SCIENCE SET
OPEN ACCESS PUBLISHERS

ISSN: 3066-7194
Research Article

Novel Journal of Applied Sciences Research

Purely Physical Processes of Mirror Reversal and its Application to Vision Research

Junichi Tanaka*

Japan.

***Corresponding author:** Junichi Tanaka, Japan.

Submitted: 15 May 2025 **Accepted:** 21 May 2025 **Published:** 27 May 2025

https://doi.org/10.63620/MKNJASR.2025.

***Citation:** Tanaka., J. (2025). Purely physical processes of mirror reversal and its application to vision research. Nov Joun of Appl Sci Res, 2(3), 01-11.*

Abstract

The significance of the mirror reversal problem has long been left ambiguous. The fact that the purely physical process of the mirror reversal has not been determined is the fundamental reason the problem has not been resolved. This study deduced the purely physical process of the mirror reversal phenomenon directly from the specular reflection for the first time, utilizing the mechanical camera structure and Cartesian coordinate system, by excluding non-physical elements, one of which is the virtual image and the other of which is directional notions such as top-bottom, front-back, and right-left, and demarcated the geometrical condition in which the reversal should not arise. By doing so, the physical process successfully became integrated into the visual process of the observer based on human factors. This analysis also clarified the cognitive process of the mirror problem, which consists of the perceptual process in the anisotropic space and the thinking process in the isotropic geometric space.

Keywords: Mirror Reversal, Physical Process, Specular Reflection, Vision Research, Cognitive Process

Introduction

It is self-evident that optics is relevant to the mirror reversal phenomenon because it cannot arise without the mirror's optical effect. The only optical law concerning the mirror is the specular reflection law (law of reflection). Therefore, it is clear that the decisive cause of the mirror reversal is the specular reflection. However, there are theories that do not admit the optical factor to the mirror reversal phenomenon. Among such theories, Gregory (1987) [1], Takano (1998, 2013) [2,3], Bianchi, Ivana & Savardi, Ugo (2008) [4], and other recent researchers insist that optics is irrelevant to the mirror reversal phenomenon at least in some instances, or they are ignoring optical conditions. On the other hand, Scientists of various fields, such as Gardner (1964) [5], Corvallis (2000) [6], and Tabata and Okuda (2000) [7], have been explaining the optical factor of mirror reversal geometrically using the enantiomorphism of the plane-symmetric pair, which can be associated with mirror reflection. However, the condition of plane symmetry can also be substantialized by using real objects of an enantiomorphic pair, such as right and left hands. Thus, enantiomorphism is not identical to the optical factor or the physical factor. Moreover, enantiomorphism alone can explain only the universal and geometric conditions for the phenomenon and cannot explain personally perceived conditions. Therefore, they have introduced and added non-physical explanations such as biological, psychological, or semantical factors to the enantiomorphism. In the process above, directional notions such as top/bottom, front/back, and right-left were applied to the enantiomorphic pair in the Cartesian coordinate system but seemed to fall into confusion, and all remain as hypotheses.

Thus, two fundamental mistakes in methodology can be seen in previous theories, as mentioned above. One is that the virtual image has been used as the basis of analyses. The connection between enantiomorphism and optical mechanism can be made only through the virtual image. The virtual image is not a physical existence, so it cannot make up a purely physical process in optics. We must analyze the physical process of the phenomenon directly from the reflection law. Physical processes concerning the optical image should have been analyzed based on the real image instead of the virtual image and object. Therefore, we must derive the mirror reversal phenomenon from the reflection law to determine the physical mechanism and resolve the misunderstanding that optics is irrelevant to the mirror reversal.

The other is that directional notions such as top/bottom, front/back, and right/left have not been introduced correctly. In other words, directional notions, which are not geometric, were applied to the Cartesian coordinate system improperly.

Those mistakes seem to have made the distinction and boundary between the physical and cognitive processes of the mirror reversal neglected or confused. Thus, we must find the purely physical process and correctly apply the physical process to vision research by properly connecting the physical process to the cognitive process.

Methodological Problems in Previous Studies in Analyzing Physical Processes of the Mirror Reversal

Defects of Haig's (1993) Argument

Haig (1993) [8] tried to explain the mirror reversal mechanism directly from the principle of specular reflection (law of reflection) unsuccessfully. He deduced the conclusion based on the analysis of physical rays. However, his ray diagram depicts only some part of the track of rays and lacks the structure of the eye (the eye was represented by a mere point) and any image formed on the image plane; in other words, his ray diagram does not make any optical system. Also, in any optical diagram that includes any image, perceptual directions such as top-bottom, front-back, and right-left must be introduced from the viewer's eye in the body structure and the property of the object, but he defined top-bottom and right-left arbitrarily without any foundation and was misled to confused conclusions. In short, he introduced human factors and directional notions such as top/bottom, front/back, and right/left into the physical process in an inappropriate manner.

Excluding Non-physical Factors

Two non-physical factors have been considered or used in previous studies as if they were physical or geometrical factors. One is the concept of the virtual image in geometric optics. The other is the concept of directional expressions such as top/bottom, front/back, and right-left. As for the former, it would be self-evident from the definition that the virtual image is not a physical existence. As for the latter, such directional notions are originally derived from the cognitive function of the human, so they are subjective. Therefore, such directional notions cannot be used to analyze geometric processes objectively. Thus, we must exclude those two factors in the methodology to analyze purely physical processes of the phenomenon.

