Translation of the article

"Zentrierung von Brillengläsern mit prismatischer Wirkung"

which was published in Deutsche Optikerzeitung: DOZ 1989 No. 9, page 9-16

Explanatory note: For the sake of convenience the German abbreviation dpt is used for dioptre instead of D and cm/m for prism dioptre.

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Centering of spectacle lenses with prismatic power*

Contents

* According to a lecture at WVAO-Congress 1989 in Baden-Baden

1 Basic Principles

1.1 Concepts

The ophthalmic optics technical committee of DIN (German institution for standardization) terminated a new version of DIN 58208 "Concepts and symbols for spectacle lenses in connection with the human eye", which contains a consistent terminology with reference to shape and power of spectacle lenses (see [1]). According to this DIN an adjective in front of the word spectacle lens always denotes the shape of the lens and not the power, which will be mentioned after the description of the form, for instance "aspheric lens with spherical vertex power".

Accordingly the present article is about spectacle lenses with prismatic power, meaning lenses with a prismatic power in the reference point in addition to a possible spherical or astigmatic power.

With a binocular fullcorrection the goal is reached of bicentral image formation of the fixation point while the eyes are in their vergence rest position. As a rule the determination of this rest position is performed with the aid of trial lenses with prismatic power. A binocular-prismatic effect in the visual points of a pair of lenses changes the orthoposition which is the vergence position necessary for a bicentral image formation of the fixation point. This consequence is shown in figure 1 for prisms with temporal and with nasal base position.

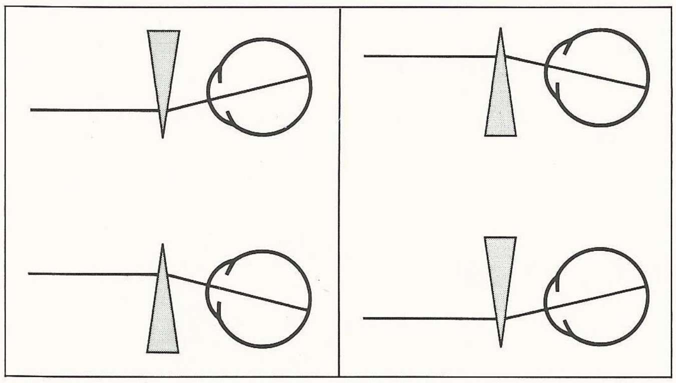

Fig. 1: Modification of the orthoposition by adducting prisms (left) and by abducting prisms (right).

A prismatic fullcorrection is characterized by providing that orthoposition cc (with correction) which simultaneously is the position of rest of the pair of eyes [2]. Thereby the bicentral image location is provided for the point of fixation while the ocular muscles are in their state of balance.

1.2 Prismatic Power of Spectacle Lenses

In the visual point of any spectacle lens the chief ray of the centrally imaging bundle will be refracted in the manner shown in figure 2 (with the exception of the visual point being identical with the optical centre of the lens).

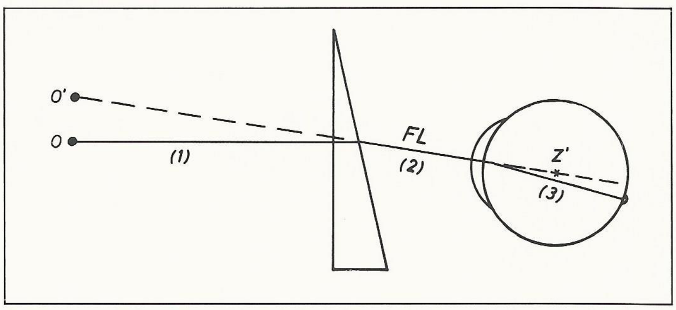

Fig. 2: Deviation of the chief ray at the visual point of a spectacle lens. O: fixated object point; O': image point produced by the spectacle lens; FL: visual axis; Z': optical ocular center of rotation; (1), (2), (3): path of the chief ray (independent of the type of lens).

Between the lens and the eye the chief ray of the centrally imaging bundle is coinciding with the visual axis of the eye.

