Journal of Experimental Psychology:
Human Perception and Performance
2015, Vol. 41, No. 2, 283–288

0096-1523/15/$12.00 http://dx.doi.org/10.1037/xhp0000027

OBSERVATION

The Effect of Object Familiarity on the Perception of Motion

Andrés Martín and Javier G. Chambeaud
ILAV, UNT-CONICET, San Miguel de Tucumán, Argentina

José F. Barraza
ILAV, UNT-CONICET, San Miguel de Tucumán, Argentina
and Universidad Nacional de Tucumán

Humans are capable of picking up the invariance of an object's physical speed regardless of the distance from which it is seen. This ability is known as speed constancy. Typically the studies of speed constancy focus on the spatiotemporal cues present in the stimulus. In this work we present a series of experiments that introduce the object's familiarity in combination with other cues to study the speed constancy. The results of the first experiment show that human observers use said familiarity in the estimation of the physical speed of the objects. When distance cues are added to the stimulus, the results show that familiarity helps the system to achieve speed constancy. In the second experiment we remove the contextual cues and show the effect of familiarity on speed constancy. Finally, we propose that familiarity needs to be included in the analysis of speed constancy perhaps by considering the prototypical size of the objects.

Keywords: familiar size, motion, velocity constancy

Humans are highly efficient in comparing the physical speed of objects, regardless of the distance at which the objects are located. That is why we can effortlessly judge that a person crossing the street in front of us is moving at the same speed as that of another person crossing much further away. This ability is known as speed constancy. Along with other constancies such as size, lightness, and color constancy, speed constancy contributes to the capacity of our perception in representing the world without alterations.

The empirical evidence collected during years of investigation on speed perception has been explained according to two main hypothesis: relational and quantitative hypotheses. *Relational hypotheses* comprise the transposition (Brown, 1931; Wallach, 1939) and the temporal frequency hypotheses (Distler, Gegenfurtner, Van Veen, & Hawken, 2000; McKee & Smallman, 1998). Both explain speed constancy from the concomitant variation of size, speed, spatial frequency, and temporal frequency with distance. Because speed constancy would be achieved from the relation of these spatial and temporal variables, no absolute estimate of distance is needed. *Quantitative hypotheses*, in turn, comprise the traverse distance hypothesis (Epstein, 1978) and the velocity distance invariant hypothesis (equivalent to Size Distance Invariant Hypothesis; Epstein, 1978; Gogel & Tietz, 1976). In this case, speed constancy requires an explicit estimate of distance to scale the traversed distance or the angular speed.

The challenge for these hypotheses is to explain the bias in the perceived speed that appears when an observer compares two different sized stimuli displayed at the same distance (smaller objects are perceived faster), and the almost perfect constancy found when two identical stimuli are displayed at different distances (Brown, 1931; Distler et al., 2000; Epstein, 1978; McKee & Welch, 1989; Tozawa, 2008; Wallach, 1939; Diener et al., 1976; Zohary & Sittig, 1993). Some empirical evidence seems to favor certain interpretations of the relational hypotheses. McKee and Welch (1989) have demonstrated that the mechanism for speed constancy does not use an explicit knowledge of the object's distance. These results support the relational hypotheses and clearly advocate against the quantitative hypotheses. However, other studies (Distler et al., 2000; Epstein, 1978; Rock, Hill, & Fineman, 1968; Tozawa, 2008; Zohary & Sittig, 1993) have shown that the perceived distance may play a role in speed constancy. Importantly, in most of these studies, observers had to compare the speed of synthetic stimuli (e.g., bars, dots, gratings, etc.).

What would be the prediction of these hypotheses if the stimuli were two different, well known objects, with different sizes, namely a basketball and a tennis ball? In this case, if both stimuli are displayed with the same angular speed, the relational hypotheses predict that the basketball will appear to move more slowly than the tennis ball. However, one would not expect the system to use such a strategy in this case because it would lead to a misperception of speed. Rather, the system would make good use of the knowledge of the objects (and their sizes) and prevent the speed scaling. Distler and collaborators (Distler et al., 2000) compared the perceived speed of a truck to that of a car and found a much

---

Andrés Martín and Javier G. Chambeaud, Instituto de Investigación en Luz, Ambiente y Visión, UNT-CONICET, San Miguel de Tucumán, Argentina; José F. Barraza, Instituto de Investigación en Luz, Ambiente y Visión, UNT-CONICET and Departamento de Luminotecnia, Luz y Visión, FACET, Universidad Nacional de Tucumán.