How We can Find the Method which Exclude the Above Two Non-physical Factors

In theories that exclude optical factors at least partly, Takano's (1998, 2013) [2,3] multi-process hypothesis is unique in that it admits the optical factor only in specific instances. Takano (1998) [2] presented the "multi-process hypothesis." He divided the mirror reversal into three types and determined that only Type III reversal is relevant to optics. He wrote, "Type III reversal is produced by a mirror's optical transformation" in that paper.

Takano (1998) [2] does not give any physical definition of Type III reversal. However, it indicates that Type III is applicable to the condition in which the observer can see both the mirror image and object simultaneously in one field of view because he describes the reversal of characters in this case as follows. "Although the mirror image can be compared with the representation of the character, it can also be compared directly with the real character because the latter is also visible in this layout." It means that it is self-evident that when the observer can see both the object and its mirror image, the mirror's optical effect is relevant to the mirror reversal because the observer can compare both in one field of view. This condition can be reproduced by a mechanical camera. Physically, the eye and camera have an identical function, but by supposing and depicting the camera structure as a mechanical camera instead of the eye, we can avoid the non-physical factors as above. That is, we cannot help but use the real image because the mechanical camera cannot perceive the virtual image that is usually used in analyzing optical systems that include the human eye. In addition, we can exclude the concept of directional notions of top-bottom, front-back, and right-left, which cannot be excluded from the human eye. Instead, we can use a Cartesian coordinate system. Thus, we can analyze the physical condition in which the observer can see both the object and its mirror image in one field of view.

Materials and Methods

The Concept of the Analysis Using the Cartesian Coordinates

What proved is that any mirror reversal cannot be analyzed physically without the set of a convex lens, image plane, and object in the treated three-dimensional space. When analyzed physically, we can use the Cartesian coordinates. See Fig. 1 and Fig. 2 below. Fig. 1 shows the situation in which the observer's eye perceives the mirror image of Pole A and B. Fig. 2 illustrates the main physical elements of the above situation in which Cartesian coordinate is applied to the image plane and optical axis of the convex lens.

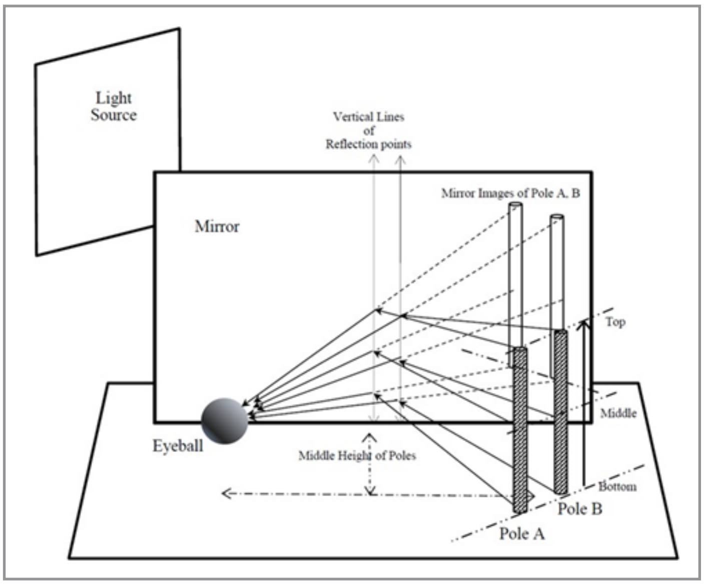

Figure 1: Schematic diagram of the analysis. This illustrates the situation rather realistically. The one eyeball and poles are depicted as such.

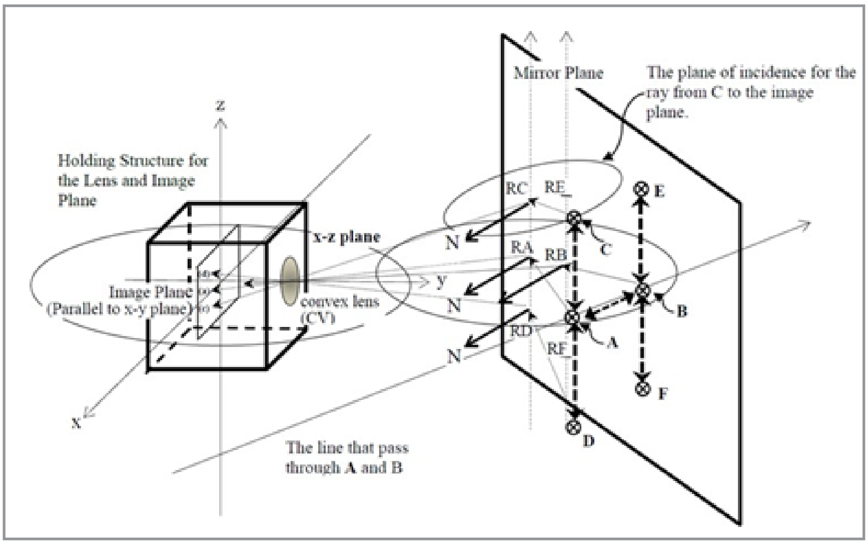

Figure 2: Applying the Cartesian coordinates to the system outlined in Fig. 1. In this Figure, the eye is replaced by a camera, and the camera and mirror are coordinated in a Cartesian coordinate system. Light points on poles are represented by a symbol, a circle represents any plane, and arrows N mean the Normal line.

In Fig. 2, the conditions are as follows:

1. The y-axis represents the optical axis of the convex lens.
2. The image plane is in the xz-plane because it is perpendicular to the y-axis, which is the optical axis.
3. The z-axis is always parallel to the mirror surface, so it is always perpendicular to the Normal line for any reflection point and can only be translated.
4. Light spots A, C, and D are on Pole A, Light spot B is on Pole B, and Light spots A and B are in the xy-plane.

