

THE "LIMIT OF DEPTH PERCEPTION"

—A NEW TENTATIVE THEORY OF VISUAL SPACE PERCEPTION—

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Introduction

So far the literature in the field of visual perception of space is voluminous and experimental material is very extensive, but the writer *does*, somehow, feel something is lacking. The existing theories to account for the perception of the visual world or the three-dimensional field are not satisfactory. For they have a great deal to say about the perceptions within a comparatively short limited distance, concerning accommodation, convergence, and disparity, but they have little to say about those of greater distance, though they may be very important in the visual space.

Publications in recent years, like "The Perception of the Visual World" by GIBSON, and "A Further Study of Visual Perception" by VERNON, though very instructive, make little mention about perceptions of great distances as above stated. It is incomprehensible to the present writer that some of everyday experiences, e. g. the apparent form of the sky, the 'moon-illusion' etc. are quite ignored. It is too important a question to be neglected. The writer's own opinion is that a certain factor which has been disregarded thus far, plays a very important part in the visual, especially, in the three-dimensional space perception. The writer will hereafter explain the essential points, but owing to limitations of space, he is obliged to state them in a very short résumé.

The writer started the present researches about thirty years ago, and made public the sections occasionally at the meetings of the Japanese Psychological Association, and, having pursued further studies from various angles, he has acquired more and more confidence in his own theory; therefore he has decided to publish a synthesis of his previous findings as a preliminary step for further research.

The writer once took a very great interest in the 'moon illusion', but being unsatisfied with the traditional expositions, he began to observe celestial bodies, the apparent form of the sky, distant mountains and so on. After various observations he got a conviction that one cannot assess positions as such, when objects lie beyond a 'certain limit'.

At this point, the writer, dipping into the works of great authors, found the thesis of ZOTH and, at a latter period, that of LÜSHER. ZOTH has advocated, on the basis of the data of BOURDON, that, if the interval of two points reaches a length of 2642 m, one cannot discriminate the difference of depth¹⁾. LÜSHER has calculated the boundary of depth perception as 450 m²⁾. However, computations from the effects obtained by the experiment at close range may not be identical with the numerical values obtained by the measurement of a huge area. Moreover, the value of the former may vary according to the apparatus, method of its operation, and the evaluation of the data, as has clearly been shown by the results of both scholars.

Experiment on "Depth Limit"

With the intention to investigate the 'limit of depth perception' the writer explored several extensive and perfectly level areas deemed essential for researches concerning a vast space, and at last selected the naval air depot at Kasumigaura. In August, 1932, the writer obtained permission from the authorities concerned to use the depot at night.³⁾

By making observation in dark nights, the writer aimed at eliminating empirical factors from visual space perception, i. e. the continuous succession of the ground, the apparent size of objects, linear and aerial perspective, superposition, relative brightness of objects, and the degree of upward angular location of the ground, etc. The subjects were four college students. The experiment was made from 100 m upwards. Its procedure was as follows. Two electric bulbs, each fixed on the top of a pole about 1.5 m in height with a storage battery for power supply, were used. A variety of bulbs from 10 to 50 candle powers were employed according to distance, and resistors were used also to make allowance for luminous intensity. The experiment was conducted by a sort of 'method of limits'. One of the lights was used for the standard stimulus (SS), the other for the comparison stimulus (CS).

By way of an example, the experiment for 100 m will be described. First, SS was planted at the position 100 m away from the viewpoint, CS, too, was set at the same distance on either the right side or the left, the order being at random; two luminous points were placed adequately, so that the observer might easily compare their brightness; the angle of two points being generally 2° from the view-point. The experimenter would ask the subject (O) whether the intensity and the height of both rays were equal or not, for the purpose of eliminating the empirical factors. After the adjustment, the lights were once put out, and when lighted again, O would be asked to tell the perception of the relative distance of the two. If the answer was of equidistant, the lights were once again put out and CS would be made to recede by relevant length, and SS and CS would be lighted again to repeat the process until CS was perceived farther. Five measurements were made for each O. Next, CS would be set farther than SS so that O could easily distinguish their

1) W. Nagel: Handbuch der Physiologie des Menschen, Dritter Band, 1905, p.416.

und Geisteswelt, 612 Band, 1920.

2) H. LÜSHER: Photogrammetrie (Aus Nature

3) The present experiment was subsidized by the Saito Gratitude Foundation, Sendai, Japan.

difference. The procedure was similar to the one above mentioned, but on the contrary, the proceeding was this time carried on till CS was perceived equidistant to SS. The arithmetical mean of the two averages should be, needless to say, the result of the test for one O concerning the 'discrimination threshold' for 100 m.

For the experiment over 200 m a portable telephone was used for the experimenter to communicate with the observer and the persons who handled the apparatus. For the 600 m experiment, the prepared apparatus becoming of no use, because of the immense distance where CS had to recede, the writer was at a loss, but unexpectedly relieved by lighting upon a matter that the intensity of the ray from the roof of a building was quite suitable for the stimulus being utilized for the experiment in question. Taking advantage of the subjects' ignorance of the fact, he executed his plan by employing that ray as CS under the same experimental conditions as other tests. All the four subjects could not discriminate the difference of distance between SS and CS. It was found by later survey that the building was about 24 km from the view-point. The data for the series of the observations are given in table I and figure I too.