This study was supported by an ANPCyT Grant PICT 2014, a CIUNT Grant 26E405, and a PIUNT Grant PE 503.

Correspondence concerning this article should be addressed to Andrés Martín, CONICET, Av. Independencia 1800, San Miguel de Tucumán, Tucu 4000, Argentina. E-mail: andres.mrtn@gmail.com

smaller bias than that found when they compared two cars of different sizes. This would suggest that the visual system used prior knowledge of the objects in the perception of speed.

In this article, we present a series of experiments that investigate the effect of object familiarity on speed constancy. We hypothesize that the identification of objects provides useful information such as identity and prototypical size for speed constancy.

Methods

Stimuli

Stimuli were images of a basketball and a tennis ball moving in the fronto-parallel plane (see Figure 1), displayed over a black background on one or two 19" CRT monitors (1024 × 768 pixels, 60 hz), depending on the experimental condition. We also used, as a control, empty circles (3 pixels line/width) of the same size as the balls. To generate and display the stimuli, we used Matlab with the Psychophysics Toolbox (Brainard, 1997; Pelli, 1997).

The different conditions were created by changing the size of the images and by locating the monitors at different distances. In the first three conditions (TvsB, bvsB, and cvsC) both stimuli, reference and test, were presented on the same monitor located 0.80 m from the observer. In Condition TvsB, the reference stimulus was a normal sized tennis ball (diameter = 66 mm), and the test was a normal sized basketball (diameter = 238 mm). Note that, in this case, both stimuli were normal sized but they subtended different retinal sizes (size ratio = 3.6). In Condition bvsB, the reference stimulus was an undersized basketball that was the same size as the tennis ball, and the test was a normal sized basketball. In Condition cvsC, test and reference were circles whose sizes were those of a tennis ball and of a basketball. This means that, in terms of the relation of size between reference and test, the three conditions were equivalent (for illustration, see Table 1). In the last three conditions, reference and test stimuli were presented on two different monitors located at 0.60 m and 2.16 m, respectively (distance ratio = 3.6). In Condition TvsB2 and BvsB2, the stimuli were normal sized balls and, in Condition CvsC2, the stimuli were two identical empty circles whose sizes were that of the basketball. Table 1 summarizes the parameters of the six experimental conditions. Both basketball and tennis ball had a luminance of 86 cd/m2; the background had 0.5 cd/m2.

Procedure

We used a two-interval forced choice paradigm with the method of constant stimuli to measure the point of subjective equality (PSE), which was computed by fitting a Weibull sigmoid to the data and taking its inverse at 50% correct response, using the Psignifit 3.0 (Fründ, Haenel, & Wichmann, 2011). In the first three conditions, reference and test were displayed on the same monitor during 500 ms, with an interstimulus interval of 200 ms. In the last three conditions the test was always presented on the furthest monitor. This meant that the observer had to shift his or her gaze from one monitor to the other during the time that elapsed between the two intervals. The order of presentation of reference and test was randomized and balanced. We presented a signal to indicate which monitor would display the first interval. The signal consisted of a flash of light shown on this monitor, 500 ms before presenting the stimulus. The stimulus duration and the interstimulus interval were 500 ms. The observers were instructed to shift their gaze to the complementary monitor during this interstimulus interval. After the presentation of the two intervals, the observer had to answer, by pressing a button on the mouse, whether the object in the first or in the second interval moved faster. The reference speed was 3.5 pix/frame (5.25 °/s), whereas the test speed varied between 1 and 6 pix/frame (1.5°/s, 9°/s).

