

Righi's Polystereoscope as a Teaching Device

Materialisation of a New Understanding of Human Vision?*

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The Polystereoscope on the model of the Italian Physicist Augusto Righi (1850–1920) as it is on display in the Museo Giovanni Poleni in Padua today became an object of interest to me when I tried to further understand the physiology of human vision. This particular object is not just one apparatus but three devices merged in a combined setup, which can easily be changed into any of three possible configurations by rotating a rigid arm with two mirrors.^{1, 2} Interestingly enough, a second very similar device is on display in the cabinet of the Institute of Astronomy and Physics in Bologna, a university, at which Righi took up a post as a professor in 1889 when he left Padua.³ Both setups were introduced to me by my hosts as teaching devices for university lectures. But there were immediately identifiable differences, albeit only a few minor ones. Did the character of the polystereoscope change or did it work the same way? For the purposes of analysis in my paper I focus on the slightly older version available in Padua and use this setup as a reference for the development which obviously took place.

The polystereoscope was added to the collection of the University of Padua in 1889, shortly before Augusto Righi left to accept a professorship in his birth town Bologna. The Padua instrument was manufactured by the university's technician Cagnato. A brass plaque is mounted onto the mirror mount's stand to commemorate his effort. It was not too long before, that Cagnato took up a permanent position as the university technician responsible to maintain the collection of instruments. Until then the University used the city's craftsmen to build new instruments or repair the old ones if needed. Cagnato, having been one of these contractors, worked his way up and became the university's mechanic in 1881.⁴ This cannot come as a surprise because Righi's predecessors as the professor of physics in Padua founded and extended the university's collection from 1600 instruments in 1872 to approximately 2200 setups and demonstration devices. For all these devices to be ready for the lectures, a university technician was needed to service the setups after lectures.

In building up such a numerous collection, the University of Padua was following a trend which involved experiments and demonstration devices to an increasing extent into teaching. This happened not only at university level but also in secondary schools, depending on the particular aims of the lessons.⁵ They may have been optimised demonstration devices providing a certain result as an illustration of



Fig. 1 The Polystereoscope on the model of Augusto Righi in the configuration for telestereoscopic observation, currently on display at the Museo Giovanni Poleni in Padua. The instrument's image in the background is taken from a summarising short paper, published by Righi in 1893.⁶ Credits © 2024 Andreas Junk, Europa-Universität Flensburg.

a well-known law or might have been non-stabilised versions which allowed learning effects pertaining to the measurement process. With these differences the experimentation process also was very much variable: the former type was suitable to be used in front of an audience which then was presented with a result whereas the latter led to own results and experiences which in turn needed further discussion to clarify what actually has been measured or even been seen. The stabilisation of the key findings was to be gained in discussions, hence by means of a social approach.

This presents me with two questions:

1) The polystereoscope is an observational instrument, the result is a personal perception of a situation observed or displayed to the instrument's operator. How do you describe to a third person, what you have possibly seen, when you are in the process of learning what the differences in the imagery are?

2) How can then the setup called polystereoscope, as it was devised by Righi in 1889, be an effective teaching instrument?

The Object of Interest: Righi's Polystereoscope on Display in Padua

The Polystereoscope can be seen in Fig. 1. It has a wooden baseplate with a width of 27 cm and a breadth of 17 cm. The mounting of

the rotatable mirror arm, which in turn has a width of 28 cm, makes the instrument 30 cm tall, when in the telestereoscopic or pseudoscopic configuration.

The operator would be sitting behind the instrument as it is displayed above and the operation to execute is to rotate the arm with the mirrors so that one perceives a comprehensive impression of one's environment by direct observation. Alternatively, you could use two stereoscopic images which had to be held into the respective lines of sight for the left and right eye. Whilst the left eye in this setup always has a direct line of sight the retinal image of the right eye is provided by reflection from the two mirrors.

