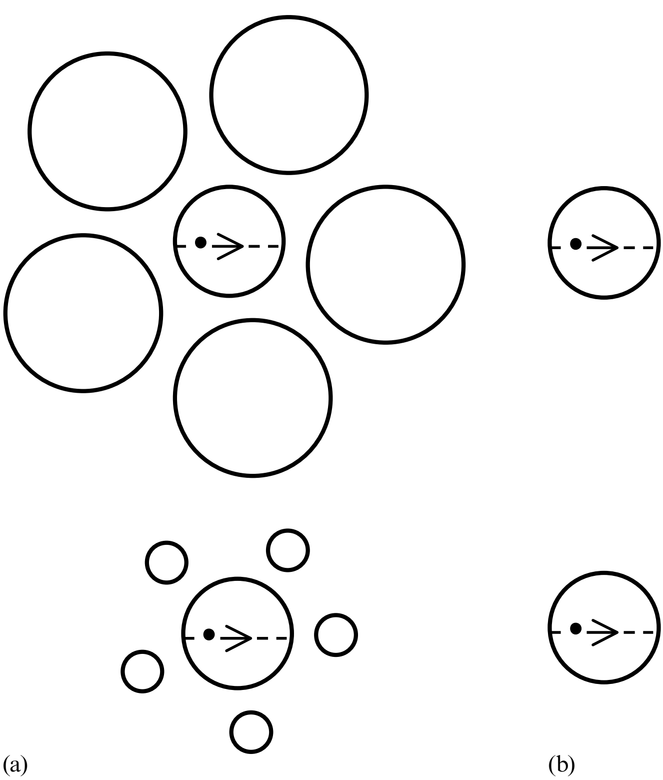
2 Method

2.1 *Subjects*

Eleven right-handed volunteers (students of the University of Padua, aged from 18 to 25 years, mean age 22.2 years, seven males) with normal or corrected-to-normal vision participated. They were naïve as to the aim of the study. Subjects were run individually.

2.2 *Stimuli and apparatus*

We used computer-generated Ebbinghaus – Titchener configurations (see eg Robinson 1998) in which the central circle was surrounded by five either small or large inducing circles (figure 1). The configurations were produced with a Tektronix system 4054 with Option 30 for animation, and displayed on a 19-inch monitor with a spatial resolution



(a) (b)

Figure 1. Schematic view of stimulus arrangements. (a) In the first presentation of each trial a dot traversed the central circle of the Ebbinghaus figures with either large (upper panel) or small (lower panel) inducing elements. (b) In the second presentation, a dot travelled across the central circle without any inducing elements. See text for details.

of 4096×4096 pixels. The size of the central circle was always 3.5 cm (3.5 deg) at a viewing distance of 57 cm. Each of the small inducing circles was 0.9 deg whereas the size of the large inducing circles was 5.5 deg. The inducing elements were placed 0.7 deg away from the central circle (from adjacent edges). On the first presentation of each trial, a moving light dot (0.15 deg with a luminance of 60 cd m^{-2}) travelled from the left to the right at a constant velocity within the central circle of one of the Ebbinghaus figures. Three different standard speeds (1.3, 2.1, and 5.5 deg s^{-1}) were used in a random order.

2.3 *Procedure*

An observer sat in a dimly illuminated room. His or her head was fixed in a head-and-chin rest. Each trial started with a warning tone. A trial consisted of two consecutive presentation intervals. During the first interval, a target appeared just next to the left border of the central circle of one of the Ebbinghaus configurations with either small or large inducing circles, and travelled horizontally to the right (figure 1a). In the second (test) presentation, observers adjusted the speed of a dot moving within the central circle that was not surrounded by the inducing elements, so as to match the speed perceived in the first presentation (figure 1b). The initial target speed in the second presentation was equal, slower, or faster than the physical speed of the moving dot in the first presentation. Each speed was repeated twelve times per size of the inducing circles, so that the two blocks completed by each observer contained a total of 72 trials ($3 \times 12 \times 2$). The order of blocks with large and small inducers was counterbalanced between subjects. Observers visually tracked the moving dot: we required this viewing strategy to avoid including additional elements (fixation point) in a stimulus configuration. Although there is some evidence that fixation leads to a greater magnitude of the velocity transposition effects (Brown 1931), binocular pursuit provides observers with a more natural strategy to accomplish the task and results in a better match of the judged and retinal speeds (Turano and Heidenreich 1999). Subjects were required to perform the task relying upon their visual impressions of motion (ie not to count time or use other secondary criteria). No feedback was given regarding performance.