For better clarity in the following figures the chief ray will not be refracted in the eye but will instead be drawn directly to the center of the fovea equivalent to a zero angle gamma (visual axis and optical axis of the eye coincide). A non-zero angle gamma does not change anything for the following explanations, only the drawings would be more complex.

Spectacle lenses with spherical power have a prismatic side effect P_{sph} in every point except for the optical center which is calculated by multiplying the distance d of the visual point from the optical centre by the vertex power S' of the lens according to the Prentice formula:

$$P_{\text{sph}} = d \cdot S'$$

This formula has to be applied when the center of rotation requirement is fulfilled, that is when the optical ocular center of rotation Z' lies on the optical axis of the lens. When the center of rotation requirement is not fulfilled, the distance b' between the center of rotation and the back vertex of the lens has also to be considered and the Weinhold formula is valid in which h is the vertical distance between the optical ocular center of rotation and the optical axis of the lens [3]:

$$P_{\text{sph}} = \frac{h \cdot S'}{1 - b' \cdot S'}$$

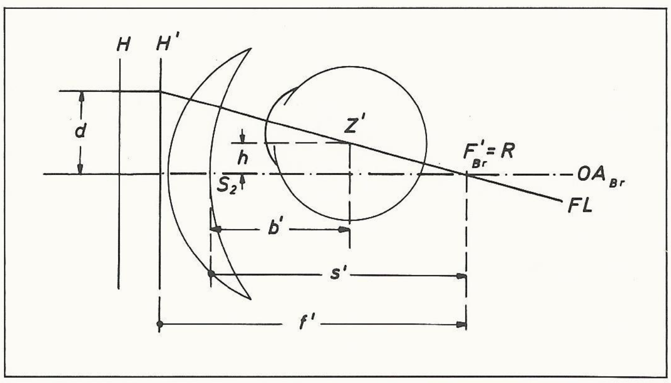

Fig. 3: Eye position behind a spectacle lens with positive vertex power when the center of rotation requirement is not fulfilled and when the fixation object lies in the direction of the optical axis of the lens.
H, H': principal planes of the lens; Z': optical ocular center of rotation;
F'_{Br}: second focal point of the lens; R: far point of accommodation;
OA_{Br}: optical axis of the lens; FL: visual axis; d: height of incidence of the chief ray; h: distance between Z' and OA_{Br}; S_2: back vertex of the lens;
b': distance between the center of rotation and the lens back vertex;
s': back vertex focal length of the lens; f': image focal length of the lens.

It is to be seen from the Weinhold formula that for spectacle lenses with positive vertex power the prismatic side effect in any visual point is larger than that calculated from the Prentice formula where d has to be replaced by the height h. This fact is shown in figure 3, whereas the prismatic side effect is smaller for spectacle lenses with negative vertex power, shown in figure 4.

Both formulas refer strictly speaking to infinitely thin lenses. The higher the prismatic side effect at the visual point of a thick lens the more important is the exact ray path [4].

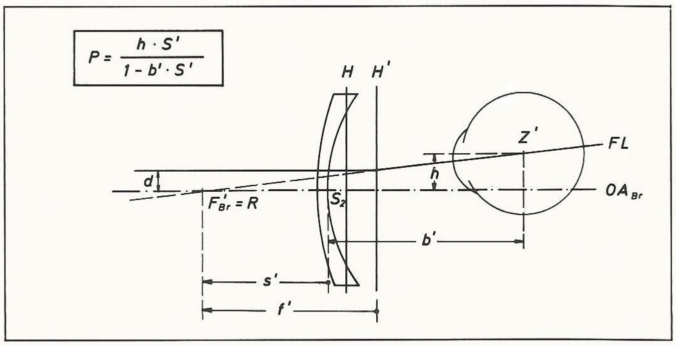

Fig. 4: Eye position behind a spectacle lens with negative vertex power when the center of rotation requirement is not fulfilled and when the fixation object lies in the direction of the optical axis of the lens.
H, H': principal planes of the lens; Z': optical ocular center of rotation;
F'_{Br}: second focal point of the lens; R: far point of accommodation;
OA_{Br}: optical axis of the lens; FL: visual axis; d: height of incidence of the chief ray; h: distance between Z' and OA_{Br}; S_2: back vertex of the lens;
b': distance between the center of rotation and the lens back vertex;
s': back vertex focal length of the lens; f': image focal length of the lens.

