

Verification of Emmert's Law in Actual and Virtual Environments

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Abstract We examined Emmert's law by measuring the perceived size of an afterimage and the perceived distance of the surface on which the afterimage was projected in actual and virtual environments. The actual environment consisted of a corridor with ample cues as to distance and depth. The virtual environment was made from the CAVE of a virtual reality system. The afterimage, disc-shaped and one degree in diameter, was produced by flashing with an electric photoflash. The observers were asked to estimate the perceived distance to surfaces located at various physical distances (1 to 24 m) by the magnitude estimation method and to estimate the perceived size of the afterimage projected on the surfaces by a matching method. The results show that the perceived size of the afterimage was directly proportional to the perceived distance in both environments; thus, Emmert's law holds in virtual as well as actual environments. We suggest that Emmert's law is a specific case of a functional principle of distance scaling by the visual system. *J Physiol Anthropol Appl Human Sci* 23(6): 325–329, 2004 <http://www.jstage.jst.go.jp/browse/jpa>

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Introduction

In general, the greater the physical distance of the surface upon which an afterimage is projected becomes, the greater the size of the afterimage appears. The relationship between the perceived size of the afterimage and distance of the surface is known as Emmert's law. Although there has been some controversy about what Emmert's law means (e.g., Edwards and Boring, 1951; Young, 1950, 1951), we here interpret it to mean that the *perceived size* of an afterimage is proportional to the *perceived distance* of the surface on which the afterimage is projected. This interpretation means that Emmert's law is psycho-physical-, not optical-, and is equivalent to the size-distance invariance hypothesis.

According to the above interpretation, the law can be represented formally by the following equation:

$$s = d \times \tan \alpha \quad (1)$$

where s is the perceived size of an afterimage, d is the perceived distance of the surface on which the afterimage is projected, and α is the visual angle subtended by the afterimage (Hershenson, 1999). Therefore, the law can be verified by measuring the perceived size of the afterimage and the perceived distance to the surface on which the afterimage is projected, for a given visual angle of the afterimage. This was done in this study.

Although a number of studies on Emmert's law have been conducted so far, the viewing distances to which Emmert's law can be applied are, as yet, unclear. In addition, several studies examining the relationship between viewing distance and apparent size of an afterimage have not included to measure the perceived distance (e.g., Dwyer et al., 1990; Price, 1961; Weintraub and Gardner, 1970). Furthermore, as far as we know, no one has examined whether or not Emmert's law can be applied in a virtual reality environment. Since the perceived distance of a surface usually differs from the physical distance of that surface in a virtual environment, it seems to be appropriate to test whether Emmert's law can be applied to the perceived distance or physical distance.

The aim of this study was to examine whether or not Emmert's law is valid in a virtual environment as well as an actual environment by measuring the perceived size of an afterimage and the perceived distance of the surface on which the afterimage was projected. We compared the mean slopes of the line fitted to the mean perceived size of the afterimage as a function of the perceived distance obtained in actual and virtual environments with the theoretical slope of Eq. (1).

Methods

Observers Nineteen volunteers (university undergraduate and graduate students), with self-reported normal or corrected-to-normal visual acuity, participated in the actual environment condition of the experiment, and six observers (graduate students and volunteers from the National Institute of Advanced Industrial Science and Technology), also with self-reported normal or corrected-to-normal visual acuity,

participated in the virtual environment condition of the experiment.