There are some preconditions to notice:

1. The arrows representing rays from light spots C, A, B, and D should be thought of as the principal ray of collective rays that pass through the lens and focus on the image plane as the image of each light spot.
2. Consequently, the endpoint of arrows that represent rays on the image plane represents the formed image of each light spot.
3. In any context relevant to the Cartesian coordinate system and optics, the simple description of "image" means "real image," so it does not mean "virtual image."

Now, on the above conditions, we shall analyze the relative position for the real image of light spots formed on the image plane both in the line parallel to the z-axis and in the line parallel to the x-axis between when the ray comes via the mirror reflection and when the ray comes directly from the light spots. The y-axis is not relevant.

Analyzing Parallel to the Z-axis

In the above conditions, RC, RA, and RD represent the reflection points of rays emitted from C, A, and D and focus on the image plane through the lens, respectively. At any reflection point, the Normal line of specular reflection is perpendicular to the mirror plane. It is perpendicular to any line on the plane and is included in any plane of incidence of the reflection point. In this situation, let us compare z-values for each reflection point. The possible z-values are given in the Table 1 below.

Table 1: Comparing relative z-values for the original light spots and the reflection points.

Original Light Spot	Reflection Point	Possible z-Value
C	RC	0 <
A	RA	0
D	RD	0 >

The z-value of the reflection point for C (RC) should be higher than the reflection point for A (RA) because if not, the ray could not reach the optical center of the lens ($z = 0$). Therefore, for RC, $z > 0$. That is because The Normal line for RA is in the xy-plane, so for RA, $z = 0$. For the reflection point for D, vice versa. Therefore, for RD, $z < 0$. Thus, the formed image of the light spots on the image plane reverses in a direction from the original order, which is the same as for rays emitted from those light spots and reach the image plane directly without mirror reflection. Therefore, in the z-axis, any reversal of image points between the mirror image and the directly (without mirror reflection) formed image on the image plane cannot arise.

Figure 3 below shows the explanation above from a projection view on the yz-plane.

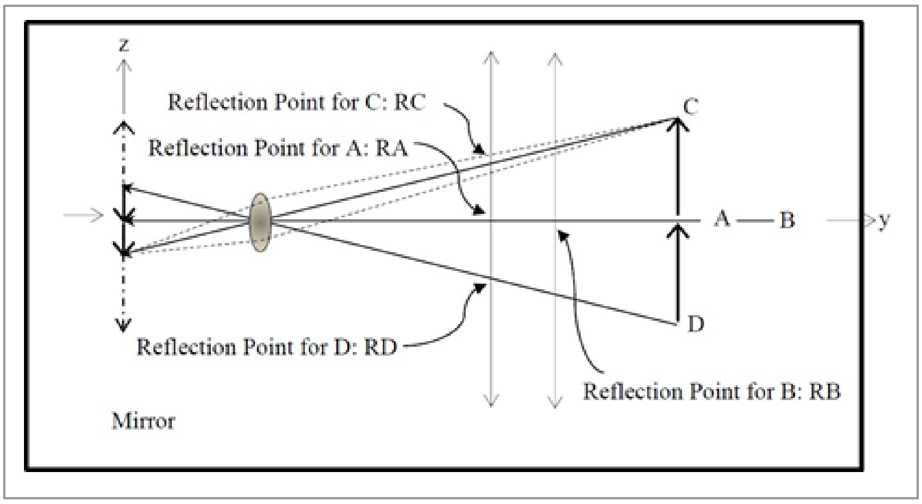

Figure 3: A projection view on the yz-plane of the optical diagram. This Figure is the visualization of the explanation represented in the analysis section and Table 1.

Analyzing the Line Parallel to the X-axis in the XZ plane

As analyzed above, every reflection points of light points in a line parallel to the z-axis has the same x-value and the same y-value. In contrast, every reflection points of light in a line parallel to the x-axis has the same z-values but different y-values, except when the x-axis is parallel to the mirror. Therefore, the difference between the z- and x-axes in the analysis is that the z-values of the real image for light spots C and D on the image plane are the functions of only the z-values of the light points, whereas x-values of the image points for light spots A and B are functions of both the x-values and y-values of the light points. That is because light spots C, A, and D are all in a line parallel to the z-axis, whereas light spots A and B are in the xy-plane.

Figure 4 below depicts a situation when the image plane is not parallel to the mirror, and both the mirror and direct images can be taken in the same image plane. The reflection points RA and RB are also in the xy-plane in this Figure. In contrast, in the analysis for the line parallel

to the z-axis, the reflection points RC and RD are in a line having the same x-values and y- values. Table 2, previous to Figure 4, presents the meaning of letter symbols.

Table 2: Meanings of abbreviations used both in Figure 2 and explanations below.