There are three distinct configurations which characterise the impression one would have if the instrument is used to observe any situation. The first would be the one in Fig. 2, where the mirror arm extends the line of sight for the spectator's right eye farther to the right whereas the left eye's line of sight is not altered. This configuration is the telestereoscopic one as it follows Helmholtz's principle of extending the baseline between the left and right eye which Helmholtz used in the two telestereoscopes he constructed from 1857 onwards.⁷

The second setup is the one where the mirror



Fig. 2 The Setup, where the big mirror of the mirror arm is in a position to the right of the right eye is called telestereoscopic. The perception of spatial effects is enhanced compared to observations with the naked eye. Credits © 2024 Andreas Junk, reconstruction of the Padua polystereoscope at the Europa-Universität Flensburg.

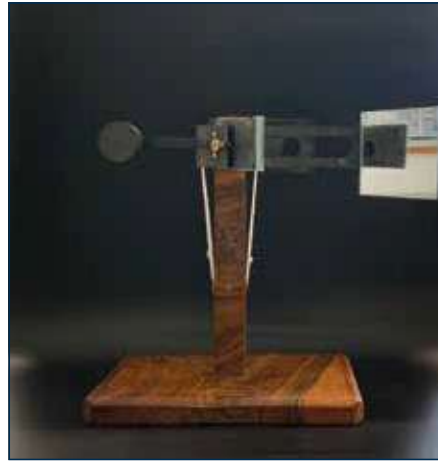


Fig. 3 In the pseudoscopic setup, the retinal image for the right eye comes from a position farther left than the one of the left eye. The spatial impression and interpretation of objects at different distances to the observer are swapped – nearer becomes farther away and vice versa! Credits © 2024 Andreas Junk, reconstruction of the Padua polystereoscope at the Europa-Universität Flensburg.



Fig. 4 The iconoscopic setup is supposed to annihilate all spatial perceptions by placing the mirror directly on top of the sighting hole for the left eye's image. Hence all parallax shifts should be reduced to zero and our brain could not make any spatial interpretations whatsoever! Credits © 2024 Andreas Junk, reconstruction of the Padua polystereoscope at the Europa-Universität Flensburg.

arm is rotated so that the bigger mirror is on the other side and above all to the left from the spectator's left eye (Fig. 3). Hence the mirrors provide the left image to the right eye, while the left eye sees the right image. This setup is called pseudoscopic configuration. The perceived imagery still seems natural, but distance relations between certain objects are inverted, i.e. if an object A is nearer to the spectator compared to an object B, then the

perceived reality is swapped and B seems to be nearer to the observer's position. This is due to the relative shifts of the objects in the retinal images. The extent of disparity between the positions gives us an estimate for the relative distance.

The third setup is what Righi calls iconoscope (on Javal's model) and this one is not easy to understand (Fig. 4). The outer mirror is

brought into a position on top of the left eye's observation tube so that the lateral disparity, the so-called parallax shift, of each and every object should be the same and – what is more – identical to zero. Thus, the objects appear to be at an 'infinite' distance to the observer. To put it another way: they seem to

