THE NATURE, TESTING, AND VARIABLES INFLUENCING FIXATION DISPARITY; ROLE OF THE FUSION LOCK

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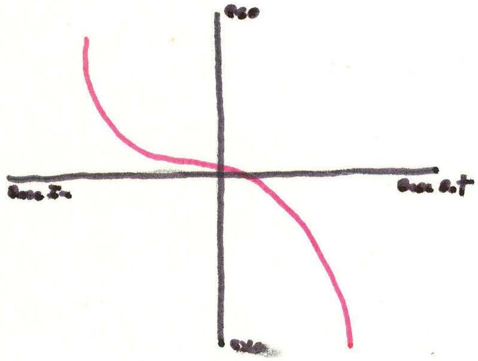

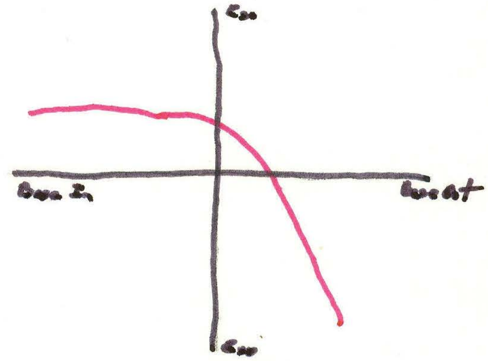

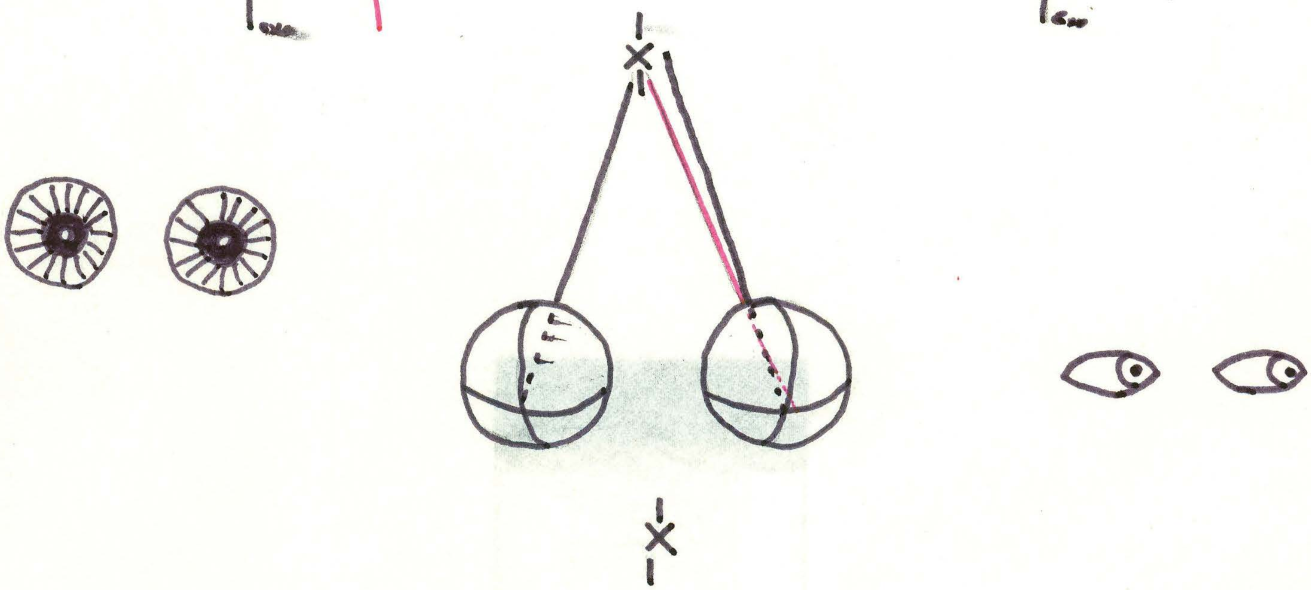

The Nature, Testing, And Variables Influencing Fixation Disparity

Role Of The Fusion Lock

Introduction

A fixation disparity is a small angular measurement of the misalignment of the two eyes which can occur while still permitting single, fused binocular vision. It represents a small error in the aiming of the eyes which occurs without diplopia being detected. Fixation disparity is allowed because of the slight "slippage" provided to the fusional system through the existence of Panum's fusional areas. So long as binocular alignment is precise enough to place the two retinal images of a single object within corresponding Panum's areas, the final perception is likely to be single and fused. Sensory fusion thus occurs in spite of a small error in motor fusion.