3 Results

The physical speed of the moving target in the first presentation was considered a standard. To compare perceived speed as a function of the apparent size of the immediate frame for motion, we computed matched-to-standard speed ratios for each subject and for each of the three standard velocities. Figure 2 (upper left panel) shows the matched-to-standard speed ratios averaged across the eleven subjects for the configurations that contained either small or large inducing circles. As seen in figure 2, the matched speed for the Ebbinghaus configuration with large inducers is consistently greater than for the configuration with small inducing elements. Inspection of the individual data shows the robustness of the obtained effect across observers.

Two-way ANOVA was performed on the individual ratios as the dependent measure with factors standard speed and configuration. The analysis reveals a strong main effect of configuration ($F_{1,10} = 16.871$, $p < 0.002$). Neither target speed nor the interaction of factors speed and configuration exert any effects on the matched-to-standard speed ratios ($F_{2,10} = 0.72$ and 0.566, ns, respectively).

Inspection of figure 2 (upper left panel) indicates that, for all speeds with the exception of 2.1 deg s^{-1} with large inducing elements, the ratio is less than unity, indicating that in the second presentation the matched speed is generally slower than the previous standard speed. It is noteworthy that for all speeds the ratios with small inducing elements statistically differ from unity ($t_{32} = 3.451$, $p < 0.01$), while the ratios with large inducing elements do not ($t_{32} = 0.046$, ns).

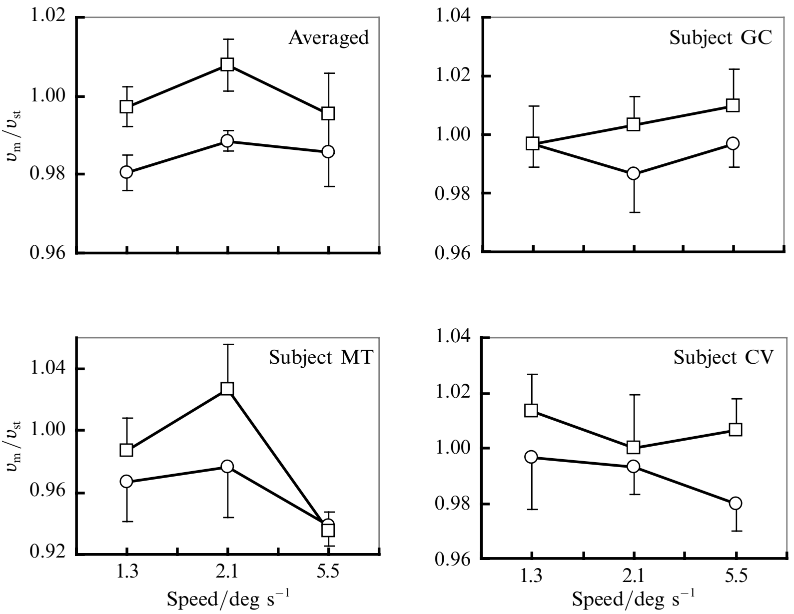


Figure 2. Matched-to-standard speed ratios, v_m/v_{st}, as a function of target speed in the Ebbinghaus figures with large (squares) and small (circles) inducing elements. Averaged data for all eleven observers (upper left panel) and for three representative subjects. A data point shows mean $\pm$SE. The matched speed is faster for the apparently smaller immediate frame for motion.