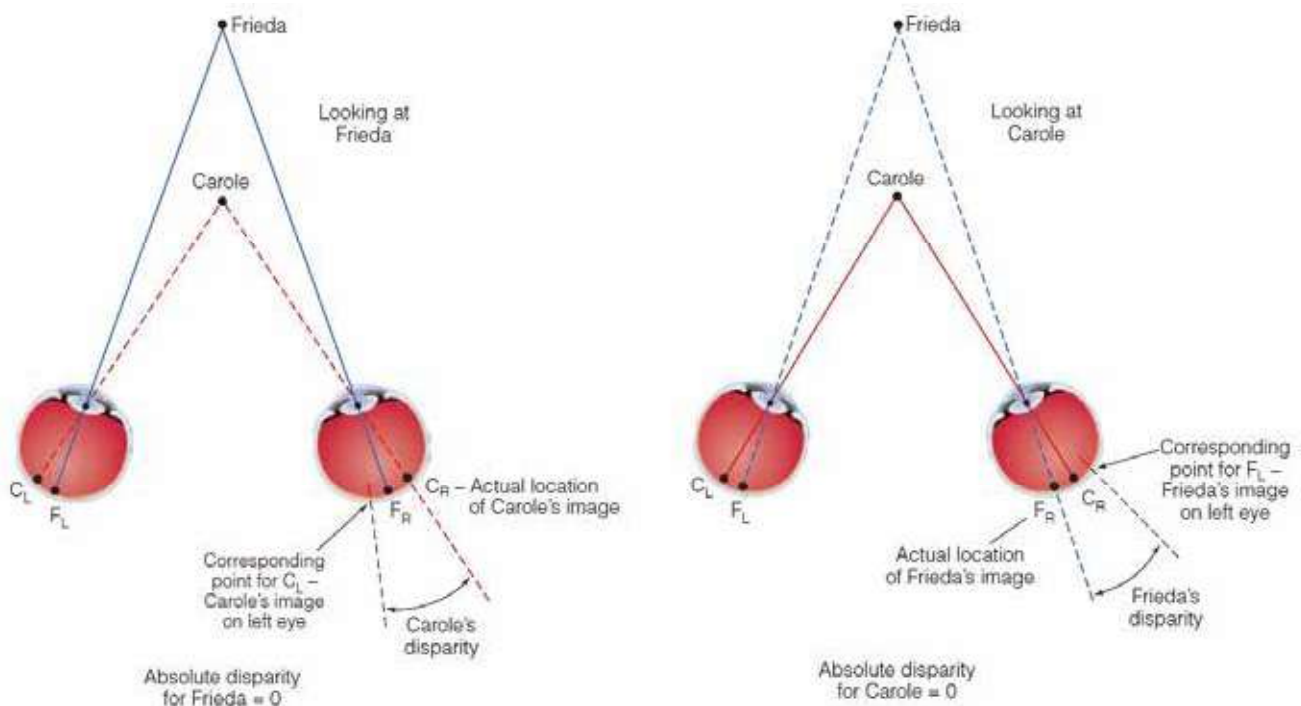


Fig. 5 Illustration of the concept of distance estimation and estimation of relative distances. When two objects are visible in an observed area, an object appears to be nearer to an observer's position, if the respective lines of sight converge harder towards the object. In terms of the retinal images this means, that if the left retinal image goes to the left and in the right retinal image to the right, then the interpretation is 'nearer'. Credits: image taken from Goldstein, Sensation and Perception, 8th edition, 2010, p. 237.

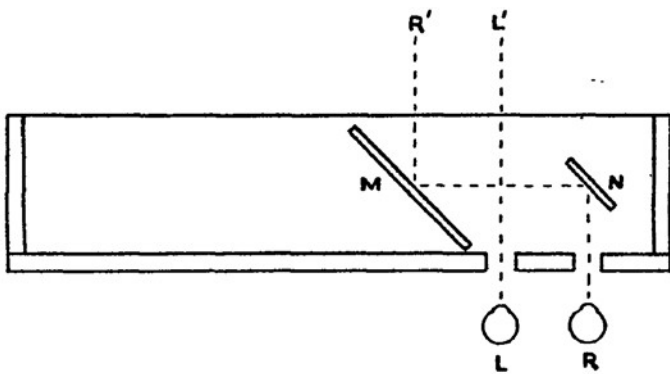


Fig. 6 Principal setup of a Stratton⁸ type pseudoscope which illustrates the image swapping process. The image for the right eye comes from a position left of the image for the left eye.⁸

be so far away, that we cannot distinguish between relative positions of any object in the field of view because of the lack of a parallax shift in the retinal images.

There were no instructions left on how to use the polystereoscope in a teaching setting at university level. Whereas the University of Padua did not seem to have any complementary material to the apparatus, there was information in Bologna, that the polystereoscope there was used together with stereoscopic images. The situation in Padua, especially to use two mirrors which were really different in size, left me to believe, that the instrument could have been used in outdoor instructions. The questions at Bologna's Institute of Physics indicated the use of the instrument in a classroom environment.

Estimating Distances: Importance of the Parallax Shift

Humans use their ability to estimate distance especially in the near field to navigate around obstacles in daily life. It is an almost innate use based on years of training caused by the minute differences in the retinal images of the left and right eye. There is a tendency that an object is interpreted to be nearer to one's

own position if the eyeballs have to converge harder towards the object, resulting in a bigger so-called opening angle at the object. The smaller the angle becomes, the farther away the object is (interpreted to be).