Stimulus and apparatus

A positive afterimage with a constant visual angle (1°) was induced by flashing into the observer's eyes with an electric photoflash (National NE-5651) masked to provide a disc-shaped afterimage. There was a fixation mark at the center of the window of the mask. The actual environment consisted of a corridor, 2.06 meters wide, 3.02 meters high, and 26.83 meters long, where the observer had an unobstructed view. The windows on the two long sides of the corridor and texture of its floor served as perspective cues to distance. A white wall at one end of the corridor was the surface upon which the afterimage was projected. The corridor was illuminated by fluorescent lamps from the ceiling of the corridor and by sunlight from the side windows. The virtual environment was made by a CAVE virtual reality constructing system as shown in Fig. 1. The chamber was surrounded by three screens, each 3 meters by 3 meters, which were the front, the right side and the left side surfaces. Texture patterns consisting of checkerboards were projected on these three surfaces. A head-mounted goggle with a liquid-shutter was set on the observer's face, for presentation of binocular disparity and for monitoring the location of the observer's head.

Procedure

After the photoflash was exposed to the observer, it was removed from the observer's line of sight. The magnitude estimation method was used to measure the perceived distance of the surface and the matching method was used to measure the perceived size of the afterimage, in both environment conditions. The observers were required for two tasks. The first task was to estimate the apparent distance of the surface by reporting a number with a modulus as a unit, which was a stick one-meter long, so that the number corresponded to the perceived distance of the surface. The second task was to match the apparent size of the afterimage with a length of tape that the observer held in the hand. The observer adjusted the length of the tape so that it corresponded to the perceived size of the afterimage. Eight viewing distances were used in the actual environment: 1, 3, 5.73, 8.59, 11.46, 13.75, 18.33 and 22.91 meters. Seven simulated viewing distances were used in the virtual environment: 1, 2, 4, 10, 14, 20 and 24 meters. Each observer completed three trials for each viewing distance condition in both actual and virtual environment conditions. The order of the viewing distance sub-conditions was randomized for each observer and each environment condition.

Results

Since we analyzed separately data obtained in the actual environment and in the virtual environment, we report separately the results of the analyses. The same method for data analysis of analysis for the data in the actual environment

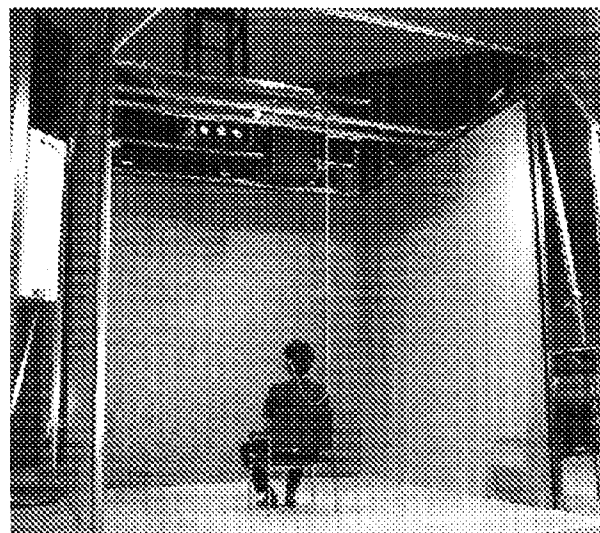


Fig. 1 A photographic representation of the CAVE virtual reality system.

was applied to those in the virtual environment. We analyzed the perceived distance of the surface on which the afterimage was projected, the perceived size of the afterimage, and the relationship between the perceived distance and size, in order.

Actual environment

Firstly, we analyzed the mean perceived distances averaged across the 19 observers. The mean perceived distance averaged over three trials for each observer and in each viewing distance sub-condition, was a basic unit for further analyses. A one way (8 viewing distances) repeated measures ANOVA showed that the main effect of viewing distance was significant [$F(7, 126)=116.961$, $p<.0001$]. This significant main effect is illustrated in Fig. 2a, in which the mean perceived distance averaged across all observers is plotted as a function of the viewing distance. We fitted a power function to the perceived distance data. The obtained exponent of the power function was .910, which was comparable to the results of previous studies (e.g., Da Silva, 1985; Loomis et al., 1992).