Each experimental condition was tested separately in a randomized order. The experiment was conducted in sessions that were run on different and consecutive days. One session consisted of 30 blocks of trials. Each block consisted of six trials corresponding to the sixvalues of constant stimuli, whose order of appearance in the block was randomized. Therefore, each psychometric function and the values of PSE were calculated from 180 trials.

The statistical analysis has been done in R with the Agricolae package for multi comparisons.

Figure 1. Example of the images used as stimuli in the experiments. See the online article for the color version of this figure.

Subjects

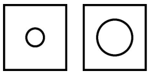
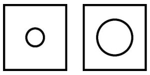
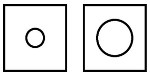
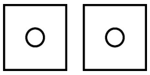
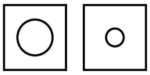
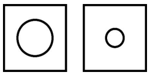
Eight volunteer subjects took part in this experiment. One of them was excluded from the group because the diagnostics plots of the fitting procedure showed a lack of goodness of fit. One of the remaining seven volunteers participated in the six conditions, and the other six were divided into two groups that were distributed between the first three and the last three conditions. All participants had normal or corrected to normal visual acuity and were naive to the purpose of this study. Their ages ranged from 22 to 33 years old.

Results and Discussion

Figure 2 depicts the ratio between test speed at PSE and reference speed for the first three conditions, for the four observers that participated in this experiment. The average results were also plotted on the right in gray scale. Values larger than 1 mean that the observer perceives the test more slowly than the reference, which denotes a bias consistent with the retinal size ratio between test and reference.

Results show that observers tend to underestimate the speed of larger stimuli in the Conditions bvsB, but not in Conditions TvsB and cvsC, which shows no bias. The statistical analysis confirms this conceptual description (please see figure captions). Interestingly, because in terms of the relation of size, the stimuli in the three conditions are equivalent, the relational hypotheses predict that there should be no differences among the results obtained in the three experimental conditions. For their part, the quantitative hypotheses predict the bias found in bvsB, if it is considered that

Table 1
The Parameters of the Six Experimental Conditions

Condition	Reference	Test	Distance ratio	Retinal size ratio	Prototypical size ratio	Frame-stimulus relation
TvsB	Normal sized tennis ball	Normal sized basketball	1	3.6	3.6	
bvsB	Undersized basketball	Normal sized basketball	1	3.6	1	
cvsC	Small circle	Large circle	1	3.6	?	
TvsB2	Normal sized tennis ball	Normal sized basketball	3.6	1	3.6	
BvsB2	Normal sized basketball	Normal sized basketball	3.6	3.6	1	
CvsC2	Large circle	Large circle	3.6	3.6	?	

Note. The conditions are labeled with the initials of the stimulus name. Lower case letters mean under sized objects and capital letters indicate normal sized objects. For example, TvsB means normal sized tennis vs. normal sized basketball, or bvsB means undersized vs. normal sized basketballs. The number 2 in the last three conditions indicates that reference and test were displayed at different distances.

the system uses the perceived distance for the computation of speed. Therefore, for equal speeds, the larger ball (perceived closer) will be perceived as slower. Note that this would not occur in the TvsB condition since, despite the size relation, the tennis ball would not be perceived as located further away than the basketball.