Table 1. The Results of Experiment from
100 m to 600 m.

$\begin{matrix} D_s \\ O_s \end{matrix}$	100m	200m	300m	400m	450m	500m	550m	600m
A	18 m	45 m	60 m	118 m	180 m	373 m	788 m	∞
B	21 "	27 "	44 "	91 "	154 "	321 "	825 "	∞
C	18 "	38 "	43 "	89 "	170 "	363 "	825 "	∞
D	18 "	46 "	62 "	117 "	198 "	405 "		∞
E	20 "	30 "	39 "	102 "	184 "		847 "	
F	17 "	25 "	59 "		167 "		761 "	
G	12 "	30 "	62 "					
H	10 "	25 "	59 "					
Mean	17 "	33 "	54 "	103 "	176 "	366 "	809 "	

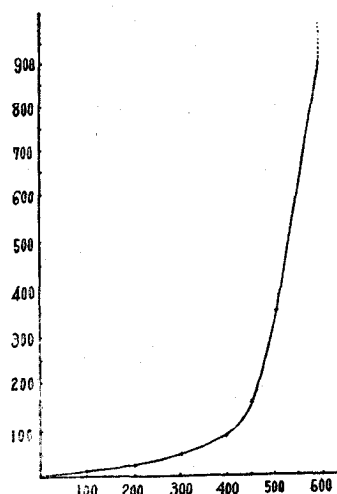


Fig. 1. Table 1 is graphically shown.

In figure 1, the co-ordinate is expressed in linear units. The ordinate gives the distance of CS from SS, the abscissa the distance of SS from O.

In view of the data, the following may be admitted. Above 400 m the distance perception becomes so insensible, especially over 450 m, that SS recedes only 50 m, whereas the 'discrimination threshold' (CS-SS) increases more than twice. It is supposed consequently, that the 'depth limit' is gradually drawing near. So it may not be a gross mistake to say that the distance of 600 m is the last extremity of depth perception under conditions lacking empirical factors. Afterward, the writer has gained confidence and tried by various observations to ascertain this assumption, among other things, by comparing a lamp-light near the 'depth limit' with a star, e. g. Mars which has a similar kind of light. In table 1,

the Os below E are data obtained from supplementary experiments made at Hirosaki Parade Ground, Aomori Prefecture, substituting other subjects in the autumn of the same year.

The diurnal visual space perception seems to embrace a huge area, but if its tiny section is cut off longitudinally, the depth of space will contract suddenly. For example, if a treetop in the vicinity almost overlaps with the distant foliage of a tree without intervening continuum of percepts, one cannot discriminate the depth as such. Consequently, the depth perception of the diurnal visual space in the conditions above mentioned may be quite equal to that of the nocturnal one. On the basis of this assumption a test was executed in November of the same year at the Meteorological Observatory for Troposphere in Ibaraki Prefecture.

A balloon of 1.82 m diameter (SS) was located at 600 m from the view-point, and in order to equalize the visual angle another balloon of 3.49 m diameter (CS) was moored at 1150 m. The colors of the two balloons were the same (yellow), but if they were shrouded by fog, the colors would seem to be different, so the test had to be carried out taking advantage of opportunities when it was windless and free from fog. SS was raised 2 m high and CS was adjusted in its elevation so that both appeared of an equal height from the view-point, and an adequate interval for a sufficient observation was kept between them. The balloons were seen above a thicket near the observer and a spatial continuum was lacking between O and the balloons. Os were four youths of the village. The observations were carried out one by one after the various conditions above mentioned were met. As for the color vision, the data were diverse, but regarding *apparent distances and sizes of two balloons, all without exception estimated them as being quite equal.*

Another observation was made to test the validity of LÜSCHER's supposition. This time, SS (of 1.82 m diameter) was located at 450 m and CS (2.91 m) at 720 m from the view-point. The other conditions were quite the same as above. About the color and apparent size, all reported that both were the same respectively. As for the apparent distance, all informed without exception that *CS appeared farther*. A series of supplementary tests were made in the winter of that year, having five school children for Os, and was corroborative of these results. That is, *in the 450 m experiment, all coincided with one another as to the relative distance of CS which was perceived farther.* But *in the 600 m experiment, CS seemed equally distant and of equal size to SS.* Considering these results, LÜSCHER's assumption may not be admitted.

Depth Limit Ought to Be Spherical

From what has been proved, the writer will advance a new tentative theory concerning the "Limitation of Depth Perception". **Supposing that a theory of visual space perception be effective enough, it must have to play its part throughout the whole of the visual world**—in the three dimensional field. The main application of the new tentative theory shall be proposed here.

As the 'depth limit' is of equal length in every direction, the percepts beyond the

'depth limit' should be perceived at the *very* 'depth limit'. Again in other words, *man's visual organ may be incompetent to discern the absolute or physical distance beyond a certain limit*. Consequently, the whole heavenly bodies, the sun, the moon, and all the stars should be localized at the same range—the 'depth limit', although the real distances to them from us are indeed diverse beyond our fancy. **That may be the reason why the starry sky appears as a vault.**⁴⁾

WUNDT has laid it down that the spherical form of the sky is based upon the movement of the eyes, as the fixation points describe continually the largest circle.⁵⁾ However, as the line of vision is immaterial and unsubstantial, it may be quite meaningless to describe the circle by it. The 'movement of the eyes' means only the continual change of the perceived objects at different distances.