2 Centering of Trial Lenses

2.1 Centering for the Refraction Procedure

For the refraction procedure the measuring frame is centered ideally in a way that each eye is looking through the geometrical center of the trial lenses. That is no big problem in the horizontal direction but it will be difficult in the vertical direction if the eyes are situated in different heights with a natural posture of the test person's body and head. Therefore it is to be wished that the relevant industry will soon provide a measuring frame where each side may seperately be adjusted in the vertical direction. The centering should then be controlled from the distance as it is suggested for the centering of correction lenses [5].

If the eyes do not look through the optical centers of the refractive correcting lenses and thus a binocular-prismatic effect is present in the visual points than the subsequent binocular test will lead to a wrong result [6]. Thus a heterophoria will wrongly be indicated for an orthophoric person and for a heterophoric person the measured result of heterophoria will be wrong as far as magnitude and/or direction is concerned.

2.2 Centering for the Binocular Testing

It should expressively be emphasized that no reliable binocular testing may be carried out with a phoropter.

There are three fundamental possibilities for the centering of the measuring frame for binocular testing which will be discussed in the following chapters.

All discussions only refer to the optical center distance that is to the centering in the horizontal direction. If measuring frames with sides to be seperately adjusted in the vertical direction as well as in the horizontal direction will be available in the future than the following considerations can correspondingly be applied also to the vertical centering.

Possibility No. 1
The optical center distance is arbitrary

In that case the optical center distance between both sides of the measuring frame must be known and has to be considered when manufacturing the spectacles so that the corrective lenses produce the same binocular effect for the eyes of the spectacle wearer as had the trial lenses in the measuring frame.

The present-day requirements are no longer fulfilled by this earlier philosophy. On the one hand the facilities for calculation and manufacturing regarding the production of spectacle lenses have improved in such a manner that respective to aberrations there may be an appreciable difference between a lens with prismatic power (reference point is different from optical center) and a lens with spherical or astigmatic power with a decentration because of a prescribed prismatic effect.

On the other hand, as mentioned before, an arbitrary optical center distance does not allow an accurate measurement of heterophoria which is compulsory for binocular fullcorrection.

Possibility No. 2
The optical center distance equals the interpupillary distance

This is the kind of centering which nowadays is probably most frequently used. But if the optical center distance which had been correctly used for the refraction procedure will remain unchanged for binocular testing then the measuring prism *P* will not show the true magnitude P_{Korr} of a heterophoria. In that case the formula

$$P_{\text{Korr}} = P + x \cdot S'$$

will apply with *x* depending as well on the vertex power *S'* as on the distance *b'* between the optical ocular center of rotation and the lens back vertex (hence the vertex distance).

When *S'* is positive (hyperopia) the heterophoria P_{Korr} is larger than the power *P* of the measuring prism as shown in figure 5. When *S'* is negative (myopia) the heterophoria P_{Korr} is smaller than the power *P* of the measuring prism as shown in figure 6.

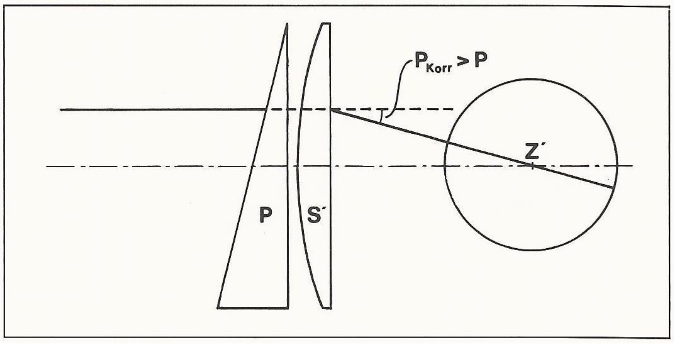

Fig. 5: Eye position at binocular testing with Possibility No. 2 in the case of hyperopia.
P: measuring prism; S': refractive correcting trial lens; Z': optical ocular center of rotation; P_{Korr}: here denoting the angle between the visual axis of the eye and the optical axis of the lens S'.