Letter Symbol	Meaning
A	Light Spot A
B	Light Spot B
C	Light Spot C
D	Light Spot D
RA	Reflection Point for A
RB	Reflection Point for B
RC	Intersecting point for the mirror plane and the y-axis (the optical axis).
LC	Optical Center of the Lens
IAm	Real Image of Light Spot A Formed on the Image Plane (xz-Plane) with mirror reflection
IBm	Real Image of Light Spot B Formed on the Image Plane (xz-Plane) with mirror reflection
IAd	Real Image of Light Spot A Formed on the Image Plane (xz-Plane) without mirror reflection
IBd	Real Image of Light Spot B Formed on the Image Plane (xz-Plane) without mirror reflection
N	Normal Line for the Mirror Plane

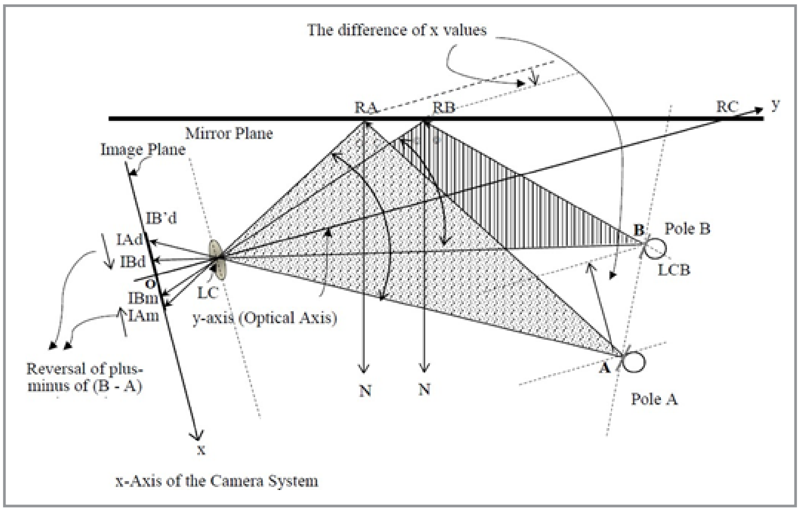

Figure 4: Ray diagram on the xy-plane when both the mirror and direct images are taken. This Figure shows the positive or negative difference of x-values between the image points for light spots A and B, which shall become the opposite between the mirror image and direct image

In this condition, the y-axis is between two reflection points and two original light points before the lens and between the two mirror images and two direct images behind the lens. Therefore, both x (RA) and x (RB) are negative, and both x (A) and x (B) are positive. As already proved in the previous section, because the mirror surface has a positive slope to the x- axis, x (RB) > x (RA).

In Fig. 4, the x-values of reflection points are as follows.

Reflection point RA is nearer than that of reflection point RB to the image plane because the reflection angle for A, at RA, is smaller than that for B, at RB, so that
x (RB) – x (RA) > 0.

In addition, because the mirror plane crosses the image plane by any acute angle, the nearer the point to the x-axis, the smaller the x-value for the point. Therefore, because the two lines cross at LC, x (IAm) > x (IBm) so that x (IBm) – x (IAm) < 0 (minus). On the other hand, x (A) and x (B), as well as y (A) and y (B), can vary independently.

When x (B) is smaller than x (A), x (B) – x (A) < 0, so that x (IBd) – x (IAd) > 0 (plus).

Thus, the reversal of the image along the x-axis between the mirror and direct images arises.

When x (B) is larger than x (A), the reversal should not arise.

Another thing to notice is that the x-values and y-values of the diagrams below of the xy- plane of the three-dimensional Cartesian coordinate system represent not only points in the xy plane, such as A and B, but also represent points in other planes than the xy-plane, each of those is the plane of incidence. That is because we consider only x-values in the three-dimensional Cartesian coordinate system. Figure 4 represents the xy-plane of the three-dimensional Cartesian coordinates so that the x-value and y-value of each point in the xy-plane can indicate any point of different z-values of the same x- and y-values. Therefore, x-values in the plane of incidence relevant to C, D, E, and F, which are not parallel to the xy-plane, can be indicated. The relative angles of both sides of the Normal line should also be the same because the Normal line is always the same for any different plane of incidence. Thus, explanations relevant to light spots A and B also apply to light spots C, D, E, and F. Such a plane is depicted in Fig. 2 as a slanted circle.

The above analysis was done by using geometric points in the Cartesian coordinate system. Physically, the light points are on the surface of actual Pole A and Pole B, so the scope in which both the mirror and direct images can be caught by the camera would be limited. Also, if both the light spots A and B are on one object, such as a plate or human face, the camera cannot take the face side surface when x (B) is smaller than x (A). Therefore, as long as one solid object, such as a human body or face, it can be said that the camera cannot take both the mirror and direct image of one side of an object in the condition without the mirror reversal. Figure 5 and Figure 6 show situations that were photographed to verify the above analysis.

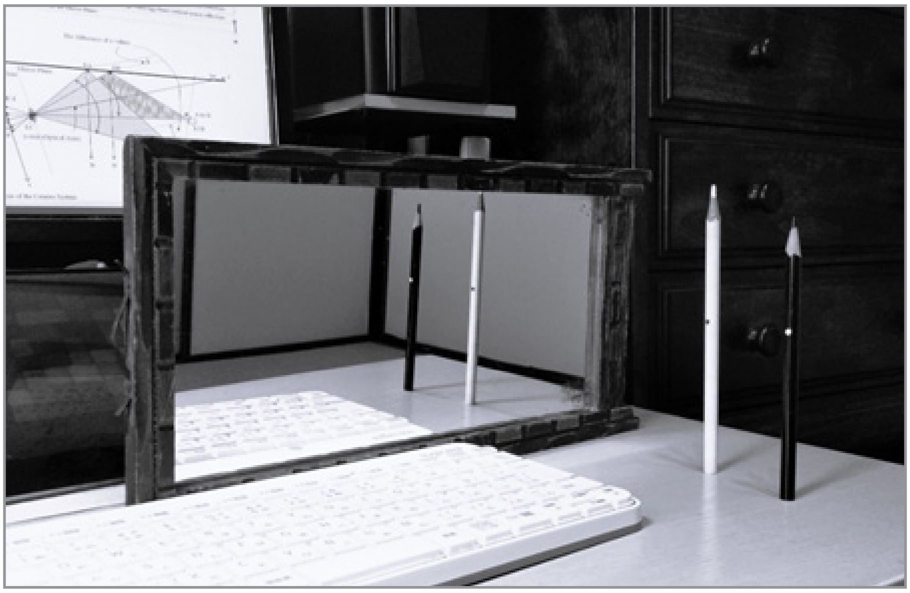

Figure 5: Photographed mirror images and direct images of a white dot on the surface of a black pencil and a black dot on the surface of a white pencil. Mirror reversal is indicated in the positions of dots and pencils.