When it is very foggy or when a nimbus hangs low, one cannot perceive the sky-vault, because *they are localized within the 'depth limit'*⁶⁾. In those conditions one can never perceive a spherical form no matter how hard one may move one's eyes. In view of this fact only, WUNDT's theory cannot be accepted.

Assuming a journey in the universe be feasible, *the visual world* of the hypothetical man *may be integrated to a perfect sphere*, because all heavenly bodies being localized at an equal distance on all directions from him who is the center. The observation of HANN *et al* may touch on the fringe of the phenomenon. Their elucidation is as follows⁷⁾. "When an observer ascends a high mountain or, by chance, goes up in the air by a balloon, he may perceive that the edge of horizon will rise contrary to his expectation that the edge would be sinking continually together with the observer in consequence of his ascending from the surface of the earth, so that the horizon continually seems to stay at the height of his eyes, and *the form of the surface of the earth below takes a concave vault*. Moreover, *the sky is of a concave vault too, so the navigator finds himself as being in the center of a gigantic hollow sphere*. The circumference where both the concave vaults meet, becomes an unnaturally elevated horizon. These phenomena are mainly expounded by the refraction which distributes rays of light coming from the horizon through the atmospheric

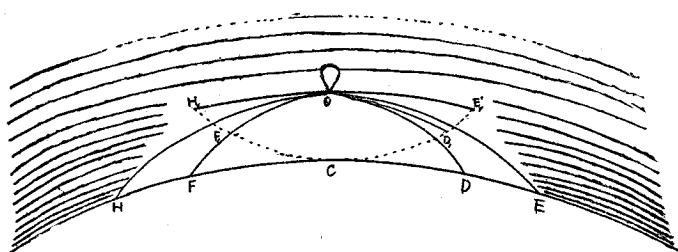


Fig. 2. The "illusion" of the shape of the earth's surface viewed from a balloon (After HANN *et al*)

layers of diverse densities. Owing to the decrease of the density of layers in proportion to altitude, the ray of light passes continually from a thick medium to a thin one, so it takes, as physics teach and as the figure illustrates, a curved way whose concave side turns

4) In this paper only phenomenal facts are described, their theoretical grounds will be discussed later.
5) WUNDT: Grundzüge der Physiologischen Psychologie, II, 6 Aufl. p.566.

6) This phenomenon is quite different from Metzger's whitewashed-wall experiment which the writer cannot touch now.
7) HANN, HOCHSTETTER, and POKORNY: Allgemeine Erdkunde, 5 Aufl. pp.6-8.

downward. Again, viewed from a different angle the elevation may also be attributed to the apparent approach of objects.⁸⁾" [The italics are the writer's].

The observation of HANN *et al* is no doubt valuable, but their explanations don't sound reasonable. For the refraction itself may not be so strong that the surface of the earth appears to be a concave vault. Moreover, HANN *et al* did not think of the fact that the 'concave vault' of the surface of the earth was of quite the same quality and has the same origin with that of the sky. The writer's own illustration is represented in figure 3. In it, from an observer, points A', B', C' and D' on the horizontal line may be localized at points A, B, C and D, the points of the 'depth limit', i. e. *the apparent surface of the earth*. The 'circumference' may be elevated and objects may appear to approach, and at the same time, *the height of them does hardly change according to the altitude of the point of view*, because the observer's elevation may be extremely small in contrast with the dimensions of the earth's surface.

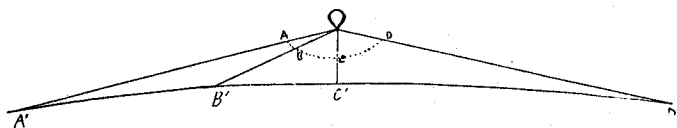


Fig. 3. The explanation of the shape of the earth's surface viewed from a balloon offered by the writer

LUCKIESH's description, also, proves no exception to the phenomenon. "At these high altitudes [four or five miles] the author is not conscious of a flattened vault as at the earth's surface but the illusion of a hemispherical dome still persists"⁹⁾. *But the writer thinks that perception may not be an illusion.*

If we glance over the sea from land or ship the surface of it near the horizontal line swells toward the margin as is plotted in figure 4. The points A', B', C is the surface of the sea; A, B, C, the perceived surface of the sea, i. e. the 'depth limit'. And the more

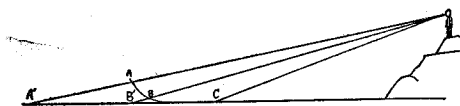


Fig.4 Explanation of the apparent form of the sea-level.

the view-point is elevated, the more the swelling will increase, the whole surface taking gradually a form of concave vault. This fact was proved by a careful observation of one of my friends, a weather-man, from an airplane many years ago.

The next example may be an apt instance of the 'depth limit'. Charles Darwin ascribed his unusual experience that "all objects appeared to be brought nearly into one plane", to the "extreme clearness of the air" and partly to "the novelty of an unusual degree of

8) Concerning such a problem, the reason "why things appear getting near" must first be explained.

9) M. LUCKIESH: Visual Illusions and their Appli-

cation, 1922. p. 167.