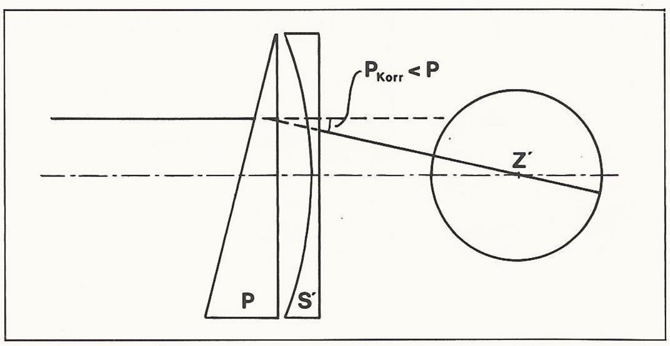

Fig. 6: Eye position at binocular testing with Possibility No. 2 in the case of myopia.
P: measuring prism; S': refractive correcting trial lens; Z': optical ocular center of rotation; P_{Korr}: here denoting the angle between the visual axis of the eye and the optical axis of the lens S'.

The above discussed difference is

$$x \cdot S' = \Delta P = P_{\text{Korr}} - P$$

The table in figure 7 illustrates the calculated magnitude of ΔP. The assumption for this calculation was that the measuring prism *P* for the correction of the heterophoria P_{Korr} is placed in front of one eye only. When the correcting prism is equally distributed in front of both eyes the difference ΔP will become smaller.

For a heterophoria of 10 cm/m for example and a myopia of 5 dpt for each eye a value of -1,51 cm/m is given in the table of figure 7, but for an equal distribution of prisms the difference ΔP would come to two times -0,66 cm/m (as seen from figure 7 as well) resulting in a total of -1,32 cm/m.

S′ dpt	P_{Korr} cm/m	P cm/m	$\Delta P = P_{Korr} - P$ cm/m
+ 5,0	5	4,36	+ 0,64
+ 2,5	5	4,69	+ 0,31
0	5	5,02	− 0,02
− 2,5	5	5,34	− 0,34
− 5,0	5	5,66	− 0,66
+ 5,0	10	8,78	+ 1,22
+ 2,5	10	9,46	+ 0,54
0	10	10,16	− 0,16
− 2,5	10	10,83	− 0,83
− 5,0	10	11,51	− 1,51

Fig. 7: Difference ΔP of the power P from the magnitude P_{Korr} of the heterophoria with Possibility No. 2 as a function of the vertex power S' of the lens for a distance between the center of rotation and the lens back vertex of b' = 25 mm with the measuring prism P in front of one eye only.

In addition to the difference ΔP between the power of the measuring prism and the magnitude of the heterophoria the displacement of the visual points against the geometrical centers of the trial lenses will also result in an unequal vignetting for both eyes and this may lead to a specific uncertainty in properly determining the binocular fullcorrection for the test person's heterophoria.

Possibility No. 3
The optical center distance will be adapted
to the prism power

In this approach for the centering procedure both sides of the measuring frame have to be adjusted in such a way that in every phase of binocular testing each eye shall look through the optical center of its refractive correcting lens, as shown in figure 8.

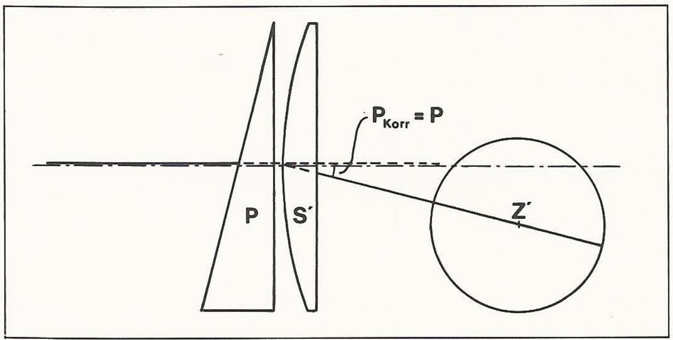

Fig. 8: Eye position at binocular testing according to Possibility No. 3 in the case of hyperopia (the same applies for myopia).
P: measuring prism; S': refractive correcting trial lens; Z': optical ocular center of rotation; P_{Korr}: here denoting the angle between the visual axis of the eye and the optical axis of the lens S'.