Figure 6: Photographed mirror images and direct images of a white dot on the surface of a black pencil and a black dot on the surface of a white pencil. Mirror reversal is not indicated in the positions of dots and pencils.

It should be noted that, in Figure 6, mirror reversal is not observed for the positions of pencils and dots on the pencils, but for each pencil, mirror reversal is indicated, though exactly the same surfaces of the pencils are not taken by the photo.

Results

The Result of Purely Physical Processes of the Mirror Reversal
When a camera can take mirror images and direct images of two light points simultaneously in its image plane, in which case, the camera's image plane is not parallel to the mirror surface, the mirror reversal arises as follows: Relative positions of real images of the two light points formed on the image plane of a camera reverse each other in the line (x-axis) perpendicular to the line (z-axis) that is perpendicular to the normal line of the mirror surface on the image plane. In the above condition, when such two light points are on the surface of one object, the reverse arises inevitably as long as such images are caught on the same image plane. However, when such two light points are on surfaces of separate objects, there should be a range in which the reversal does not arise, as indicated in Figure 4 and Figure 6. The condition and range in which the reversal does not occur can be determined on the xy-plane of the coordinate system defined in Chapter 3.1 by plotting points.

When the camera cannot take a direct image with the mirror image in one image plane, including when the image plane and mirror plane are parallel, the camera must move and rotate to some extent to catch the image of the object directly. However, the direction to move and the axis around which to rotate cannot be determined physically. In order to do so, any human factor is needed. However, the nature of the mirror image when the camera cannot take a direct image with the mirror image in one image plane, cannot differ from that when the camera can take both images in one image plane simultaneously, so it cannot be denied that the physical optical process is involved in the mirror reversal phenomenon as the cognitive phenomenon.

Verification

The verification of the above result can be done using photographs, as seen in Figure 5 and Figure 6. We can find photographs that can verify the above results and considerations in various places. Generally, photos are taken without using mirror reflection, except for the camera's inner mechanism, but when any mirror on the wall is included in the scene, it is generally said that the image within the mirror in the scene taken on the film is right-left reversed, for example, the dial plate of the clock, or displayed letters. When physically expressed, the right-left reversal above is expressed as a lateral or horizontal reversal on the photo paper. Mirrors and cameras are both vertical to the ground in these cases. Therefore, the z-axis of the camera is parallel to the mirror and perpendicular to the normal line, so the reversal should arise along the x-axis according to the result written in 4.1 above. The x-axis of the camera corresponds to the observer's right-left, so the above result in 4.1 is verified in these cases. On the other hand, horizontal reflecting surfaces such as the water surface are often photographed in the scenery. In such cases, both the direct image and mirror image of the object have been taken generally, and the direct and mirror images are vertically reversed each other. In this case, the horizontal axis of the film is parallel to the mirror surface, so perpendicular to the normal line. Therefore, the x-axis in which the reversal arises should be vertical in the photo paper, which coincides with the top-bottom of the viewer's top-bottom. Thus, the above can be verified. When the camera's film (image plane) is parallel to the mirror plane, both x- and z- axes are perpendicular to the normal line, and the direct image cannot be taken in the image plane, so objective comparing cannot be made, and the verification is outside of the physical process.

There should have been many photos that illustrated such mirror reversal. Why could such theories as above that insist optics is irrelevant to mirror reversal be presented? It must be because directional notions of top-bottom, front-back, and right-left could not be eliminated in the physical process in previous theories. For example, Ittelson et al. (1991) [9] used photos in their paper, but they explained the situation in the photo using directional notions such as top- bottom, front-back, and right-left of each item seen in the photo. However, the top-bottom, front-back, and right-left of such individual items have physically no meaning. Thus, thus far, photography has not functioned as a tool to analyze the mirror reversal physically.

Application of the Purely Physical Processes to the Cognitive Processes of the Mirror Reversal

The mirror reversal phenomenon itself is a cognitive phenomenon, although the cause should be physical, so the physical process must be applied to the cognitive process. Then, what is the connecting point or boundary between both processes? It should be the real image. The real image consists of physical light points. On the other hand, any image is the content of the recognition. The real image can be considered a dual physical and cognitive existence in optics. In the problem, the real image is no other than the retinal image in the human eye, which is integrated into the human body's functions. The factor relevant to the human body can be mentioned as the human factor.

Integrating the Human Factor and Physical Process Into the Cognitive Process

The human factor can be applied to the physical process as the initial condition. It is clear that the above camera can represent the human eye. The y-axis should be the optical axis of the crystalline lens; thus, it agrees with the front-back axis of the human eye and roughly of the head and upper body. Also, the front-back applying to the plus-minus of the y-axis is fixed. However, the right-left and top-bottom axes cannot be fixed to x- or z-axes. In addition, the right-left and top-bottom axes have polarity. Therefore, there are four types of application of the three-dimensional space of top-bottom, front-back, and right-left axes in which the front- back axis is fixed to the y-axis, but the top-bottom and right-left can rotate around the y-axis to meet the x-- or y-axes with each polarity.