A slight muscle imbalance is the rule, rather than the exception in individuals even with normal assymptomatic binocular systems. It is rare that all twelve extraocular muscles are precisely balanced in their agonist-antagonist relationships, and thus the inate drive to achieve single vision requires a fusional effort to overcome existing imbalance. When binocularity is dissociated (as with a covertest) the fusional drive is interrupted and the eyes deviate out of alignment under the influence of the muscle imbalance. This deviation under dissociation is referred to as the heterophoria. When both eyes are permitted to view without dissociative conditions the fusional drive to achieve single binocular vision pulls the eyes toward alignment in opposition to the phoric "stress" operating to deviate the alignment.

Because of Panum's areas, motor fusion need only achieve alignment within the corresponding regions, rather than obtain pin-point-precise binocular alignment, and fusion will occur. Thus fixation disparity measures the amount of misalignment occurring under fused (though "stressed") binocular viewing situations.

It is the intent of this paper to briefly summarize the history and techniques of measuring fixation disparity, and to then examine one of the major variables of the measurement technique - the size of the fusional stimulus (fusional "clue", fusional "lock", fusional "ring") and its impact on the measurements obtained.

History

The earliest work on fixation disparity came from observations by Hofmann and Bielschowsky with the synoptophore which revealed that exo f.d. increased as convergence demand increased.

Ames and Glidden also worked with haploscopic targets, consisting of central large block E letters with peripheral horizontal and vertical dots. They found that superimposion of the peripheral dots could still leave the E slightly doubled indicating a slight misalignment of the lines of sight, which they called an "inexactness of fixation associated with a heterophoria."

The majority of the f.d. experimentation was done under the supervision of Ogle. (I) His experiments show that patients with a phoria (in which the eyes have a tendency to turn inwards or outwards) will actually under - or overconverge by a small amount, thus resulting in disparate images falling on the two retinas. These disparate images will be fused, however, and the subject will not be aware of disparity.

Through trial-and-error experimentation Ogle found that vertical vernier lines would provide the most accurate means of investigating these small deviations in alignment of the eyes.

To measure fixation disparity most accurately requires that the vernier lines be seen foveally where accuity is at its finest, and that they be seen bi-ocularly with one eye viewing one line while the other eye views the other line. This means that central-region fusional details must be eliminated, and thus peripheral fusion clues are utilized while central target lines are used to measure misalignment under fusing conditions.

In a patient with normal acuities in both eyes, a displacement of $\pm$ 1.0 minute of arc can be detected in vernier lines.

An interesting sidelite is that the test of fixation disparity using small centrally located vernier lines can indicate a foveal suppression if one line is not visible while all of the peripheral clues, and the other line, are visible.

Ogle determined that the fixation disparity was evidence that an oculomotor muscle imbalance exerts a continuous effort to deviate the eyes to the heterophoric position, and that it was an entity called "fusional convergence" which acted in opposition to the phoria to direct the eyes to "near-enough" alignment that diplopia was avoided. A small error in precise convergence (or divergence) occurs most often in the same direction as the phoria, thus causing a single fixation point to be imaged onto slightly noncorresponding (disparate) points on the two retinas; the amount of this disparity Ogle called the "fixation disparity". A f.d. cannot be larger than the limits of corresponding Panum's fusional areas or diplopia (or suppression) will occur.

Therefore, Ogle tells us that a fixation disparity is evidence that fusion occurs without full compensation of the phoria, and represents a manifest deviation of the visual axis in spite of successful fusion. The size of the fixation disparity depends primarily upon the size of the muscle imbalance (the amount of the phoria), but Ogle also felt that it must depend upon the stimulus to fusion.

According to Ogle, as larger fusional clues stimulate more peripheral areas of the retina where Panum's areas are larger, he would expect fusion to occur with less precise binocular alignment. With more "slop" permitted in alignment, he should expect to have larger fixation disparities.

Ogle also felt that the fixation disparity will increase as the effort to maintain fusion is increased. As one works harder to achieve fusion (for example near the vergence limits) the f.d. will increase in size.

Clinical Measurement of Fixation Disparity

Measurement of fixation disparity becomes a more meaningful indicator of a healthy binocular system when it is checked under various levels of fusional "stress". Prisms are used to alter the demand on the convergence/divergence mechanism, shifting the fusional demand, and changing the innervation to the extraocular muscles. Fixation disparity is measured under various conditions of fusional stress. (II)

Base-in prism will create an innervational esophoria because the stimulus to accommodation will be nearer than the stimulus to fusion, requiring negative fusional innervation in order to see clearly and singly. Accommodative convergence is acting to turn the eyes inward while fusional drive acts to aim the eyes outward (innervational esophoria!)