The process illustrated in Fig.5 uncovers one of the inherent evaluations of our physiology of vision: we interpret one object being nearer because the second object was instinctively chosen as the reference point for distance estimation. The retinal images of the reference object is then used as points of origin with which the retinal images of all other objects are compared. In Fig.6 you also see what it takes to interpret one object being nearer to oneself than another object. The nearer object's retinal image in the left eye goes to the left and in the right eye to the right. If it were to go to the right in the left eye and vice versa, then the interpretation would be farther away.

Having stated that, the instruments called pseudoscopes can become of particular interest, because these swap the retinal images. This can be achieved by a set of prisms or mirrors. Any distance evaluation would then be swapped as well, because the changes in the retinal images to the left and right are in-

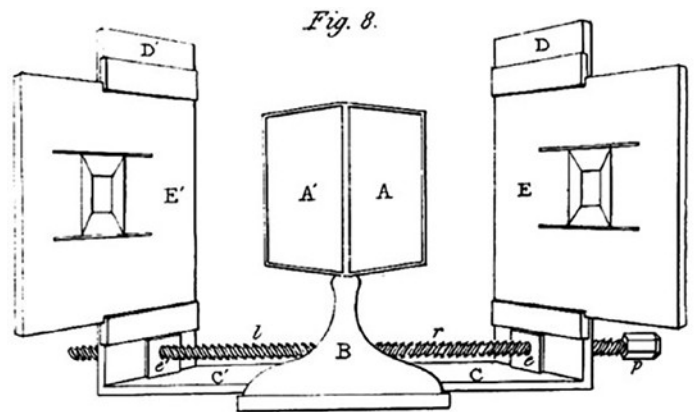


Fig. 7: Design of a mirror stereoscope by Charles Wheatstone: two carefully designed stereoscopic drawings were mounted onto the screens E and E'. A person observing the reflections of these images simultaneously in the plane mirrors at A and A' would have a spatial impression of the scene full well knowing that he was looking at two two-dimensional images. Image taken from Wheatstone1838.⁹

terchanged. Yet the situation observed would be described as perfectly natural because the proportions in the images concur with daily experiences and expectations. And now imagine there was an instrument which could demonstrate this kind of change to you by means of a smooth, continuous transition of the perceived image of any observed situation!

Precursors to the Polystereoscope and their Meaning for the Development of an Understanding of Human Vision

Two setups without which the functionality of the polystereoscope could not be as easily understood are the mirror stereoscope by Charles Wheatstone presented in 1838 and the telestereoscope as devised and built by Hermann Helmholtz in 1857.

Wheatstone's stereoscope (Fig. 7) visualised by very simple means, that the perception of a spatial environment is not formed by some reality, but by the impression of that reality perceived as the retinal images of the left and right eye.⁹ It was well known already, that the retinal images of the left and right eye for any given situation must be different from one another, if we want to have some sort of spatial impression of our environment. But the two

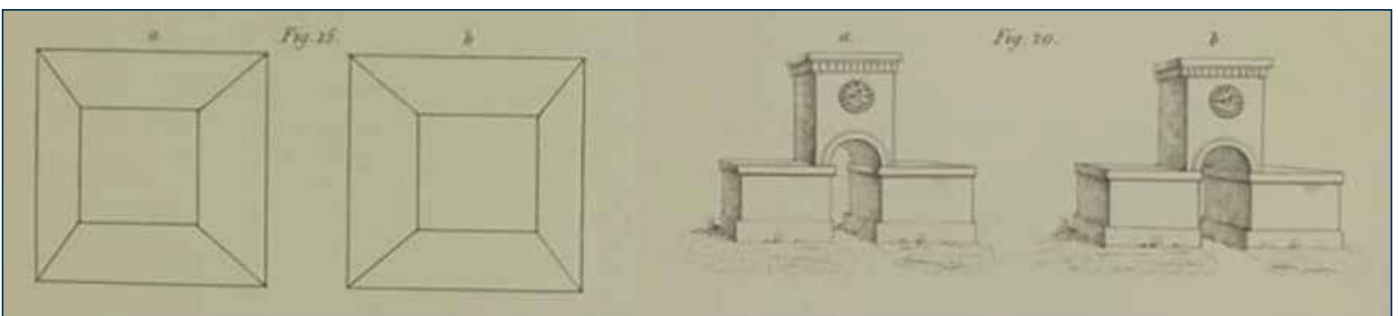


Fig. 8: Two out of 20 stereoscopic image pairs which Wheatstone had made for demonstrations sake in his stereoscope. These drawings were supposed to be mounted onto the screens on either side of the instrument and being looked at simultaneously. The pair on the left was supposed to deliver the impression of looking down a rectangular hollow tube, the right one a city gate. Images taken from Wheatstone1838.⁹