The distance between the center of rotation and the lens being about 25 mm leads to the necessary alteration of the measuring frame's center distance as given in figure 9 and figure 10.

For each cm/m of the inserted measuring prism
the optical center distance OCD
has to be altered by ¼ mm,
compared to the interpupillary distance PD,
opposite to the base position of the prism,
leading to an enlargement with abducting prisms (base in)
and to a reduction with adducting prisms (base out):
OCD = PD ± 0,25 mm per cm/m of the prism

Fig. 9: Necessary alteration of the optical center distance for the trial lenses at binocular testing for the Possibility No. 3.

With binocular fullcorrection the necessary
optical center distance z of the trial lenses in cm is

$$z = p - 0{,}025\ m \cdot P$$

The interpupillary distance p has to be inserted in cm
and the power P of the measuring prisms in cm/m,
being positive with base out prisms
and negative with base in prisms.

Fig. 10: Necessary alteration of the optical center distance for the trial lenses at binocular testing in mathematical formulation.

The above rule leads to smaller center distances *z* compared to the interpupillary distance *p* with base out prisms to correct an esophoria and to larger center distances *z* compared to the interpupillary distance *p* with base in prisms to correct an exophoria. Both cases are illustrated in figure 11 and figure 12.

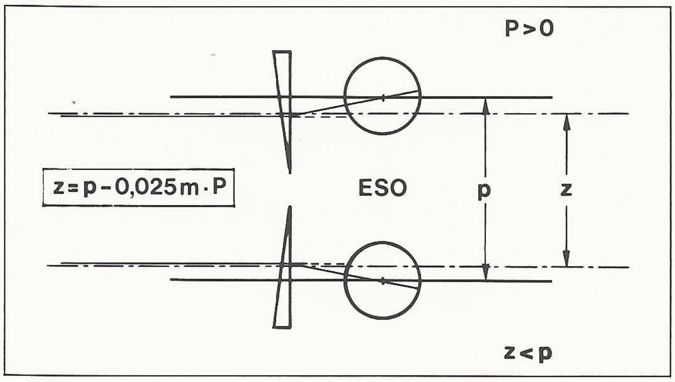

Fig. 11: Eye position at binocular testing according to Possibility No. 3 in the case of esophoria (valid for hyperopia as well as for myopia) when the center distance is reduced according to the formula in figure 10.
z: distance between the visual points in the plane of the measuring frame; p: interpupillary distance; P: power of the correcting prism.

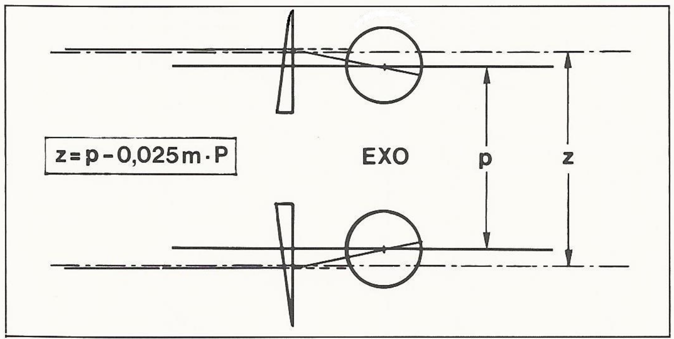

Fig. 12: Eye position at binocular testing according to Possibility No. 3 in the case of exophoria (valid for hyperopia as well as for myopia) when the center distance is increased according to the formula in figure 10.
z: distance between the visual points in the plane of the measuring frame; p: interpupillary distance; P: power of the correcting prism.