Base-out prism acts in a reverse manner to create the innervational situation of an exophoria.

As base-in prism is increased toward the limits of the negative vergence, then the fixation disparity will most often increase in the eso disparity direction (an underdivergence), showing an increasing esophoric oculomotor imbalance. Once the base-in break point is reached diplopia occurs and the eyes shift to their natural phoric position.

Again the reverse situation is found for increasing base-out prism. Most often this will give an increasing exo-disparity up to the convergence breakpoint.

Fixation disparities are quite small angles, measured in minutes of arc. They are interpreted based upon their curve when plotted on a two coordinate graph. The abscissa lists the base-in and base-out prism power placed before the eyes, while the ordinate lists the eso or exo disparity measured.

That value of prism power before the eyes when the f.d. is found to be zero is called the "associated horizontal phoria". It indicates the amount of muscle imbalance when the eyes are precisely aligned upon the fixation target (notice the assumption of normal retinal correspondence has been made!) The term "associated" phoria is used because the binocularity has not been drastically "disassociated" as by maddox rod or vertical prism used to determine the "disassociated phoria". The point on the fixation disparity graph where the oculomotor imbalance is zero (where the curve crosses the abscissa) indicates the prism value of the associated phoria. It indicates the relative rest position of the extraocular muscles for the subject for that observation distance, when fusion is maintained. (III)

Accuracy of f.d. measurement by the use of a two-line nonius alignment is acuity dependant, and subjects with 20/20 acuity in each eye are able to discriminate 1' of arc or even smaller disparities. Sensitivity is altered only slightly if both eyes are equally blurred, but is more significantly decreased if the two acuities are significantly different, and is quite variable in subjects with larger oculomotor imbalances. The amount of f.d. tends to vary directly as the size of the phoria.

As mentioned previously, Ogle considered the role of "peripheralness" of the fusion-lock in determinations of f.d. by the vernier lines method. He expected more retinal slippage (more misalignment) to be tolerated by the system before diplopia occurred, when using a more peripheral fusion target. The small Panum's areas associated with the macular area could not tolerate much disparity, or misalignment, before diplopia would occur. Thus Ogle predicted larger f.d. for a more peripheral target for fusion.

Ogle's preliminary investigations did find larger fixation disparities when the fusion-lock portion of the test target was made larger (therefore made more peripheral on the retina). One major finding of this initial work was that the associated phoria was not changed by the size of the fusion-lock. Instead, the graphed curves while varying in slope and amount all seemed to cross the abscissa at the same point - to pivot around the value of the associated phoria. (IV) However later experiments by Ogle, as well as by Shepherd gave conflicting results which seemed to show the f.d. was actually not affected by the size (peripheralness) of the target's "frame for fusion", (fusion lock). Shepherd concluded that f.d. was not dependant on Panum's area in the periphery. (V)

There are thus a number of interrelated variables operating to influence the fixation disparity curve. We have mentioned specifically the impact of the phoria, the muscle imbalance, the stability of the vergence system, the individual visual acuities, and the possible role of the size of the fusion-lock. One would also predict that accommodation through accommodative-convergence can contribute toward, or help relieve, stress on the fusional system. Thus fixation distance and ophthalmic lenses may contribute to the fixation disparity curve through their impact upon accommodative demands.

The goal of this study was to look at the impact of the size and peripheralness of the fusion-lock upon the f.d. plot. Recognizing the existence of the several other impacting variables, we determined to evaluate our data in terms of several curves plotted for each of twenty subjects. Each individual curve measured with a different fusion lock can be usefully assessed only in comparison to other individual curves generated for that same subject. In this way we can judge the role of the fusion lock alone, by assuming that all other variables remain constant for that individual subject. For instance the subject with .50 anisometropia will demonstrate the aniso under all viewing situations; the accommodative-excess subject will demonstrate the disorder as a constant while generating each curve. In our experimental design the only variable was to be the size of the peripheral fusion lock.

After determining the fixation disparity data for each subject under the different fusion-stimulus conditions, the data would be combined to create a set of fixation disparity curves for a "theoretical observor" made from the mean values obtained from the combined subjects. In this way the averaged data would minimize the individuals' variability by spreading it across the several plots and averaging it into a mean value.