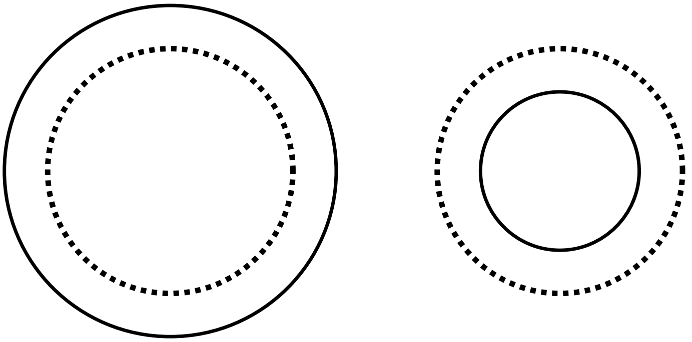
4 Discussion

By using the Ebbinghaus – Titchener illusion we have demonstrated that perceived speed depends on the apparent extent of motion: the smaller the apparent size of the central circle the faster the perceived speed. It seems, therefore, that the apparent size of the immediate frame for motion affects perceived speed in a way similar to that of physical size. The findings conform to the predictions of transposition effects in visual and extrapolated motion (Sokolov et al 1998).

The perceived speed may vary with mode of stimulus presentation. For example, the effect of physical contrast on speed perception is greater with simultaneous than with successive presentation of stimuli (Blakemore and Snowden 1999; Stone and Thompson 1992). These and other related data suggest that the effect of apparent size on speed perception would be more pronounced if the Ebbinghaus and test configurations were presented simultaneously. Likewise, simultaneous presentation of both Ebbinghaus figures by using one of the configurations as a standard and the other one as a test may also amplify the effect.

In fact, there was no misperception of speed with large inducing elements. One would expect that an apparently smaller immediate spatial frame for motion in the configuration with large inducers would result in an increase of perceived speed. The obtained ratios, however, were statistically close to unity. We assume that the successive order of presentation may account for this result. Harris and Rushton (1997) reported that temporal order of presentation affects perceived speed: it increases in the second presentation. This may cause the slowing down of the matched speed in the second presentation, thereby cancelling the effect of the apparent size of the frame. However, because an increase in perceived speed should occur in the second presentation after exposure to both types of Ebbinghaus configurations with large and small inducers, it is unlikely that temporal order contributes to the difference in the matched speed in the present study.

Our findings agree with the observations of Stucchi et al (1996) that a target appears to move faster when travelling across subjectively shorter distances. For example, the apparent curved trajectory of a dot revolving along a central circle of the Ebbinghaus – Titchener figure affected its perceived speed in this way. Yet, in the Delboeuf illusion, a target looked as if it were moving slower over apparently shorter distances. Figure 3 illustrates the Delboeuf illusion. Because the outer (dashed) circle in figure 3b usually appears smaller than the same-sized inner circle in figure 3a (see also da Pos and Zambianchi 1996; Weintraub and Schneck 1986), one would expect that a target revolving along the outer circle would look faster. It seems that the variations in the physical size of the movement field may be responsible for the curious outcome obtained by Stucchi et al. Under successive mode of presentation, for motion along the outer circle, the immediate frame may be defined by the screen borders and, therefore, the frame is larger than for motion along the inner circle. This may result in the slowing down of perceived speed along the outer circle.



(a) (b)

Figure 3. Illustration of the Delboeuf illusion. The outer dashed circle in (b) usually appears smaller than the same-sized inner circle in (a).

Gamma (40 – 90 Hz) oscillations of the cells in monkey's primary visual cortex (areas V1 and V2) exhibit a specific sensitivity to reciprocal variations in the size and speed of a moving target: either increase in the target size or slowing down its speed alters the mean oscillation frequency in the same direction (Eckhorn et al 1994). Similar neural mechanisms might underlie the dependence of perceived speed on the physical and apparent size of the immediate frame for motion.

Acknowledgements. The experiments were done during our stay at the Department of General Psychology, University of Padua, Italy, which was supported by the University of Padua. We thank Giovanni B Vicario for discussions, Osvaldo da Pos, Sergio C Masin, and Daniele Zavagno for generous support, two anonymous reviewers for their helpful comments, and Sandro Bettella for considerable technical assistance. We especially appreciate John C Baird for valuable advice on the manuscript, Niels Birbaumer for providing us with excellent working facilities during the paper preparation, and Arseny Sokolov for patience. MP was supported by a Human Frontier Science Program Organization Fellowship and by the Faculty of Medicine, University of Tübingen (Fortüne-Program 716-0-0). Part of the study was presented at the 22nd European Conference on Visual Perception (Trieste, Italy).