For the case of Possibility No. 3 the table in figure 13 shows how small the difference ΔP between the magnitude P_{Korr} of a heterophoria and the prismatic Power *P* of the measuring prism will become (the prism being placed in front of one eye only), assuming a distance between the optical ocular center of rotation and the lens back vertex of *b'* = 25 mm, the distance of the back vertex of the lens from the corneal apex then being about 12 mm.

For a heterophoria of 10 cm/m for example and a myopia of 5 dpt for each eye a value of -0,16 cm/m is given in the table of figure 13 (the prism being placed in front of one eye only), but for an equal distribution of the prisms the difference ΔP would come only to two times -0,02 cm/m (as seen from figure 13 as well) resulting in a total of -0,04 cm/m.

The values for ΔP in the table of figure 13, as well as in the table of figure 7, show the importance of an equal distribution of lenses with a prismatic power in front of both eyes, particularly for the correction of any larger heterophoria.

To what extent the distance *b'* between the optical ocular center of rotation and the lens back vertex may be modified without a noteworthy influence upon the difference ΔP between the magnitude P_{Korr} of a heterophoria and the prismatic Power *P* of the measuring prism is indicated for a hyperopia of 5 dpt in the table of figure 14 and likewise for a myopia of 5 dpt in the table of figure 15.

3 Binocular Centering of Correction Lenses

3.1 Centering of Single-Vision Lenses

The centering of single vision lenses appears to be simple at least for spectacle lenses without prismatic power. But this appearance is deceptive as the centering of lenses with merely spherical or astigmatic power according to Possibility No. 2 is strictly speaking only correct for an orthophoric pair of eyes.

For heterophoric eyes with fixation disparity (which is the rule when binocular fullcorrection has not been accomplished [8]) such a centering leads to the distance between both visual points being smaller than the optical lens center distance with an eso fixation disparity as the visual points are situated more to the nose than the optical centers and vice versa with an exo fixation disparity as the visual points are situated more to the temples of the head than the optical centers.

Therefore a binocular-prismatic side effect will prevail in the visual points resulting in either a corrective effect for the heterophoria or an adverse effect which artificially increases the heterophoria. Which of both cases in question prevails will depend on the algebraic sign of the refractive correcting lenses.

S′ dpt	P_{Korr} cm/m	P cm/m	$\Delta P = P_{Korr} - P$ cm/m
+ 5,0	5	4,99	+ 0,01
+ 2,5	5	5,00	0
0	5	5,02	− 0,02
− 2,5	5	5,02	− 0,02
− 5,0	5	5,02	− 0,02
+ 5,0	10	10,09	− 0,09
+ 2,5	10	10,13	− 0,13
0	10	10,16	− 0,16
− 2,5	10	10,16	− 0,16
− 5,0	10	10,16	− 0,16

Fig. 13: Difference ΔP between the magnitude P_{Korr} of the heterophoria and the power P of the measuring prism, the prism being placed in front of one eye, as a function of the vertex power S' of the refractive correcting lens for a distance between the optical ocular center of rotation and the lens back vertex of b' = 25 mm when the alteration of the measuring frame's center distance is performed according to the formula in Fig. 10, that is using Possibility No. 3.

Single vision lenses with prismatic power are properly centered if the distance between the reference points of the lenses in the spectacle frame is equal to the center distance between both sides of the measuring frame after the eye examination had been finished. But if this center distance is equal to the pupillary distance then problems may arise at least with aspherical lenses because these should be considered as progressive-power lenses with zero addition [9].

P_{Korr} dpt	b′ cm/m	P cm/m	$\Delta P = P_{Korr} - P$ cm/m
5	20	5,11	− 0,11
5	25	4,99	+ 0,01
5	30	4,86	+ 0,14
10	20	10,36	− 0,36
10	≈ 22		− 0,25
10	25	10,09	− 0,09
10	27	9,99	+ 0,01
10	30	9,83	+ 0,17
10	≈ 32		+ 0,25
10	35	9,56	+ 0,44

Fig. 14: Difference ΔP between the magnitude P_{Korr} of the heterophoria and the power P of the measuring prism, the prism being placed in front of one eye, with a refractive correcting lens of vertex power S' = +5 dpt as a function of the distance b' between the optical ocular center of rotation and the lens back vertex when the alteration of the measuring frame's center distance is performed according to the formula in Fig. 10, that is using Possibility No. 3.