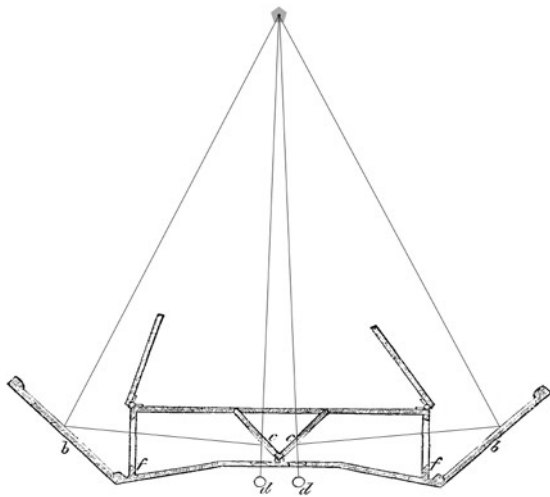


Fig. 9 Working principle of Helmholtz's telestereoscope: if the opening angle at an object (grey pentagram on top of the image) by direct observation with the eyes (at d and d') becomes too small, then the telestereoscope can enlarge the interocular distance by observation via two sets of mirrors (at b/b' and c/c'). The retinal images are provided from an extended baseline. Credits © 2024 Andreas Junk, Europa-Universität Flensburg, own image altered for illustration, based on Helmholtz 1857.

images only have very subtle shifts and this can basically best be recorded by means of photography, a technique which Wheatstone had not (yet) at his disposal.

The Fox-Talbot photographic process was not yet established and the first Daguerreotypes were only published in 1838. So, Wheatstone had handmade drawings made for the use of his stereoscope (Fig. 8). Whilst it was obvious, that these images were working nicely in the stereoscope, when a user could look at them simultaneously and also bring the images into overlap, Wheatstone already took it a step further and made a remarkable postulate on the side: if the images were to be swapped, the spatial relations of any object would be inverted, i.e. if two objects in the images could be interpreted as being nearer to the observer or farther away, the exchange of images would make the object being farther away become the one, that appears to be nearer now.

It also seems, that Wheatstone did not go into the endeavour, to prove his postulate or prove it wrong. Soon after 1838 he left the fields of optics and vision and turned to research on electricity and acoustics. It was not until 1851, when so-called pseudoscopes on the model of Wheatstone appeared on occasion of the Great Exhibition in London and even were enjoyed by Her Majesty Queen Victoria. That being said, all of the instruments mentioned so far were designed to work as stereoscopes or pseudoscopes, but not simultaneously as

one and the other. Even swapping the images on Wheatstone's 1838 model would have taken (too much) time and the observer would lose focus on whatever details he should remember.

The telestereoscope on the model of Helmholtz as he devised it in 1857 is very much a direct precursor to the realisation of the telestereoscopic setup in Righi's polystereoscope.¹⁰ Helmholtz argued, that his apparatus would overcome a specific human limitation, the angular resolution of the human eye, which was supposed to be a one arc minute, i.e. the sixtieth part of one degree (Fig. 9). If a human focusses an object at big distances and the triangle between the left eye's pupil, the right eye's pupil and the object has an opening angle of less than one arc minute, then a spatial interpretation would not be possible anymore. To put this in numbers, a human with an interocular distance of 68 mm (supposedly and allegedly an average for humans) would be able to make spatial interpretations at distances up to 234 metres. If the interocular distance, the so-called baseline, is enhanced, then the angle at the object becomes bigger again and it should be easier to make interpretations such as nearer and farther away.