The "theoretical observor" would produce a series of fixation disparity curves for each of the different sized fusion lock targets. These mean plots would then be combined, averaged, and a graph consisting of the mean of the mean values generated. This curve would serve to describe the standard deviation and allow statistical analysis of the impact on fixation disparity caused by changing the size of the fusional stimulus clue, while minimizing the role of individual variables other than fusion lock size.

Experimental Design

Twenty volunteer observors were chosen based on their willingness to participate in the study. They were all in the 20 to middle 30 age group, with approximately one half not associated with the college.

Each subject was seated behind a phoropter to allow use of binocular Risley prisms, and each wore a pair of research grade polarized spectacles precisely aligned to obtain bi-ocular perception of the polarized vernier target lines and binocular perception of the fluorescent peripheral fusion ring. Subjects made all observations wearing their habitual distance prescription in the form of their own contact lens or spectacle correction, behind the polaroids.

The subject controlled the vernier line adjustment by means of a knob which was geared to the upper line segment in such a way as to displace it horizontally as the knob was twisted, until the perception of alignment resulted. This adjustable upper line was seen by the left eye only, due to polarization. The adjustment knob was at the same time connected to a volt meter calibrated to read the actual disparity of the vernier lines in terms of minutes of arc.

The bottom line was seen by the right eye only, and was continuously flashed to overcome any macular suppression tendencies. Additionally the right eye viewed two short, narrow polarized horizontal lines placed below the vertical nonius line, and intended to help stabilize accommodation by requiring accurate focusing in order to maintain resolution of their separateness.

Fusion ring stimuli were prepared with fluorescent green paint on flat black backgrounds. The center portion of each ring was removed to allow visibility of the vernier alignment apparatus within the ring when the fusion target was placed in front of the vernier portion of the apparatus. A horizontal fluorescent line bisected each fusion ring and separated the vernier lines. This was done to act as a strong stimulus for precise vertical fusion to minimize the influence of vertical disparities.

The experiment was performed in total darkness except for Burton-lamp blacklight illumination of the fusion ring and fluorescent horizontal line, and the polarized light emerging from the vertical vernier lines and the horizontal accommodation lock. Peripheral extraneous fusional clues were eliminated by the flat black paint on the testing apparatus and the total darkness of the room.

The testing apparatus was located at one meter before the phoropter. Initial alignment adjustments were made with no fusional ring stimulus, followed in turn by four progressively larger ring-shaped fusional locks. For each fusional situation the fixation disparity was measured for prism of 0, 4 base-in, 4 base-out, 8 base-in, 8 base-out, 12 base-in, 12 base-out, and 20 base-out prism diopters, respectively. In this way five separate fixation disparity curves were generated for each of the twenty subjects, while attempting to minimize tonic and innervational changes in the vergence system.

Each value of fixation disparity was recorded and graphed under the appropriate size fusional clue.

Upon completion of all twenty test sessions, the mean fixation disparity was found for each value of prism, for each of the five fusional situations. In this way the plots for the "theoretical observer" were generated for each fusional situation. Instances of diplopia were dropped from the mean calculations except for those prism demand situations where diplopia was the common response, in which case "diplopia" was accepted as the mean value.

Finally, from this set of averaged data a plot consisting of the mean-of-the means was calculated and used to determine the significance of the variability for the five mean plots.

Analysis of Data

As mentioned previously, it was not felt that fixation data could be meaningful compared amongst subjects due to the large number of uncontrolled variables. However the data for each single observer could be compared to other data for that same observer under conditions where only the size of the fusion ring was varied. By looking at variability among the subgroups of data for a single subject, the key variable becomes the size of the fusion lock. A statistical analysis of variance, as well as simple "eyeball" comparison of the subgroups of data, allows evaluation of impact of differential fusion clues for that observer. First the graphs were objectively compared and a "common sense" evaluation made of the significance of the fusion lock. Next the Fisher or "F" test was used to statistically analyze the variance among the subgroups. The "F" test assesses the effect of different treatment upon subgroup means. With five subgroups of data based on the five different fusional conditions tested, the mean for each group was compared to the other four subgroup means for a significant amount of difference. Thus the effect of altering the fusional lock was evaluated for each individual observer. Similarly the averaged data (our so-called "theoretical observer") was evaluated by observation, then by the F test.

In all twenty sets of data for individuals, as well as the data for the theoretical observer, the size of the fusion ring was found to be <u>insignificant</u>. The graphs <u>appeared</u> similar with allowance for chance variability. This was confirmed in all cases by the <u>F test</u> where the differential treatments were found <u>insignifi-</u>

cant at the 5% and 1% levels. The size of the fusion ring did not change the disparity curve. Peripheralness of the fusion lock did not change the curve found.