P_{Korr} dpt	b′ cm/m	P cm/m	$\Delta P = P_{Korr} - P$ cm/m
5	20	4,89	+ 0,11
5	25	5,02	− 0,02
5	30	5,15	− 0,15
10	20	9,89	+ 0,11
10	25	10,16	− 0,16
10	≈ 26,5		− 0,25
10	30	10,51	− 0,51

Fig. 15: Difference ΔP between the magnitude P_{Korr} of the heterophoria and the power P of the measuring prism, the prism being placed in front of one eye, with a refractive correcting lens of vertex power S' = -5 dpt as a function of the distance b' between the optical ocular center of rotation and the lens back vertex when the alteration of the measuring frame's center distance is performed according to the formula in Fig. 10, that is using Possibility No. 3.

3.2 Centering of Multifocal Lenses and of Progressive-Power Lenses

With the centering of multifocal and progressive-power lenses the field of vision requirement takes precedence over every other consideration. In this regard the field of vision for near vision should be as large as possible (which requires a small vertex distance) and both the fields of vision of the eyes should superpose each other for the working distance.

The centering of lenses with prismatic power has therefore to be carried out in the same way as had been discussed for the measuring frame [10]. But the correct binocular-prismatic effect will only be reached if the centering rule of Possibility No. 3 had already been followed at the eye examination or if a difference in centering is considered when ordering the lenses [11]. In other cases mistakes will result amounting to the magnitude ΔP which can be taken from the table in figure 7.

4 Assumptions of the Manufacturers for the Calculation of Correction Lenses

In order to find out which basic assumptions are made in the calculation of spectacle lenses with prismatic power I had asked five lens manufacturers for an answer to the four questions which are summed up in figure 16. All of them kindly returned my questionnaire fully completed and I want to thank them once again for their helpful cooperation.

Questions concerning the assumptions for calculating correction lenses with prismatic power:

1. Arrangement of the measuring prisms relative to the other trial lenses?
2. Arrangement of the measuring prisms as to their surfaces?
3. Distance of the measuring prisms from the eyes?
4. Binocular centering of the measuring frame?

Fig. 16: Four questions to five manufacturers of correction lenses.

The answers to the questionnaire are shown in figure 17 to 20.

Arrangement of the measuring prisms relative to the other trial lenses

1	The arrangement of measuring prisms is arbitrary. Therefore it is not considered in the calculation.
4	The measuring prisms are placed at the object side in front of other trial lenses.
–	Other assumption (please specify)

Fig. 17: Answers to question number 1.

Arrangement of the measuring prisms with regard to their surfaces

1	The arrangement of measuring prisms is arbitrary. Therefore it is not considered in the calculation.
4	The back surface of the measuring prisms is parallel to the plane of the measuring frame so that the inclined surface is directed towards the object side.
–	Other assumption (please specify)

Fig. 18: Answers to question number 2.

The answers in figure 17 and 18 reveal that four manufacturers consider the arrangement of measuring prisms in the frame. One manufacturer gives no consideration to this aspect. The other four manufacturers have reported that they calculate their lenses considering the measuring prisms are placed in front of other trial lenses and point with their inclined surface towards the front.

Distance of the measuring prisms from the eyes

3	The distance of measuring prisms is arbitrary. Therefore it is not considered in the calculation.
1	The distance of the measuring prisms from the eyes will be assumed to ……. mm in the calculation. (Please specify the distance).
1	Other assumption (please specify)

Fig. 19: Answers to question number 3.

Three of the five manufacturers do not consider the distance of the measuring prisms from the eyes in their lens calculation at all as shown in figure 19. One of the five reports that a back vertex distance of 12 mm is implemented in the lens calculation which is equivalent to a distance between the optical ocular center of rotation and the lens back vertex of about 25 mm.

As specified other assumption a more sophisticated calculation was reported by one of the five, also using a back vertex distance of 12 mm. But this special calculation will also take into account a variable distance between the optical ocular center of rotation and the lens back vertex in order to allow for the nature and magnitude of ametropia as that is most frequently due to a variation in the overall length of the eye.