10) DARWIN: A Naturalist's Voyage in the Beagle (Everyman's Library). p. 312.

fatigue"¹⁰⁾. The former reason must be right, for the clearness of the air dissolved the air perspective and deprived him of his capacity of discriminating relative distances of objects. And for lack of the spatial continuum of the ground the "objects at different distances" were localized at the 'depth limit'. Accordingly, "all objects appeared to be brought nearly into one plane". As for the latter reason: the "unusual degree of fatigue", it may not be so essential to be discussed in particular.

Cause of Flattened Sky-Vault.

However, the 'vault' is not a hemisphere but somewhat flat—this being a general agreement among many scientific investigators. According to the writer's opinion this phenomenon is also based upon the same factor. The 'depth limit' is relatively a very small size as above alluded to, so, a *continuous surface of the terrain*¹¹⁾ can *prolong our discerning range only in the horizontal direction*. But as to the limit-expanding function, however excellent the conditions may be, the arrangement of the physical objects itself can not make it possible for us to discriminate them differentially beyond a certain limit. Thus we may get a 'secondary depth limit'.

Its value may be twice or three times as large as the 'primary depth limit'. This may be the reason why the vault of the sky appears flat. The influence of the limit-expanding function may be revealed by the phenomenon that the sun or the moon on the horizon, when they are rising, will suddenly contract at a certain altitude. The above influence, or in other words, the influence of the surface of the earth, is illustrated by the curves of the empirical surface and the 'Referenzfläche' which has been based upon the elaborate measurements of V. STERNECK. The following two figures (Figs 5 and 6) are examples in point. In figure 6, I indicates that of the moon observed in the clear sky by day. II also observed in the clouded sky by day, and III observed in the twilight. But if the spatial

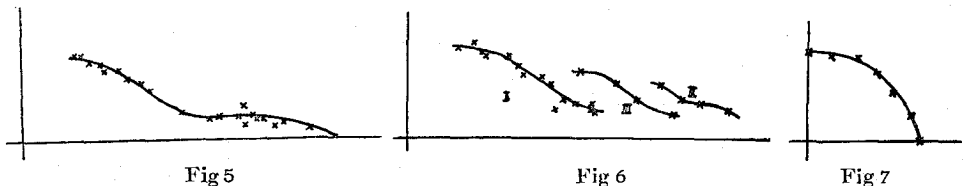


Fig. 5. The curve of the slightly cloudy sky.¹²⁾

Fig. 6. The curves of the Rfl. of the moon¹³⁾

Fig. 7. The meridian section of the Rfl. of the starry sky.¹⁴⁾

continuum is comparatively homogenous, e. g. the surface of the sea, in spite of chopping, the extension of the depth perception may not be so great. What is more, on a moonless night when the spatial continuum of the ground cannot be perceived, the 'depth limit' in the

11) The writer thinks highly of Gibson's "Ground theory" that places great importance on "a continuous background surface", but he is not a little disappointed to know that it is making little progress as a theory.

12) A. MÜLLER: Die Referenzfläche des Himmels und der Gestirne, 1918. p. 67.

13) Loc. cit. p. 77.

14) " " p. 79.

horizontal direction takes almost the same length as the 'primary depth limit', owing to the shortage of rays of light. So it may be easily supposed that the starry sky should appear almost as a hemisphere. It has been corroborated, among others, by the STROOBANT'S measurements. The illustration is represented in figure 7. One of every day experiences that proves the present theory is *a fire at night* localized near the 'primary depth limit', in the light of which one cannot perceive the spatial continuum of objects.

The clouded sky may also be illustrated by the same theory; its form appears as a flat vault too. The clouds, however, should be an 'even roof', for a cirrus at the horizon, e. g. is almost forty times as far away as one at the zenith. The illustration is presented in figure 8. In it, from the observer, points A', B', C' and D' of the cloud may be localized at points A, B, C and D respectively, the points of the 'depth perception'. It may be easily supposed that the form of clouded sky may change in conformity to the states of clouds. Accordingly, the results of many investigators are manifold.

How does the form of the blue sky become materialized? The writer was once informed of the experience of a certain person who observed a search-light from its source. Contrary to his expectation, *he perceived a disc of light at a certain short distance*, instead of seeing a straight beam of light going into a far distance. In addition, the writer was told by a meteorologist at a certain local weather bureau, how he attempted one night to observe clouds by means of throwing a search-light over them. But the plan proved abortive owing to the interruption of a disc of light appearing in front of him. Incidentally, the writer thinks, a search-light should be thrown from a place at a certain distance from an observer.

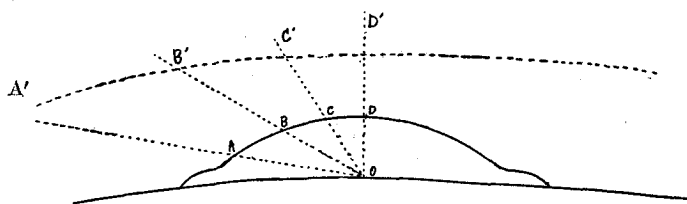


Fig. 8. Illustration of the perceived shape of the clouded sky.