In typical day life, mirror surfaces are vertical to the ground, like the wall mirror, or horizontal, like the water surface, and the human head is virtually vertical in both conditions. Thus, when the mirror is on the wall, the z-axis typically represents the vertical line of the human head because the normal line is horizontal, so when the mirror is vertical to the ground, the x-axis represents the right-left line of the head, which is vertical to the top-bottom axis and is not the front-back axis, and the mirror reversal arises in the right-left. Also, when the mirror surface is horizontal to the ground, like the water surface, the normal line is vertical to the ground, so the z-axis is horizontal, and the x-axis represents the top-bottom line of the head, and the reversal occurs in the top-bottom line of the head. In both cases above, the reversal occurs along the observer's right-left or top-bottom.

Thus, the mirror reversal as a cognitive phenomenon has been roughly but firmly explained by adding the human body factor to the physical processes as the initial condition.

Limitations of the Physical Analysis in the Mirror Reversal Phenomenon

Applying the physical analysis to the mirror reversal without initial conditions is impossible. Furthermore, the above resolution in the previous section cannot wholly answer the mirror reversal question. Another problem in integrating the human factor is that the image plane of the camera is two-dimensional and represented two-dimensional by the x- and z-axes. On the other hand, in human cognition, any perceived image has three dimensions and is perceived by directional notions of top/bottom, front/back (face/back), and right/left, even when the perceived image is two-dimensional. Moreover, those directional notions are applied to both the observer and perceived image of the object separately, and each perceived image has independently defined directional notions, which are sometimes represented as top/bottom, front/back, and right/left like the human body. This means that only the physical process cannot explain the mirror reversal phenomenon as a whole, but I think the following principle has been proven in the above analyses and considerations: The Cartesian coordinate system cannot be used for describing and analyzing the space represented by directional notions of top-bottom, front-back, and right-left. This problem will be discussed in the next chapter.

Discussion

Significance of Two Factors Excluded from the Physical Analysis

In the analysis of the purely physical processes, I excluded two kinds of means of analysis. One is the virtual image, and the other is the directional notion, such as top-bottom, front- back, and right-left. However, in order to analyze the mirror problem totally, the above two factors are inevitable. For the former, it is because virtually everyone, including scientists, has mentioned or analyzed the mirror reversal based on mirror symmetry or enantiomorphism, which are identical to the geometric drawing of the virtual image thus far. For the latter, as a cognitive phenomenon, mirror reversal is defined as the reversal of top-bottom, front-back, or right-left. Therefore, I introduced these directional notions in applying the physical process to the cognitive process. Thus, we must consider the significance of these two factors.

The virtual image is not any physical existence. Then, to what category does it belong? As the optical concept, the virtual image can be described as a supposed object that can be depicted in the optical ray diagram as if it can be seen by the eye, which is also in the same optical ray diagram. In the ray diagram, it is geometrically drawn, corresponding to the real image formed in the eye. Therefore, it is no other than a geometric drawing, so it is the product of geometric thinking, which can be included in the cognitive process but differs from perceptual processes. Perceptual processes should be, unlike the cognitive process, linked to the sense organ, the eye in this case. Thus, perceptual processes are directly linked to the physical process, but thinking processes are not linked directly to any sensation.

Therefore, the difference between thinking and perception is represented in the difference between the virtual and perceived images. The fundamental difference between them is that thinking is objective, but perceiving is subjective.

Virtual Object as the Result of Mirror Recognition

I wrote that the mirror symmetry or enantiomorphism of the pair of the object and its mirror image represent the universal condition of the mirror reversal in my previous works [10-12]. The virtual image is the objective and geometric representation of what the observer can perceive, so it is different from what is perceived by any observer, in other words, the content of the perception. If we redefine the virtual image as a "virtual object," the virtual object can be supposed to be seen from any viewpoint. Therefore, it can be thought of as a virtual object rather than a virtual image. When the observer cannot notice the presence of the mirror, the observer cannot distinguish it from a real object. Therefore, the virtual image must be considered as something that contains not only physical processes but also cognitive processes so long as it can be distinguished from the real object. When the virtual image is any mirror image, the pair of the mirror image and object can be recognized as two separate objects. In this situation, the mirror surface is recognized, and the one object beyond the mirror surface is recognized as a virtual existence; the recognition of the recognizer has been defined as mirror recognition. Thus, mirror symmetry and enantiomorphism as the geometric condition of the virtual image in mirror optics are relevant to and are the product of mirror recognition. The observer can recognize mirror symmetry and, or enantiomorphism to some extent. Therefore, the mirror recognition process must be considered to explain the mirror reversal process as a whole.

The mirror recognition process is relevant to the positions of the images and not to the features of the image itself, such as the shape and color, which are relevant to perception through sensation. On the other hand, the mirror reversal concerns the shape of images as the nature of images and not the positions of images, and the condition of mirror symmetry is not directly relevant. The concept of mirror symmetry is objective and allows any viewpoint of the observer, but the viewpoint of the observer is only one, and the perception is subjective. Thus, the mirror symmetry itself cannot be the basis of the mirror reversal specifically recognized by any observer, but it provides the ground for the enantiomorphism of the pair, which is relevant to the cognitive process of the mirror reversal. However, it is irrelevant to the physical processes.