Binocular centering of the measuring frame

2	The center distance between trial lenses is arbitrary. Therefore it is not considered in the calculation.[1)]
3	The optical center distance OCD of the trial lenses is equal to the pupillary distance PD during the whole eye examination.[2)]
–	The OCD will be adapted to the prism power by a change from the PD of 0,25 mm per cm/m of the measuring prism.[3)]

Fig. 20: Answers to question number 4.
[1), 2), 3)]: equivalent to Possibility No. 1, 2, 3 from chapter 2.2.

The answers to the most important question for our problem are given in figure 20. Here two of the five manufacturers give no consideration to the aspect of frame centering which is the Possibility No. 1 from chapter 2.2. The other three calculate their lenses according to the Possibility No. 2 from chapter 2.2 where the optical center distance of the trial lenses is equal to the interpupillary distance. But as already discussed in chapter 2.2 this method of calculation will lead to a wrong binocular-prismatic power in the visual points for the correction of heterophoria, particularly when multifocal and progressive-power lenses are correctly centered according to the field of vision requirement. As can be taken from the table in figure 7 (see the values in the column for ΔP) this error may be far in excess of the allowed binocular tolerances.

Unfortunately a binocular fullcorrection which had previously been properly determined with a measuring frame will then be nullified in these cases unless the optometrist will prevent this mistake by means of performing a complex calculation before ordering the appropriate lenses [11].

5 Suggestions for a Consistent Procedure in the Future

Through proper centering of the correction lenses in spectacles the ray path for the eyes should provide the same effect as had the ray path through the trial lenses in the measuring frame. Therefore it is my main concern in this article to suggest a basis that will provide a consistent procedure for centering spectacle lenses with prismatic power with the objective that the efforts to fully correct heterophoria shall not be nullified just because of either miscalculated spectacle lenses or poor centering.

The above discussions have shown that spectacles as a rule will provide the desired binocular-prismatic effect if and only if the lenses are centered in the same way as the trial lenses in the measuring frame had been centered. As for special types of lenses the field of vision requirement will be prior-ranking a consistent centering procedure for the measuring frame as well as for the spectacle frame shall be irrespective of the type of lens. Centering rules to that effect are suggested in figure 21.

- Spectacle lenses without prismatic power have to be centered to the pupillary distance.
- Spectacle lenses with prismatic power have to be centered in a manner that the distance between the reference points deviate from the pupillary distance by 0,25 mm for each cm/m of the prism power in the direction contrary to the base position of the prism.

Fig. 21: Suggestions for a consistent centering.

These consistent centering rules ensure that the anterior chief ray of the centrally imaging bundle will strike the spectacle lens in the reference point with a zero angle of incidence as the drawing in figure 2 shows. In figure 22 this is expressed as a new centre of rotation requirement which for lenses without prismatic power corresponds to the old centre of rotation requirement.

New centre of rotation requirement

A spectacle lens is centered correctly if the central object chief ray is perpendicular to the front surface of the lens when looking through the reference point.

Fig. 22: New centre of rotation requirement for a correct centering of all spectacle lenses.

The best solution for the calculation of lenses with prismatic power regarding aberrations will as well result when the lens manufacturers in future will stick to this consistent centering rule.

I hope that the foregoing discussion has clearly shown in every respect that the proper centering of lenses with prismatic power already starts with the frame centering for the eye examination and will then be continued by a consistent centering of the lenses in the spectacle frame.

My suggestions for a future procedure are once more shortly summarized in figure 23.

(1) Measuring frames:

Both sides shall be separately adjustable in the horizontal as well as in the vertical direction.

(2) Eye examination with measuring frames and manufacture of spectacles:

Lenses without prismatic power shall be centered to the pupillary distance.
Lenses with prismatic power shall be centered different from the pupillary distance by 0,25 mm for each cm/m of the prism power contrary to the base position of the prism.

(3) Calculation of correction lenses:

The requirements according to the rules under (2) shall be used for lens calculation.

Fig. 23: Suggestions for an implementation of binocular fullcorrections.

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