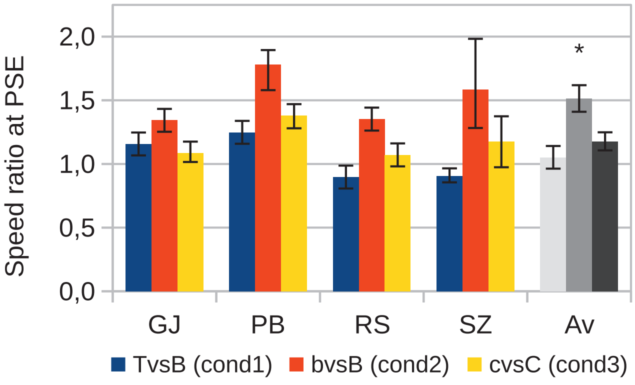


Figure 2. The speed ratio at point of subjective equality (PSE) as a function of the experimental condition and observer. The different conditions are designated with different textures: TvsB (striped bar), bvsB (white bar), and cvsC (dotted bar). The average data are designated in gray. Light, medium, and dark gray bars represent TvsB, bvsB, and cvsC respectively. Error bars represent the confidence interval of the computed PSE at 95% except for the error bars of the average data, which represent ± 1 standard error of mean (SEM). An asterisk above a bar means that the value is significantly different to 1 [$t(4) > 2.77$, $\propto = 0.05$]. The analysis of variance [$F(2, 9) = 6.6$, $p = .017$] and Tukey's honest significance difference posttest show that there is a significant difference between TvsB ($M = 1.05$, $SD = 0.19$) and bvsB ($M = 1.5$, $SD = 0.20$); the difference is marginal between bvsB and cvsC ($M = 1.17$, $SD = 0.14$; $p = .07$); and there is no difference between TvsB and cvsC ($p = .6$). See the online article for the color version of this figure.

Figure 3 shows the speed ratio at PSE for the conditions in which reference and test were displayed at different distances. In this situation, when reference and test have identical physical speeds, their retinal speeds have a relation of 3.6. Therefore, a speed ratio equal to 1 means speed constancy. Data show a high level of constancy for those conditions in which the stimuli are

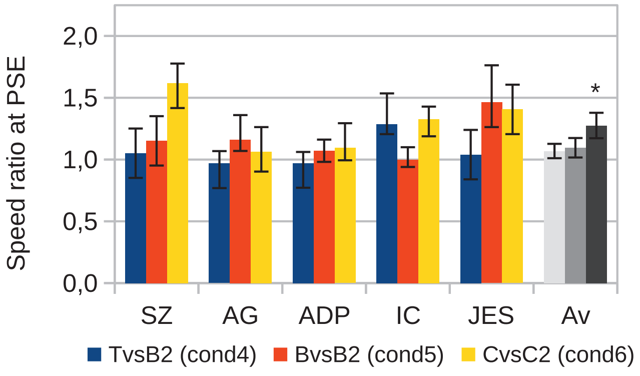


Figure 3. The speed ratio at PSE as a function of the experimental condition and observer. The different conditions are designated with different textures: TvsB2 (striped bar), BvsB2 (white bar), and CvsC2 (dotted bar). The average data are designated in gray. Light, medium, and dark gray bars represent TvsB2, BvsB2, and CvsC2, respectively. Error bars represent the confidence interval of the computed PSE at 95% except for the error bars of the average data, which represent ± 1 SEM. An asterisk above a bar means that the value is significantly different to 1 ($t(5) > 2.57$, $\propto = 0.05$). The analysis of variance show no difference among conditions [$F(2, 12) = 2.74$, $p = .105$]. See the online article for the color version of this figure.

familiar objects (TvsB2 and BvsB2), and a small bias for circles (CvsC2), although the analysis of variance (ANOVA) shows that this difference is not statistically significant (please, see the caption of Figure 3). The speed constancy found for BvsB2 and CvsC2 is predicted by all hypotheses. However, the constancy found in TvsB2 can be accounted for by the quantitative hypotheses and, at first glance, cannot be accounted for by the relational hypotheses because, in this condition, the reference and the test have the same spatial frequencies but different temporal frequencies. Interestingly, in a previous experiment performed with synthetic stimuli, angular size was manipulated equivalently (please see Experiment 2 in Zohary, & Sittig, 1993), and the authors found no constancy at all (the quantitative hypothesis failed). In our experiment, the subtended angular sizes of reference and test are the same despite the different distances because the objects are different (near tennis ball and far away basketball), and the observer clearly uses this information to match the speed, which revalidates the relational hypotheses.

In summary, the results shown so far suggest that a correct estimate of the physical speed cannot be obtained from the retinal information (size and speed) alone but that the information provided by the object identification must be considered.

Analyzing the Contextual Information

In the present experiment, we test the last three conditions in an experimental setup that allows us to manipulate the contextual cues of the stimuli. We investigate the role of familiarity when all the external references are eliminated, in contrast to the situation in which the frame of reference is present.