Applying the Concept of Isotropic Space and Anisotropic Space to the Analysis

Both the physical process and mirror recognition process are geometrically analyzed, so as long as we think within the geometric concept, the reversal can be only relatively defined, and the top-bottom and right-left cannot be allowed in the geometric concept. On the other hand, we have to describe the process using directional notions of top-bottom, front-back, and right-left. In order to apply the physical process determined in this study to the perceived mirror reversal, we have to replace the camera with the observer's eye, which has directional notions of top-bottom, front-back, and right-left, as described above. In the replacing process, there is no physical inevitability in applying which of the top, bottom, front, back, right, and left to plus or minus directions of one of the three axes in the Cartesian coordinate system. This means that the geometric space represented the Cartesian coordinate system and the perceptual space indicated by directional notions of top-bottom, front-back, and right-left are fundamentally different from each other, and the intervention of the human body and mind must exist, and the perceptual space is not represented by the Cartesian coordinate system.

For the application of the mirror recognition process to the mirror reversal, I studied and published in my previous works: Tanaka, J. (2021, 2022, and 2024) [10-12], the main title of which is "Concept of the Isotropic Space and Anisotropic Space as Principal Methodology to Investigate the Visual Recognition."

I learned about the concept of isotropic space and anisotropic space from E. Mach (1905, 1918) [13,14] and E. Cassirer (1925) [15] in the Japanese translation. This concept can be applied to the mirror reversal problem and mirror recognition straight. I excluded directional notions of top/bottom, front/back, and right/left, which are anisotropic, from the analysis of the physical process because the physical process had to be analyzed geometrically by using the Cartesian coordinate system, which represents the isotropic geometric space. Figure 7 below illustrates the whole process, which schematically includes mirror recognition and mirror reversal processes.

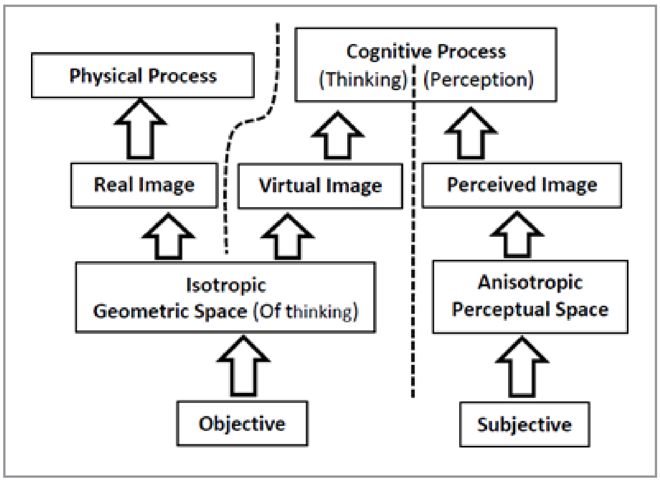

Figure 7: Schematic illustration of conceptual relations of factors and their nature concerning the physical and cognitive processes in the mirror recognition and mirror reversal phenomenon.

In previous papers mentioned above [10-12], the mirror problem is comprehensively analyzed and described from both physical and cognitive aspects. However, those are rather eclectic in a combination of physical and human factors, so physical processes lacked some preciseness. Therefore, this study analyzed the purely physical process precisely and clarified the boundary. In those papers, I introduced the concept of the M-D-Rotation. The term M-D- Rotation as the physical explanation might be inappropriate; however, even when both the mirror image and direct image can be taken in the image plane at a time, the rotation of the optical axis (z-axis) should be needed in order to take the direct image of the same face of the object as the mirror image. Thus, the term M-D-Rotation would be conveniently adopted. We must notice that cameras or physical human eyes cannot reverse in one direction without rotation. Therefore, the rotating mechanism and the selection of the rotating axis should be the decisive human factor. Such rotation can be performed mentally, so a space that can be mentally rotated can be supposed to be. Such space cannot be reversed in any applied axis, and such axes cannot be exchanged (Both are able in the Cartesian coordinate system). It is not in the scope of this study to describe comprehensively those two contrasting spaces in the mirror problem, including the mirror recognition problem. For reference, Table 3 below roughly shows the concept gained by the previous study.

Table 3: Conditional Cognitive Spaces relating to mirror-related problems

Conditional Cognitive Spaces	Isotropic/Anisotropic
Visual Space	Anisotropic (Perceptual)
Partial Space Occupied by an Image	Anisotropic (Perceptual)
Space of Mirror Recognition	Isotropic (Thinking)
Space of Optical System	Isotropic (Thinking)
Space of Free Comparison	Isotropic (Thinking)

In this table, only "Space of Optical System" is purely physical and isotropic, though it cannot exist without supposing the perceived space. In my previous works above, the "Space of Optical System" in this table was written as "Space of Optical Real Image."

Conclusion

This study resolved the optical and physical mechanism of the mirror reversal when both the mirror image and direct image of the same object can be caught on the image plane of the mechanical camera. The mechanism of the image forming on the image plane of the camera of the mirror image and direct image does not differ when both the mirror image and direct image can be caught on one image plane and when both mirror image and direct image cannot be caught on one image plane. Therefore, the optical and physical processes must be involved also when both mirror and direct images of one object cannot be caught simultaneously in one image plane. The difference between those two situations is that the positions of the camera differ between when catching the mirror image and when catching the direct image when both the mirror and direct cannot caught in one image plane. Therefore, the camera must move and or rotate. The rotation axis and direction of the moving is brought by the human factor.

The above analysis was performed based on the real image formed in the camera and human eye. We do not view the real image formed on the retina from the outside; we perceive the object as the visual image through the real image formed in the eye. In other words, the perceived image is within the anisotropic space, whereas the real image formed in the eye is in the isotropic space. Nevertheless, relative differences between two real images formed on the retina can be perceived in the anisotropic space. Thus, the function of the specular reflection of the mirror as the cause of the mirror reversal has been verified.