You could go for another extreme instead by going to observe objects, which have been far beyond the aforementioned 234 metres – and this is what Helmholtz did and wanted to show. He looked at object in distances of one or two kilometres and had good spatial

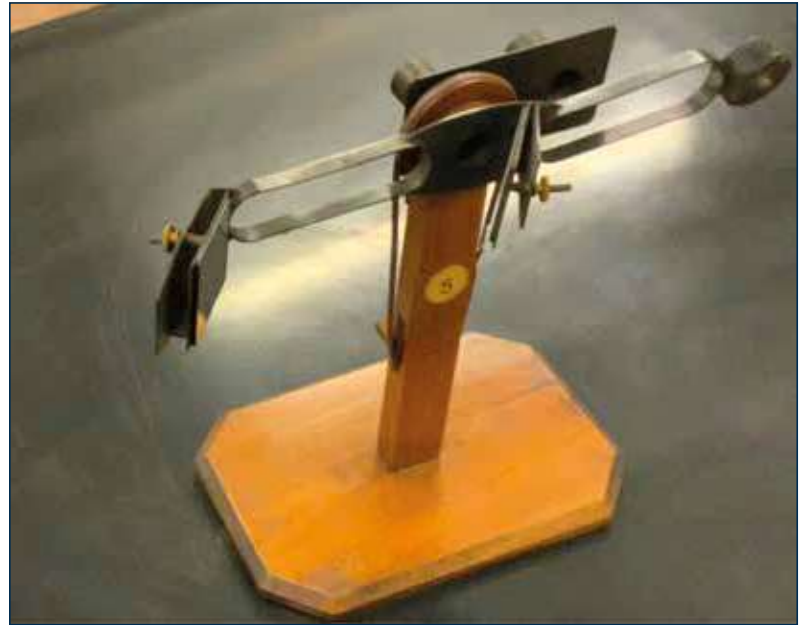


Fig. 10 Detail of the Bologna apparatus, compared to the one in Padua: the arm holding the counterweight to the right is now a metallic tape not anymore obstructing the line of sight for the left eye! Credits © 2024 Andreas Junk, Europa-Universität Flensburg.

impressions of an observed landscape, in his test scenario an area in the mountains. Whilst the impression at far distances was very much natural to him and what he would expect to experience in his daily life without any optical apparatus, the spatial distortion in the near field using the telestereoscope was pretty extreme and strenuous to bear. Enhancing the baseline from 68 mm to 1020 mm as Helmholtz realised it with his telestereoscope was only called for observations in the far field. Making experiences in the near field required not much more than doubling or tripling the baseline, pretty much the dimensions of the telestereoscopic setup in the apparatus devised by Righi!

Comparison Between the Devices in Padua and Bologna

The devices in Padua and Bologna (Fig. 10) have of course a lot in common, the exterior measurements of the baseplate and the instrument's height are very much alike. The materiality of both devices are also directly comparable, there are basically two distinct differences, which make the impression of improvements made by an engineer, not necessarily a physicist. The first is the substitution of the arm holding the counterweight and its replacement by a metallic band. The mount of the now smaller counterweight changes accordingly. This improvement effects, that the counterweight arm does not obstruct the line of sight of the left eye, when the polystereoscope is in the telestereoscopic configuration.

This alteration did not seem to be necessary, because the mounting arm in the Padua instrument did not give an observer real trouble, either because the eye ignored the obstacle in the near field when focusing in the far field or because the arm could be tilted slightly upwards or downwards. The second change to the apparatus could indicate a tremendous change in the teaching concept though.

The outer mirror of the Bologna instrument is significantly smaller than in the precursor from Padua, the mirror area being reduced by some 50%. This would not matter much, if you thought about the human line of sight in terms of a singular light ray, but that is just plain wrong. The human eye is constantly moving, changing its momentary direction of observation and hence scans an area around a targeted object. If we consider now, that two mirrors are used to extend the baseline, the deviation in the observational direction might lead to missing a second small mirror by a lot. The immediate effect on any observation is illustrated in Fig. 11 below. If the right eye's image is only reflected in parts (red box), but the left eye's image seen in full, then the stereoscopic perception is reduced to the area of the red box as well.