Methods

Stimuli. This new experimental layout consisted of two monitors located parallel to one another, to one side of the observer in such a way that they could not be seen from the observation point. Their images were projected to the observer through two beam-splitters as shown in Figure 4. It can be noted that the two stimuli were perceived along the same optical axis. Because the room is practically dark, the stimuli were perceived as floating in a dark space bereft of any spatial references. The luminance of the two stimuli was equalized to compensate for the different transmittance of the two optical paths. The stimuli were the same as those used in the previous experiment except that now we included, in one of the tested conditions, a frame of reference that consisted of an empty rectangle (1 cm line-width) drawn on the edges of each monitor. This reference was used to test the transposition principle against a situation in which the observer has no spatial references at all.

Procedure. The procedure was the same as the one used in the previous experiment except that now we included a reference point to help the observer accommodate to the stimulus distance. This point appeared 500 ms before the stimulus presentation and disappeared at the beginning of the stimulus presentation. The use of this reference is critical because the observer has no cues to accommodate before the stimulus presentation.

Subjects. Four volunteer subjects took part in this experiment. All participants had normal or corrected to normal visual acuity and were naive to the purpose of this study. Their ages ranged from 22 to 35.

Results and Discussion

Figure 5 depicts the speed ratio at PSE for the three conditions and the four observers, obtained with and without a frame (a and b, respectively).

There are two important things that deserve to be pointed out. First, the increment of the bias for the three conditions with respect to the one found in the previous experiment (the bars representing the average conditions for cases with and without frame, were all significantly different to 1). Apparently, the significant reduction of the cues informing about distance causes the observers to perceive the further stimulus (test) to be slower than the stimulus located closer (reference). This bias would be driven by the relationship between the angular velocity of the reference and the test. The importance of the context in the perception of speed of familiar objects is remarkable. The meaning of these objects seems to be more relevant when all the elements that compose the scene

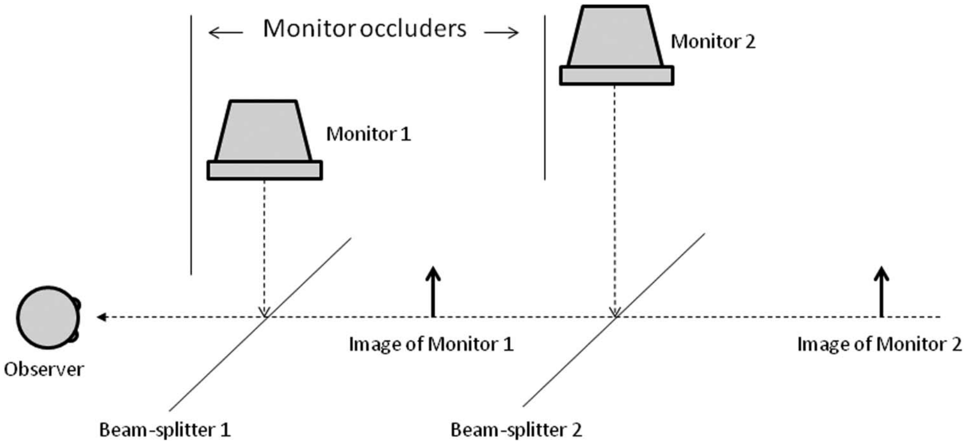


Figure 4. Schematic illustration of the layout of the experimental apparatus. The entire room was darkened and covered with black curtains. Monitors were also coated to prevent the observer from seeing them directly. By means of this device, we made the observers perceive the balls and the circles as objects floating in a dark space.