A significant reason why the question of the mirror reversal phenomenon has not been resolved until now is that many people, including scientists, tend to think of the problem by considering the virtual image as if it were a physical existence. For example, Ittelson et al. (1991) [9] say, "Gardner (1964) clearly answers the physical question by showing that a mirror optically reverses the axis perpendicular to it." Gardner (1964) [5] himself says, "A mirror, as you face it, shows absolutely no preference for left and right as against up and down. It does reverse the structure of a figure, point for point, along the axis perpendicular to the mirror." Gardner's answer can be, in fact, geometrical, but it is not physical because it is based on the virtual image, which is not physical existence. The virtual image is a geometric product, but geometry is not only relevant to physical existence but also to non-physical existence, such as the virtual image in optics. Haig (1993) [8] seems to have used only apparently the physical method or concept, but he omitted the needed, indispensable physical factor, the physical structure of the human eye. On the other hand, some scientists, especially psychologists, denied the involvement of the physical factor in at least some instances. The reason would be that the optical mechanism had not yet been analyzed enough despite it being evident to be the cause of the mirror reversal.

Another significant reason for the above should be that directional words or notions such as top-bottom, front-back, and right-left have been used in geometric analyses. Authors of papers that explain mirror reversal based on enantiomorphism noticed the difference between the right- left axis and the other two axes. Corballis (2000) [6] and Tabata (2000) [7] noticed the precedence of top-bottom and front-back in the definition or establishment of those three axes of objects. However, they did not notice the observer's eye and its top-bottom, front-back, and right-left, and perceptual space, which is anisotropic.

Not a few other physical scientists, including famous Nobel laureate theoretical physicists such as R. Feynman and S. Tomonaga, have been explaining or considering the problem. Shin'ichiro Tomonaga (1965) [16] wrote in his book entitled "The World in a Mirror" that the typical right-left mirror reversal, as well as non-right-left reversal, cannot be explained by means of geometric optics purely. This idea should be correct because right-left, as well as top- bottom and front-back, are not relevant to the isotropic, geometric space. However, the mechanism of geometric optics as the decisive physical cause of mirror reversal can be explained within the physical concept when the concepts of top-bottom, front-back, and right- left are eliminated, as shown in this study, though physically and geometrically, directions can be only relatively defined. S. Tomonaga (1965) [16] also suggested that the concept of "psychological space" is relevant to the nature of the top-bottom and front-back. His idea of "psychological space" seems close to the concept of anisotropic perceptual space by E. Mach (1905, 1918) [13,14] and E. Cassirer (1925) [15]. However, from the concept of the isotropic and anisotropic spaces, right-left, not only top-bottom and front-back, are equally attributed to the anisotropic space, as E. Mach (1905, 1918) [13,14] states.

The author thinks this study clarified the importance of demarcating the boundary between physical and non-physical factors.

Acknowledgement

I am grateful to Tatsuo Tabata, the emeritus professor of Osaka Prefecture University, who introduced the problem to the author and has aided the author from the beginning to now in studying the problem, including offering recommendations and literature despite some deviance in the theory of the author from his papers.

Disclosures

The author declares no conflicts of interest.

References

1. Gregory, R. L. (1987). Mirror reversal. In R. L. Gregory (Ed.), The Oxford companion to the mind (pp. 491–493). Oxford University Press.
2. Takano, Y. (1998). Why does a mirror image look left–right reversed? A hypothesis of multiple processes. Psychonomic Bulletin & Review, 5(1), 37–55. https://doi.org/10.3758/BF03209456
3. Takano, Y. (2013). Mirror reversal of slanted objects: A psycho-optic explanation. Philosophical Psychology, 28, 240–259.
4. Bianchi, I., & Savardi, U. (2008). The relationship perceived between the real body and the mirror image. Perception, 37, 666–687. https://doi.org/10.1068/p5744

5. Gardner, M. (1964). The new ambidextrous universe. Basic Books.
6. Corvallis, M. C. (2000). Much ado about mirrors. Psychonomic Bulletin & Review, 7(1), 163–169.
7. Tabata, T., & Okuda, S. (2000). Mirror reversal simply explained without recourse to psychological process. Psychonomic Bulletin & Review, 7(1), 170–173.
8. Haig, N. D. (1993). Reflections on inversion and reversion. Perception, 22, 863–868.
9. Ittelson, W. H., Mowafy, L., & Magid, D. (1991). The perception of mirror-reflected objects. Perception, 20, 567–598.
10. Tanaka, J. (2021). Concept of the isotropic space and anisotropic space as principal methodology to investigate the visual recognition. PhilSci Archive. http://philsci-archive.pitt.edu/19392/
11. Tanaka, J. (2022). Resolution of the mirror problem. LAP LAMBERT Academic Publishing.
12. Tanaka, J. (2024). Isotropic and anisotropic spaces in visual recognition: Analysis and resolution of mirror problem [Kindle edition]. Independently published.
13. Mach, E. (1905). Erkenntnis und Irrtum: Skizzen [Knowledge and error: Sketches]. J. A. Barth.
14. Mach, E. (1918). Die Analyse der Empfindungen und das Verhältnis des Physischen zum Psychischen (G. Sudo & W. Hiromatsu, Trans.). Hosei University Press. (Original work published 1918)
15. Cassirer, E. (1955). The philosophy of symbolic forms: Volume 2, Mythical thought (R. Manheim, Trans.). Yale University Press.
16. Tomonaga, S. (1965). The world in a mirror. Misuzu Shobo.