Perhaps the phenomenon, *a disc of rays, may be ascribed to the localization on the 'depth limit' of the integrated rays* scattered by dust and moisture particles and the molecules of the air itself beyond the 'depth limit'. The phenomenon described by LUCKIESH must be a case when a searchlight beam was observed from a rather distant place¹⁵⁾. **The dome of the blue sky may surely result from the same causes.** *Rays of shorter wave-lengths, reflected by innumerable very minute particles in the atmosphere of high altitudes, may be localized, though very obscurely, at the 'depth limit' on all directions from an observer, the center, constituting a shape of flattened vault.*

15) Cf. M. LUCKIESH: L. c. pp.160-162, especially Fig. 77.

16) HELMHOLTZ: Handbuch der Physiologische Optik, 3 Aufl. III, 1910, p.243.

17) v. STERNECK: Der Sehraum auf Grund der

Erfahrung, 1907, p.55.

18) F. BERNSTEIN, Das Leuchtturmpheänomen und die scheinbare Form des Himmels. Zeitschr. f. Psych. 34, 1904.

It is not appropriate to attribute the apparent form of the starry sky to that of the clouded sky as HELMHOLTZ attempted¹⁶⁾, or to ascribe the form of sky at night to the wide influence of that of the daytime, as v. STERNECK¹⁷⁾. The forms of the sky may not depend upon one another, but all *do* depend upon the same common factor, that is, the 'depth limit'.

Lighthouse Phenomenon

The phenomenon of the lighthouse stated by BERNSTEIN is a special instance connected with the apparent form of the sky¹⁸⁾. He made observations about the aspect of the beam of light emitted from a lighthouse standing 40 m above the sea-level on the isle of Helgoland, Germany. The beam seemed dome-shaped like a vault of heaven to the observer who was situated on the lowland at sea-level. When the upper beam was observed at the foot of the lighthouse, the curvature disappeared and it seemed straight, but when the lower part of the beam was surveyed, it assumed the form of a sky-dome extending, as it were, to a great distance.

BERNSTEIN ascribed the curvature of the beam to the magnifying of the acute angle which resulted from the intersection of the line of vision and the beam of light. However, as the line of vision is not substantial, the 'magnifying of the angle' seems quite absurd. The writer thinks this case may be quite alike to those stated before, i. e. the beam of light beyond the 'depth limit' may be localized at the *very* 'depth limit', as presented in figure 9. The line A'B'C' shows the ray of light and ABC' means the perceived ray.

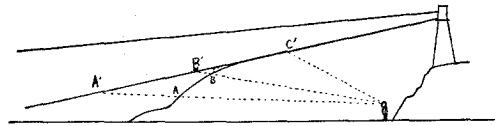


Fig. 9 Imaginary diagram of the apparent form of the beam offered by the writer.

BERNSTEIN, besides, refers to the phenomenon that the curvature diminishes strikingly towards the horizon. This case may be of the same kind as Figs. 5, 6 and 12.

Other Phenomena Concerning 'Secondary Depth Limit'

"In the high Rockies where the atmosphere is unusually clear" "a person inexperienced in the region is likely to construe this absence of haze as a shorter distance than reality" and perceives distant, large mountains as near, small ones. The explanation offered is that 'aerial perspective' is the primary cause of the illusion¹⁹⁾. But it appears to the writer that it is rather the secondary cause of the illusion, but the primary cause may be the 'depth limit'. The explanation is given in figure 10.

Such a fresh green color at the secondary depth limit (AB) is, in ordinary experience, of very near distance. Therefore such a formation with such a color must always be perceived as a "hill" at a short distance. So, a newcomer may become a victim of illusions. On the

19) M. LUCKIESH: Loc. cit. pp. 165—166.

contrary, in ordinary regions, a formation at the 'secondary depth limit' may change its color owing to the aerial or color perspective making it look distant and large.

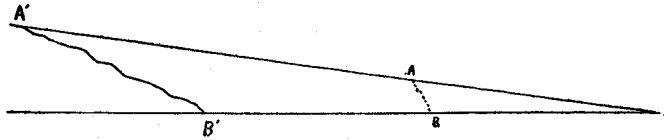


Fig. 10. The perception of a distant large mountain at the 'secondary depth limit.'

It has been definitely shown by v. STERNECK's scrupulous observations that the moon near the horizon appears larger when observed in a bright moonlight night, but the sun near the horizon appears larger when it is covered with thin clouds²⁰⁾. The moon in a moonlit night must seem larger because it is observed across the stretches of spatial continuum of the ground between it and the observer, but when it is cloudy, the spatial continuum of the ground cannot be seen, so it appears smaller. On the contrary, when it is clear, the sun can be observed only for an instant, on account of the intense rays of light, so that the observer can see only the sun itself without glancing over the stretches of spatial continuum, as though he looks at it through a narrow pipe. However, when the sun is covered with veil-like clouds, the condition becomes similar to that of the moon on a clear night. While on this subject, the 'spatial continuum' is more effectual when it consists of more heterogeneous surfaces, so the homogeneous ones, e. g. the surface of the sea, though chopping, is not effective enough to bring about a conspicuous 'moon illusion' as v. STERNECK's researches showed.

Comment on Representative Explanation and Writer's Illustration

As mentioned before, the space is limited, and thus it is impossible for the writer to comment on every theory concerning the visual space, but in order to point out the fact that they may have a tendency to be open to errors on account of overlooking the main factor that plays an important part, only one of them shall be criticized by way of example.