Secondly, we analyzed the mean perceived sizes of the afterimage averaged across the 19 observers. The mean perceived size averaged over three trials for each observer and in each viewing distance sub-condition was a basic unit for further analyses. A one-way (8 viewing distances) repeated measures ANOVA showed that the main effect of the viewing distance was significant [$F(7, 126)=176.770$, $p<.0001$]. This significant main effect is illustrated in Fig. 2b, in which the mean perceived sizes averaged across all observers are plotted as a function of viewing distance.

Thirdly, we compared the obtained data with the prediction of Emmert's law. Following Eq.(1), when α is one degree, which was the size of the afterimage used in this experiment, we obtain the following equation:

$$s = \tan 1^\circ \times d = 0.0175d \quad (2)$$

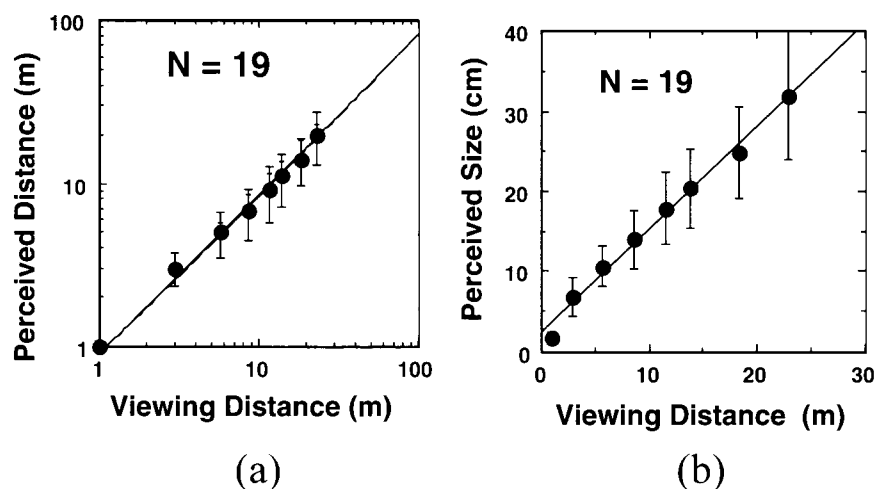


Fig. 2 The obtained perceived distances and sizes of the afterimage in the actual environment. (a): The mean perceived distance as a function of the viewing distance. (b): The mean perceived size as a function of the viewing distance.

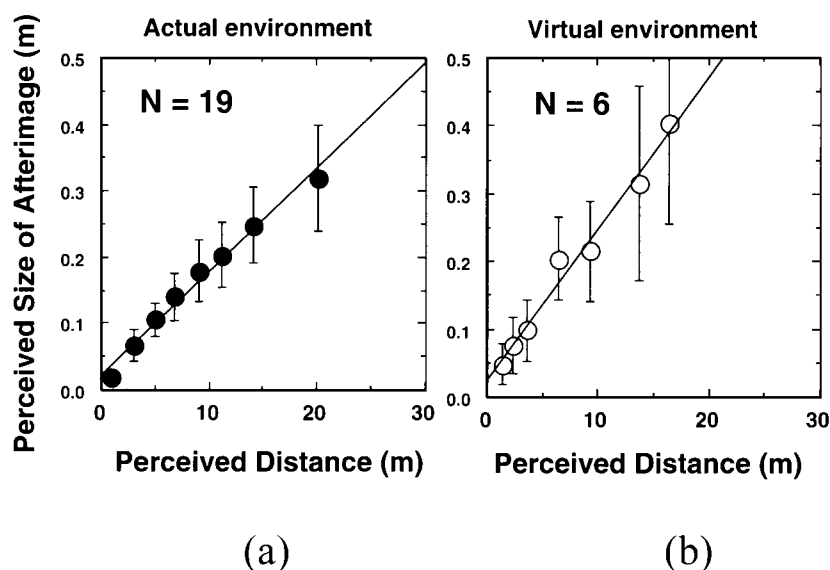


Fig. 3 The mean perceived size of the afterimage as a function of the perceived distance in the actual environment (a) and in the virtual environment (b).