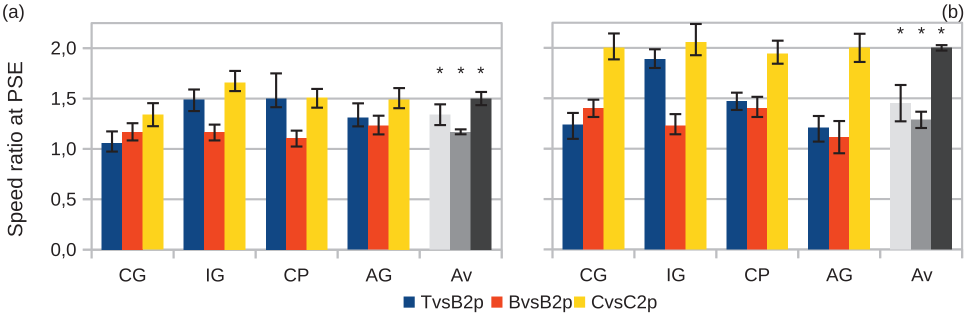


Figure 5. The speed ratio at point of subjective equality (PSE) as a function of the experimental condition and observer. The different conditions are designated with different textures: TvsB2p (striped bar), BvsB2p (white bar), and CvsC2p (dotted bar). The average data are designated in gray. Light, medium, and dark gray bars represent TvsB2p, BvsB2p, and CvsC2p respectively. Error bars represent the confidence interval of the computed PSE at 95% except for the error bars of the average data, which represent ± 1 SEM. The panels (a) and (b) correspond to the frame conditions: "with frame" and "with no frame." The asterisks above bars indicate values significantly different to 1 ($t(4)>2.77$, ∝ = 0.05). A two-way analysis of variance (ANOVA) with Condition and Frame as factors were ran and followed by a post hoc analyses using the Bonferroni post hoc criterion (∝ = 0.05). The ANOVA output showed that both factors are significant [$F(2, 18) = 18.54$, $p = .0$], [$F(1, 18) = 11.29$, $p = .003$] and that there is no interaction between them [$F(2, 18) = 3.27$, $p = .06$]. The post test showed that only condition CvsC2p without frame is significantly different ($M = 2.0$, $SD = 0.05$) to all other conditions and frame situations. See the online article for the color version of this figure.

maintain a certain consistency. The fact that in this experiment the balls are perceived as floating in the dark seems to reduce their naturality.

The second issue to note is the prominent effect of the frame of reference on the circles and not on the balls. Results show that the presence of a frame of reference clearly reduces the bias in the case of the circles. This would suggest that transposition may have a larger effect when the stimuli are not familiar objects, perhaps because the familiar objects act as a frame of reference on their own.

General Discussion

The experiments presented here indicate that object familiarity is an important factor that contributes to the perception of speed constancy. Because object familiarity has not been considered in previous theoretical accounts of speed constancy, these results therefore provide a challenge to them (Epstein, 1978; Distler et al., 2000; McKee & Smallman, 1998; Wallach, 1939). In what follows, we will consider several ways in which these new data may be incorporated into theoretical accounts of speed constancy.

When an individual identifies an object, she/he also identifies its prototypical size which, to some extent, informs about its distance from the observation point (Fitzpatrick, Pasnak, & Tyer, 1982; Gogel, 1976). In terms of the quantitative hypotheses, the prototypical size could be assimilated by informing about relative distances between objects. In turn, prototypical size could be built-in the relational hypotheses as a means to scale the spatial frequency. For example, in TvsB2, when test and reference move with the same physical speed, (because the basketball is further away than the tennis ball) both have the same spatial frequency but different temporal frequency, and yet the observers perceive constancy. This can only be explained if we assume that the basketball is bigger than the tennis ball, even if they both have the same retinal size.

Furthermore, familiarity, in addition to informing about the prototypical size and relative distances, may help to verify the coherence between the different cues present in the images. This is not a trivial problem. Size and distance are two variables that are so intertwined that the independence of their perceptual processes is very difficult to verify. Haber and Levin (2001) proposed that our knowledge of the world and not our perception of the world determine our estimates of the size of objects in the world. On the other hand, the estimation of distance must rely on the information available at the time of perception because distance is constantly used to support a variety of tasks (Cutting & Vishton, 1995). Therefore, although the perception of size does not depend on distance perception, the perception of the distance of an object seems to depend on the retinal size of the object (Fitzpatrick et al., 1982; Gogel, 1976). It is in this context that familiarity provides a way to verify the coherence among the cues that inform about size and distance.