As to the apparent flattened vault, a representative explanation of the 'moon-illusion' has been formulated by ROBERT SMITH nearly two and half centuries ago and was accepted by WUNDT and others. It is plotted in figure 11. Many errors can be revealed in the explanation. First, SMITH and others presumed that the figure represented a hemisphere acting as a sky-dome, but essentially it is nothing but an orbit or a semi-circle. The sky-dome is quite different from the orbit, the one is an outcome of perception, and the other is a product of imagination and cannot be perceived; again, the one is three dimensional, the other two dimensional. Secondly, according to WUNDT (and others) the flattening of the sky-dome is due to the following two factors: (1) The elevated view-point of the observer, i. e. the height of his eyes from the ground and (2) The divided surface of the ground by objects

20) v. STERNECK: *Der Sehraum auf Grund der Erfahrung*, 1907, pp.59—66, 72—84.

21) WUNDT: *Loc. cit.* p. 697.

between the observer and the horizon²¹⁾.

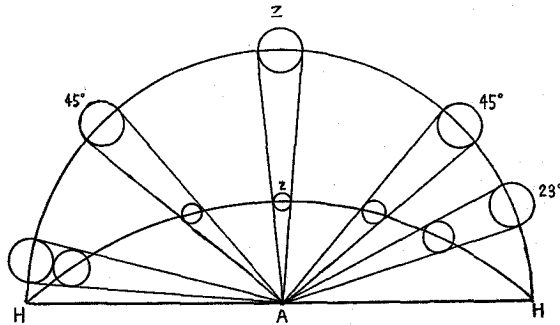


Fig. 11. Illustration offered by Smith of the apparent enlargement of the heavenly bodies near the horizon (After Wundt).

As for the bodily height, such a small amount deserves little consideration in a question like the sky-dome. So the 'divided surface' may be the main cause of the lengthening of distance between the observer and the horizon. Therefore, in Fig. 11, the line HAH must be lengthened and HZH must not be lowered to HzH. Thirdly, the illusion that a divided line looks longer than an undivided one is a phenomenon within a limited small part of space. It cannot be applied to the orbit of the sun or the moon, which reaches literally astronomical figures. *The horizontal 'continuum of objects' is limited on the surface of the earth, not extending as far as the sun or the moon.* What is more, *even on the earth's surface the 'continuum of objects' is limited again to a short distance which can be discerned.* Even if there exists a 'continuum' physically outside that space, it cannot become an object of perception. Assuming that the 'discernible' space is 4km and the distance to the moon 400,000km, the explanation will make the following **fatal mistake**, that *one of two given equal lines becomes twice or three times as large as the other, if only its 1/100,000 is divided.* The writer's own explanation is presented in figure 12. SZS means the primary 'depth limit', HZH the secondary 'depth limit' and ω subtends the diameter of the sun or the moon²²⁾.

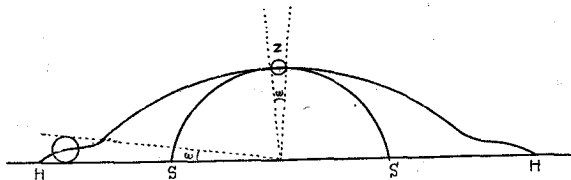


Fig. 12. Explanation offered by the writer of the sky and apparent enlargement of heavenly bodies near the horizon.

22) The details, 'The Perception of the Magnitude of the Sun or the Moon', are published in a collection of papers: Studies in Art and Psychology (In Japanese) Vol. I, 1931, pp. 303—328.

23) This experiment was carried out in 1952 at

the Meteorological Observatory for Troposphere, Ibaraki Prefecture, with a subsidy of the Ministry of Education.

24) Red color was used that the balloon might be distinguishable against the clouds.

Experiment Concerning Secondary Depth Perception

The writer arranged other experiments concerning the extension of the 'depth limit'²³⁾. The procedure of one of them was as follows. A red balloon²⁴⁾ of 2.5 m diameter was sent up in the air and a disk of the same color and the same diameter was set on the ground, both having the same distance from the view-point. O_s observed both the stimuli from an observation tower 11 m high. Between the disc and the observer the continuous surface of the ground intervened. The subjects were weathermen and the youths of the village. The observation was executed in calm weather.

First, the experiment of 1,500 m was carried out. The results are given in table 2.

Table 2. Results of Experiment of 1,500 m.

O_s	A	B	C	D	E	F	G	H	I	J	K	L	Mean
R_s	1.8	3.0	4.0	2.0	1.5		2.0	1.3	2.3	1.5	1.5	1.5	2.0

R_s means ratio of the assessed size of the diameter of the disc to that of the balloon, taking the latter as 1. Among O_s , G to L represent weathermen.

On this occasion, for reference, the writer arranged another test which was an observation of the disc in supine position. The measurements are presented in table 3.

Table 3. Results of Experiment of 1,500 m in Supine Position.

O_s	B	C	D	E	F	G	H	I	J	Mean
R_s	2.0	2.0	1.0	1.5	1.2	1.2	2.0	1.3	1.0	1.5

O_s are identical. About the data obtained by observation in supine position the writer will discuss later collectively.

Next, the test of 1,200 m was made. The results of both normal and supine observations are given in tables 4 and 5 respectively.