References

Blakemore M R, Snowden R J, 1999 "The effect of contrast upon perceived speed: a general phenomenon?" *Perception* **28** 33 – 48

Bonnet C, 1982 "Thresholds of motion perception", in *Tutorials in Motion Perception* Eds A H Wertheim, W A Wagenaar, H W Leibowitz (New York: Plenum) pp 41 – 79

Brown J F, 1931 "The visual perception of velocity" *Psychologische Forschung* **14** 192 – 232

Chen Y, Bedell H E, Frishman L J, 1998 "The precision of velocity discrimination across spatial frequency" *Perception & Psychophysics* **60** 1329 – 1336

Diener H C, Wist E R, Dichgans J, Brandt T, 1976 "The spatial frequency effect on perceived velocity" *Vision Research* **16** 169 – 176
Eckhorn R, Frien A, Bauer R, Woelbern T, 1994 "Oscillation frequencies (40 – 90 Hz) in monkey visual cortex depend on stimulus size and velocity" *European Journal of Neuroscience* **7** Supplement, 90
Gegenfurtner K R, Hawken M J, 1996 "Perceived velocity of luminance, chromatic and non-Fourier stimuli: influence of contrast and temporal frequency" *Vision Research* **36** 1281 – 1290
Harris J M, Rushton S K, 1997 "Mistaken identity: Temporal-order biases in the perception of speed" *Perception* **26** Supplement, 74
Kinchla R A, 1971 "Visual movement perception: a comparison of absolute and relative movement discrimination" *Perception & Psychophysics* **9** 165 – 171
Linde N D, Sokolov A N, 1986 "Detection of motion and spatial localization of object" *Soviet Journal of Psychology* **7** 143 – 147
McKee S P, Silverman G, Nakayama K, 1986 "Precise velocity discrimination despite random variations in temporal frequency and contrast" *Vision Research* **26** 609 – 619
Mashhour M, 1964 *Psychophysical Relations in Perception of Velocity* (Stockholm: Almqvist and Wiksell)
Mateeff S, Hohnsbein J, 1996 "Perception of visual motion with modulated velocity: effects of viewing distance and aperture size" *Vision Research* **36** 2873 – 2882
Norman H F, Norman J F, Todd J T, Lindsey D T, 1996 "Spatial interactions in perceived speed" *Perception* **25** 815 – 830
Pos O da, Zambianchi E, 1996 *Illusioni ed Effetti Visivi: Una Raccolta* (Milano: Angelo Guerini)
Robinson J O, 1998 *The Psychology of Visual Illusion* (New York: Dover)
Rock I, Hill A J, Fineman M, 1968 "Speed constancy as a function of size constancy" *Perception & Psychophysics* **4** 37 – 40
Snowden R J, 1999 "The bigger they are the slower they move: the effect of field size on speed discrimination" *Perception* **28** Supplement, 24 – 25
Snowden R J, Stimpson N, Ruddle R A, 1998 "Speed perception fogs up as visibility drops" *Nature (London)* **395** 450
Sokolov A N, Ehrenstein W H, Pavlova M A, Cavonius C R, 1997 "Motion extrapolation and velocity transposition" *Perception* **26** 875 – 889
Sokolov A, Pavlova M, Ehrenstein W H, 1998 "Perceived and extrapolated visual motion: Brown reassessed", in *Advances in Perception – action Coupling* Eds B Bril, A Ledebt, G Dietrich, A Roby-Brami (Paris, France: Éditions EDK) pp 74 – 78
Stone L S, Thompson P, 1992 "Human speed perception is contrast dependent" *Vision Research* **32** 1535 – 1549
Stucchi N, Purghé F, Costa T, 1996 "Optical-geometric illusions in kinetic conditions" *Perception* **25** Supplement, 136
Thompson P, 1982 "Perceived rate of movement depends on contrast" *Vision Research* **22** 377 – 380
Turano K A, Heidenreich S M, 1999 "Eye movements affect the perceived speed of visual motion" *Vision Research* **39** 1177 – 1187
Weintraub D J, Schneck M K, 1986 "Fragments of Delboeuf and Ebbinghaus illusions: contour/context explorations of misjudged circle size" *Perception & Psychophysics* **40** 147 – 158
Zohary E, Sittig A C, 1993 "Mechanisms of velocity constancy" *Vision Research* **33** 2467 – 2478