Figure 3a shows the mean perceived size (s) of afterimage averaged across the 19 observers plotted as a function of the perceived distance (d). The slope of the line fitted to the means was 0.0178 (SD=0.0068), which is very close to the theoretical slope, and the coefficient of determination (r^2) was 0.984. The theoretical value of the slope, i.e., 0.0175 was contained within the 95% confidence interval calculated from the mean slope and the standard deviation, which ranged from 0.0210 to 0.0145. This means that Emmert's law holds in the actual environment of the present experiment.

Virtual environment

Firstly, we analyzed the mean perceived distance averaged across the six observers. The mean perceived distance averaged over three trials for each observer and in each viewing distance sub-condition, was a basic unit for further

analyses. A one way (7 distances) repeated measures ANOVA showed that the main effect of the simulated distance was significant [$F(6, 30)=20.438, p<.001$]. This significant main effect is illustrated in Fig. 4a, in which the mean perceived distance averaged across all observers is plotted as a function of the simulated distance. We fitted a power function to the perceived distance data. The obtained exponent of the power function was .745, which was smaller than that obtained in the actual environment condition and also those in previous studies (e.g., Da Silva, 1985; Loomis et al., 1992).

Secondly, we analyzed the mean perceived sizes of the afterimage averaged across the six observers. The mean perceived size averaged over three trials for each observer and in each simulated distance sub-condition was a basic unit for further analyses. A one way (7 distances) repeated measures ANOVA showed that the main effect of the simulated distance

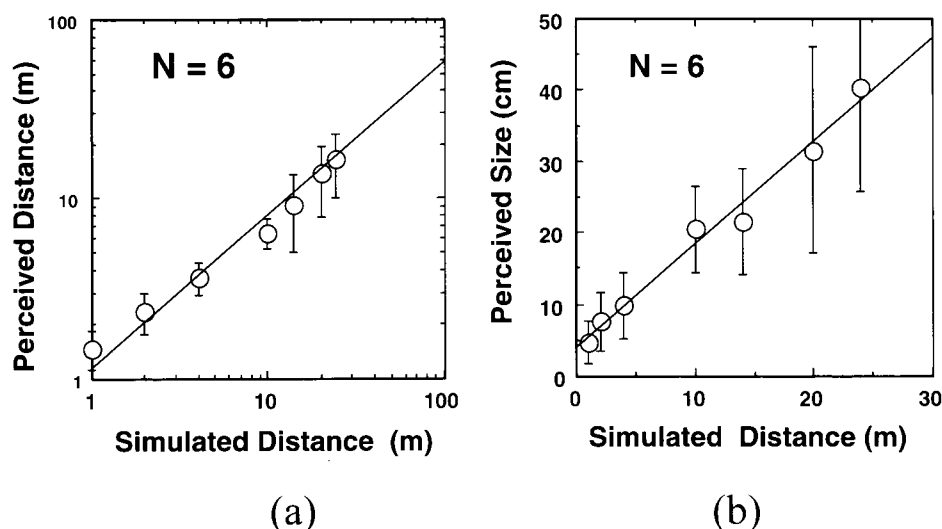


Fig. 4 The obtained perceived distance and size of the afterimage in the virtual environment. (a): The mean perceived distance as a function of the simulated distance. (b): The mean perceived size of the afterimage as a function of the simulated distance.

was significant [$F(6, 30)=19.189, p<.001$]. The significant main effect is illustrated in Fig. 4b, in which the mean perceived sizes averaged across all observers are plotted as a function of the simulated distance.

Thirdly, we compared the obtained data with the prediction of Emmert's law. Figure 3b shows the mean perceived size averaged across the six observers plotted as a function of the perceived distance. The slope of the fitted line to the means was 0.0219 (SD=0.0033) and the coefficient of determination was 0.980. The theoretical slope 0.0175 was not contained within the range of 95% confidence interval calculated from the mean slope and the standard deviation, which ranged from 0.0254 to 0.0184.