Table 4. Results of Experiment of 1,200 m

O_s	A	B	C	D	F	G	H	J	Mean
R_s	1.4	4.0	2.0	1.3	1.3	1.4	1.4	1.5	1.9

Table 5. Results of Experiment of 1,200 m in Supine Position

O_s	A	B	C	D	F	G	H	J	Mean
R_s	1.2	2.0	1.0	1.2	1.0	1.3	1.25	1.0	1.3

For the test of 100 m, both results are presented in tables 6 and 7.

Table 6. Results of Experiment of 1,000 m

O _s	A	B	C	D	F	G	H	J	L	Mean
R _s	1.4	3.0	3.0	1.4	1.8	1.3	1.5	2.0	1.5	1.9

Table 7. Results of Experiment of 1,000 m. in Supine Position.

O _s	A	B	C	D	F	G	H	J	L	Mean
R _s	1.2	2.0	1.0	2.0	1.1	1.2	1.1	1.1	0.7	1.2

The measurements of the 600 m test are given in the following tables.

Table 8. Results of Experiment of 600 m.

O _s	A	B	C	D	F	Z	G	J	mean
R _s	1.2	1.5	2.0	1.3	1.1	1.5	1.35	1.1	1.4

Table 9. Results of Experiment of 600 m in Supine Position.

O _s	A	B	C	D	F	Z	G	J	Mean
R _s	1.2	1.5	1.0	1.0	1.0	1.0	1.25	0.9	1.0

Taking a general view of the results obtained so far, the tentative theory stated before seems reasonable. The apparent size of the diameter of CS which is in the horizontal direction and localized at the position around the 'secondary depth limit', was almost twice as large as that of SS which was in the vertical direction and localized at the position of the 'primary depth limit'. Though the experimental conditions of the background were not satisfactory, a fair result was gained.

In the 'supine' observation, both SS and CS reversed their relative positions. SS is now in front of O and CS overhead. In the measurements the value of CS is remarkably low, especially in the short distance. The chief reason may be the oversight of the spatial continuum rather than the function of the anisotropy of space. Accordingly, the writer carried out the following test. Two balloons of 2 m diameter were used, one was raised to a height of 1,200m, while the other was set on a horizontal place measuring the same 1,200m from the view-point which was a spot at one of the windows of the observation tower 6 m high above the ground. The condition to observe the lower balloon was on the window-sill, a little apart from it, so that O_s might see the balloon just on the window-sill *eliminating the continuous space* of the ground. The data are given in table 10.

Table 10. The Special Experiment of the 1,200 m Comparing of SS with CS Which is Lacking in Spatial Continuum.

O _s	A	B	C	D	G	J	M	N	O	Mean
R _s	1.2	1.0	1.1	1.3	1.1	0.9	1.1	0.9	1.1	1.1

In the 600 m test a special observation was made to compare and contrast with that from a supine position. O_s lying on their belly observed both balloons. The conditions were similar to those of supine observation. The results are presented in table 11. The data of both tests are quite equal as the tables show.

Table 11. The Special Experiment of the 600 m, Lying on Their Bellies, CS Lacks Spatial Continuum.

O _s	A	B	C	D	F	Z	G	J	Mean
R _s	1.0	1.0	1.5	1.1	1.0	1.1	1.1	1.0	1.1

The writer surveyed carefully the postures of O_s when they observed the objects in every direction. Even in supine position or on their bellies, they observe the objects in their natural postures, that is to say, *by bending the neck*, to say nothing of looking up at the objects right above. He could find no exception. When we look at things, no matter

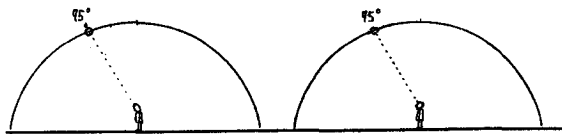


Fig. 13. The natural (right) and unnatural postures.

in what direction they may be located, *we are accustomed to see them right in front of our faces*. In Fig. 13, the right figure represents the natural posture slightly bending the neck to look at the moon which is located at 75°. The left figure is very unnatural posture 'raising the eyes' to look up the same moon. Perhaps no one assumes such a posture. Accordingly, it is not pertinent to explain the 'moon illusion' by such an unnatural observation method as 'raising the eyes', e. g. the rotation of the eyeballs. *As a matter of fact, the 'moon-illusion' always occurs by observing the moon at the zenith in supine position or by bending the neck backward*. It may be the traditional way of observing the moon since the world began to see it right in front. So, works like E. SCHUR's are surely very interesting and suggestive from a special point of view, but they are not adequate as a study concerning the 'moon illusion'²⁵⁾. It is very regrettable that this subject cannot be dealt with further for want of space.

25) E. SCHUR: Mondtäuschung und Sehgrößenkonstanz Psychol. Forsch. 7, 44, 1926.

'Moon Illusion,' is Outcome of Indirect Comparison

The method of observation, so far, has been a direct comparison, but that of the 'moon illusion' is an indirect one. This means that *we compare the present perception of the moon at the zenith with the memory image of the moon at the horizon and vice versa. So it is easily imagined that the magnitude of the illusion of the latter may be considerably greater.* The writer, thereupon, made a series of tests to corroborate this fact. He divided 80 subjects (junior high school pupils) into three groups. The first group, to begin with, observed the above balloon 1,200 m high at the foot of the observation tower and then ascending the tower, observed the balloon at the horizontal position 1,200 m away from the view-point. The experimental order of the second group was the reverse. The third had recourse to the ordinary method mentioned before. The results are given in table 12, answering the writer's expectation.