In summary, we show that object familiarity provides key information to achieve a correct estimate of the physical speed of the objects. The identification of an object allows the observer to retrieve the prototypical size which, in combination with the retinal size, allows the system to appropriately scale retinal speed to estimate physical speed. Moreover, the identity of the object would help to check the coherence of the scene by allowing the system to verify whether the objects being compared are the same or not and, thus, whether their relative sizes inform about their relative distances or not.

References

Brainard, D. H. (1997). The Psychophysics Toolbox. *Spatial Vision, 10,* 433–436. http://dx.doi.org/10.1163/156856897X00357

Brown, J. F. (1931). The visual perception of velocity. *Psychologische Forschung, 14,* 199–232. http://dx.doi.org/10.1007/BF00403873

Cutting, J. E., & Vishton, P. M. (1995). Perceiving layout and knowing distances: The integration, relative potency, and contextual use of different information about depth. In W. Epstein & Rogers (Eds.), *Handbook of perception and cognition* (Vol. 5, pp. 69–117). San Diego, CA: Academic Press.

Diener, H. C., Wist, E. R., Dichgans, J., & Brandt, T. (1976). The spatial frequency effect on perceived velocity. *Vision Research, 16,* 169–177. http://dx.doi.org/10.1016/0042-6989(76)90094-8

Distler, H. K., Gegenfurtner, K. R., van Veen, H. A., & Hawken, M. J. (2000). Velocity constancy in a virtual reality environment. *Perception, 29,* 1423–1435. http://dx.doi.org/10.1068/p3115

Epstein, W. (1978). Two factors in the perception of velocity at a distance. *Perception & Psychophysics, 24,* 105–114. http://dx.doi.org/10.3758/BF03199536

Fitzpatrick, V., Pasnak, R., & Tyer, Z. E. (1982). The effect of familiar size at familiar distances. *Perception, 11,* 85–91. http://dx.doi.org/10.1068/p110085

Fründ, I., Haenel, N. V., & Wichmann, F. A. (2011). Inference for psychometric functions in the presence of nonstationary behavior. *Journal of Vision, 11,* 16–19. http://dx.doi.org/10.1167/11.6.16

Gogel, W. C. (1976). An indirect method of measuring perceived distance from familiar size. *Perception & Psychophysics, 20,* 419–429. http://dx.doi.org/10.3758/BF03208276

Gogel, W. C., & Tietz, J. D. (1976). Adjacency and attention as determiners of perceived motion. *Vision Research, 16,* 839–845. http://dx.doi.org/10.1016/0042-6989(76)90144-9

Haber, R. N., & Levin, C. A. (2001). The independence of size perception and distance perception. *Perception & Psychophysics, 63,* 1140–1152. http://dx.doi.org/10.3758/BF03194530

McKee, S. P., & Smallman, H. S. (1998). Size and speed constancy. In J. Walsh & J. J. Kulikowski (Eds.), *Perceptual constancy: Why things look as they do* (pp. 373–408). New York, NY: Cambridge University Press.

McKee, S. P., & Welch, L. (1989). Is there a constancy for velocity? *Vision Research, 29,* 553–561. http://dx.doi.org/10.1016/0042-6989(89)90042-4

Pelli, D. G. (1997). The VideoToolbox software for visual psychophysics: Transforming numbers into movies. *Spatial Vision, 10,* 437–442. http://dx.doi.org/10.1163/156856897X00366

Rock, I., Hill, A. L., & Fineman, M. (1968). Speed constancy as a function of size constancy. *Perception & Psychophysics, 4,* 37–40. http://dx.doi.org/10.3758/BF03210444

Tozawa, J. (2008). Speed constancy and the perception of distance. *Perception, 37,* 3–21. http://dx.doi.org/10.1068/p5585

Wallach, H. (1939). On constancy of visual speed. *Psychological Review, 46,* 541–552. http://dx.doi.org/10.1037/h0060976

Zohary, E., & Sittig, A. C. (1993). Mechanisms of velocity constancy. *Vision Research, 33,* 2467–2478. http://dx.doi.org/10.1016/0042-6989(93)90127-I

Received June 4, 2014
Revision received December 4, 2014
Accepted December 7, 2014 ■