Next, we calculated the slope of the fitted line to the means obtained from 1 m to 20 m simulated distance; the obtained mean slope was 0.0206 (SD=0.0068). The 95% confidence interval ranged from 0.0280 to 0.0137, containing the theoretical slope 0.0175. This means that Emmert's law holds in the virtual environment up to the 20 meters of the present experiment.

Discussion

Emmert's law for the perceived size of an afterimage as a function of the perceived distance of a surface on which the afterimage is projected, holds in both actual and virtual environments. The applicability of the law, however, differs slightly between the actual and virtual environments; in that in the actual environment the law holds at least to 24 m of the physical distance, but in the virtual environment the law does not hold in that simulated distance. This small difference might be due to incomplete simulation of the virtual space.

The notion that the law means that the perceived size of an afterimage is proportional to the *perceived* distance was strengthened by Price (1961) and Dwyer et al. (1990). Both

studies examined the apparent size of an afterimage under the condition in which apparent distance appeared differently from the actual distance, i.e., distance illusion. Price (1961) observed qualitatively that the apparent size of the afterimage was dependent upon the apparent distance when it was projected onto two surfaces at different physical distances of which the physically further surface appeared perceptually to be nearer. Whereas, Dwyer et al. (1990) examined quantitatively the perceived size of the afterimage projected on the two surfaces in Ames's distorted room. The distance of one rear window of the room appeared to be equal to the distance of another rear window of the room, irrespective of differences in the actual distances of the two windows in Ames's demonstration. Consequently, they found that the perceived size of the afterimage projected onto one window was almost equal to that projected onto another window. These findings clearly indicate that the perceived size of an afterimage depends on the perceived distance of the surface on which the afterimage is projected.

The present finding, that Emmert's law holds for the limited range of the simulated distances in the virtual environment means that the perceived size of the afterimage is not dependent on the physical distance of the surface on which the afterimage is projected, but on the perceived distance of that surface. In the experiment reported here, the physical distance of the surface simulated virtually was always approximately 2 m from the observer's eyes. The surface, however, appeared virtually as much as 24 m away. The perceived size of the afterimage projected onto the surface increased linearly as the perceived distance of the surface increased.

Emmert's law, which states that the perceived size of an afterimage is proportional to the perceived distance, is equivalent to the size-distance invariance hypothesis. One formulation of the hypothesis states in a more general form that the ratio of the perceived size (s') of an object to the

perceived distance (d) is a constant for a given constant visual angle of the object (e.g., Hershenson, 1999; Howard and Rogers, 2003). This statement is formally equivalent to Eq. (1) as described in the introduction section if s is replaced by s' , i.e., the perceived size of the actual object instead of the afterimage.

Some experiments (e.g., Foley, 1968; Oyama, 1974) have confirmed the hypothesis but other experiments (e.g., Gogel et al., 1963) have disconfirmed it. The confirmation or disconfirmation of the hypothesis depends on the instructions, the methods of measurements, full-cues or reduced cues to distance and depth, and so on. The results of the present experiment confirm the hypothesis in the virtual environment as well as in the actual environment within the limited range of the viewing distance.

Emmert's law can be thought of as a specific case of the functional principle of distance scaling by the visual system. Distance scaling has been reported in the domains of stereoscopic depth and motion parallax depth (e.g., Nakamizo and Shimono, 2000; Ono and Comerford, 1977). That is, the visual system can yield veridical depth perception by calibrating the depth produced by binocular disparity or motion parallax by using the perceived distance information. This process could also occur in the domain of size perception. When one views the afterimages projected on surfaces at various distances in the actual environment and even in the virtual environment, the visual system yields an apparent size by calibrating the proximal size using the perceived distance information.

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