Table 12. Results of Indirect Comparison.

(Group 1)								
O _s	1	4	3	10	1	12	2	Mean
R _s	7.0	5.0	4.0	3.0	2.5	2.0	1.5	3.0

(Group II)					
O _s	1	1	21	3	Mean
R _s	6.0	3.0	2.0	1.5	2.1

R_s means the ratio of CS (lower balloon) to SS (upper balloon), O_s the number of the observers who measured the respective ratio. The mean value of the second group is comparatively low, perhaps because of the circumstances that the subjects, when they got on the tower, as a first step, to observe the lower balloon, probably saw the upper one in disregard of the instruction to see only the former, making one kind of direct comparison. The mean ratio of the third group was 1.8 which was quite equal to the data of the experiments shown before.

Though very few, there are such extreme cases as esteeming the size of the horizontal stimulus six or seven times larger than that of the vertical one. A similar case is also found by a direct comparison like the subject C of previous tests. Perhaps she judged the size of the stimulus on the basis of the first impression when she cast a glance upon the stimulus, never comparing them carefully. Anyhow, there may possibly be some persons who have an extreme disposition to overrate dimensions; accordingly, they may have a tremendous 'moon-illusion'. The writer will touch this matter again at a later date.

Observations of Experimental Moon by Looking Up

The writer thinks that the 'moon shrinking', may not be caused simply by 'looking

up'. 'Looking up' may mean in general, the privation of the spatial continuum of objects, so that we localize the moon on the 'primary depth limit'. However, *if the moon were to rise above a perpendicular cliff that attains to a height of several kilometers, and the surface of the cliff presents a spatial continuum, the moon were likely to appear as large as in a horizontal position.*

The writer made an exploration for a place where the above mentioned condition may be satisfied *to a certain degree*, paying due regard to the facilities for experimentation. At length, he selected a comparatively steep slope of Mt. Tsukuba, Ibaraki Prefecture, on the upper half of which the spatial continuum of treetops extended from the breast up to the summit. The observations were made from a certain position of the breast. The procedure was as follows. Two rubber balloons of the same size were used. Both had red spherical silk covers whose diameter was exactly 2 m. One was put up at the peak so as to be seen at the end of the continuum of treetops. The other was raised at the foot so that it had the equal height of the view-point of the breast. Special regard was paid to get rid of the continuum of the ground by taking advantage of a grove about 150 m away, so that the balloon was seen just above the grove. The distances of both balloons from the view-point were equal, being approximately 1,640 m. When you face the balloon at the top, you may have a feeling that you are 'looking up' at it, although the angle of elevation is only 24 degrees.

The experiment was at first scheduled for the summer of 1953. In such an experiment, weather conditions are very delicate, so the program was postponed three times on account of unfavorable weather. Even in clear weather, the wind generally blew considerably, so that the experiment had to be carried out making the most of the lull in the evening which lasted only a short time. O_s were chiefly school children of the neighborhood.

First, the lengths of the diameters of both the balloons were compared, under the conditions above mentioned, the lower balloon being SS. The results of the test are given in table 13.

Table 13. Comparison of Upper Balloon with Horizontal One.

O_s	13	6	2	2	Mean
R_s	1.1	1.3	1.2	1.0	0.9

O_s means the number of subjects who measured the ratio, R_s the ratio CS : SS. Referring to the data, the 'looked up' stimulus was estimated larger than the horizontal one though its increasing rate is only ten percent or more, perhaps on account of the insufficient conditions, for the continuum of treetops was not satisfactorily heterogeneous. Among the subjects there were 4 adults, particularly 2 were weather experts used to observation. But their appraisals had no special features, being of mean value.

The sufficient conditions for investigating the present problem must be such, that the spatial continuum of a steep slope extend so far away that the 'primary depth limit' may

be lengthened considerably. That is to say, the perceived size (of the diameter) of the balloon at the horizon and the one at the top of the slope may be in the ratio of one to two or three.

Next, the following procedure was intended. The upper balloon was to be observed when the intermediate spatial continuum of the treetops was eliminated by using a curtain, but the condition of the horizontal one remains the same as above. But unfortunately, the wind began to blow considerably and the latter disappeared behind the grove. So, out of sheer necessity, we were compelled to compare the upper balloon 'with the spatial continuum' with the same one 'without the continuum'. The measurements are presented in table 14.

Table 14. Comparison between 'Spatial Continuum' and 'Without Continuum'.

O_s	8	4	1	1	Mean
R_s	1.3	1.1	1.4	0.8	1.2

The signs O_s and R_s are the same as those of table 13. The mean value of table 14 is greater than that of table 13. The prime factor may be the successive comparison, i. e. a kind of indirect comparison caused by the short intervals of time.

With the above investigations, one may well acknowledge how important the 'depth limit' and the 'spatial continuum' in the visual space perception are.

S u m m a r y

It seems so far, that an essential factor that plays a very important part in the visual space perception has been passed unnoticed. By means of that factor many phenomena in the visual space, e. g. the forms of the blue, the starry, and the clouded skies, the 'moon-illusion' and others can be explained systematically and consistently.

(To Be Concluded)