The solution to this problem made it a necessity to work with carefully designed images. The Bologna setup had been improved in a way, that direct observation of your environment with this instrument is not feasible anymore. Only with a set of drawings with a very much uniform background (most certainly a blank background) outside the area of overlap the instrument could still work. This would also mean, that the drawing or photographs to be used were pretty small and had to be held close to the apparatus.

At this point I am convinced, that Righi wanted to have an apparatus at hand with which he could show, that the spatial impression could be enhanced by means of a telestereoscope which then could be annihilated by smoothly changing the setup into the iconoscopic configuration and make the three-dimensional effects visible again with the pseudoscope only

that the spatial relations in the image were all swapped.

From experiences made with replicas at the Europa-Universität Flensburg I am able to say, that the use of a telestereoscope would easily provide results even to an untrained observer. The iconoscopic setup is pretty tricky and does not provide a stable effect of the annihilation of all spatial perception effects. There still is some sort of parallaxic displacement in the image, but it is vertically aligned and our eyes usually are not. You would almost instantly regain a three-dimensional impression, if you tilt your head by 90 degrees or make a misalignment of the mirror arm! The pseudoscopic configuration should only give results after a good amount of training your sights with stereoscopic or pseudoscopic imagery. It is possible to achieve a certain ability to 'see pseudoscopic', but our eyes tend to do this rather in highly symmetrical bodies (e.g. cubes or rods). Teaching with the polystereoscope cannot have been an easy task, because the learning progress for untrained users favours the effects of the telestereoscopic sights over pseudoscopic and above all iconoscopic. Looking at the setups, I believe now that the Bologna apparatus has been an alteration very much designed for classroom scenarios. The Padua instrument rather displays an experimental approach testing out the limitations of the instrument, regarding dimensions of the mirrors and also the diameter of the sighting tubes. Its setup is very close to Helmholtz's early development of the large telestereoscope. It might have been used for observations at distances of several tens of metres, but the lack of recognisable details could have made instructions very difficult – especially when one takes into account, that all observations by students and their instructors were individual experiences, which had to be verbalized for a concise teaching process.

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this dive into the world of a not-so-easy-to-understand device.

Keywords: *stereoscope, Charles Wheatstone, Hermann Helmholtz, physiology of vision, optical instruments, parallaxic shift.*

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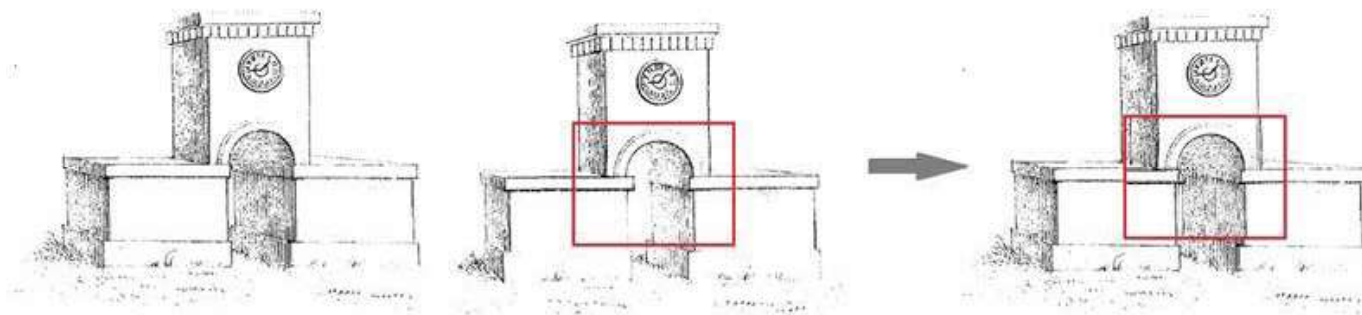


Fig. 11 Principle of the area of overlap for the design of the Bologna apparatus: the outward mirror is only able to reflect a small part of the observable area. The left eye's image (left part) and the right eye's image (centre) can only produce a stereoscopic effect in the small area of overlap, which is as big as the part reflected into the right eye by the mirrors. The stereoscopic perception should not be possible, if the images are bigger than the reflected area indicated by the red box. Credits © 2024 Andreas Junk, Europa-Universität Flensburg, own image altered for illustration, based on Wheatstone 1838.