Summary

By testing the fixation disparity while varying the size and peripheralness of the clue for fusion, the impact upon the fixation disparity plot was determined. Direct observation and statistical analysis for twenty observers showed no significant impact of the fusion lock upon the fixation disparity measured. For these twenty subjects it was not how they were influenced toward fusion, but the fact that their systems were driven to seek fusion in spite of prism-induced obstacles that resulted in nearly identical performance under the five situations tested. The fusion lock was of lesser importance.

Sources

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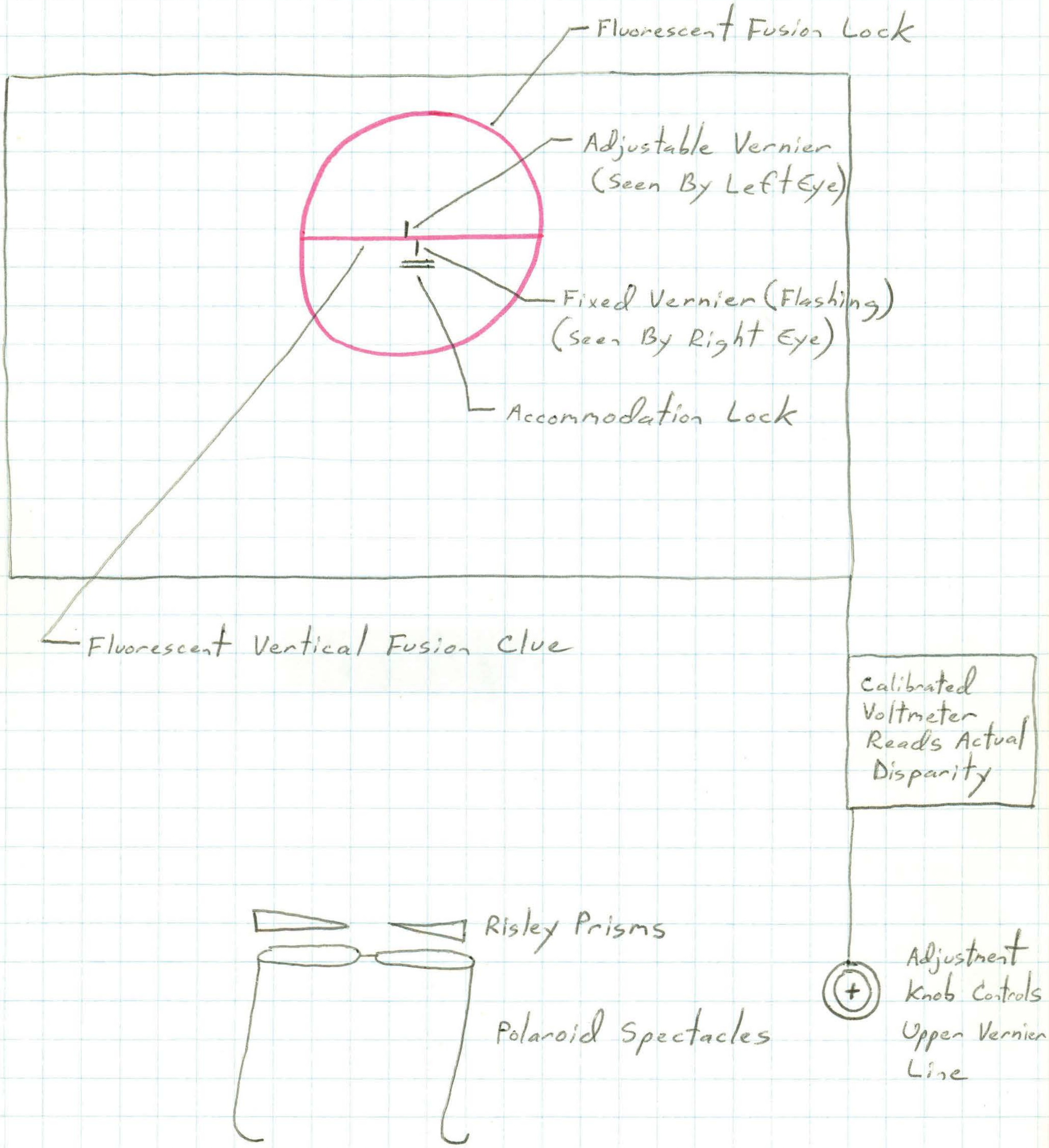
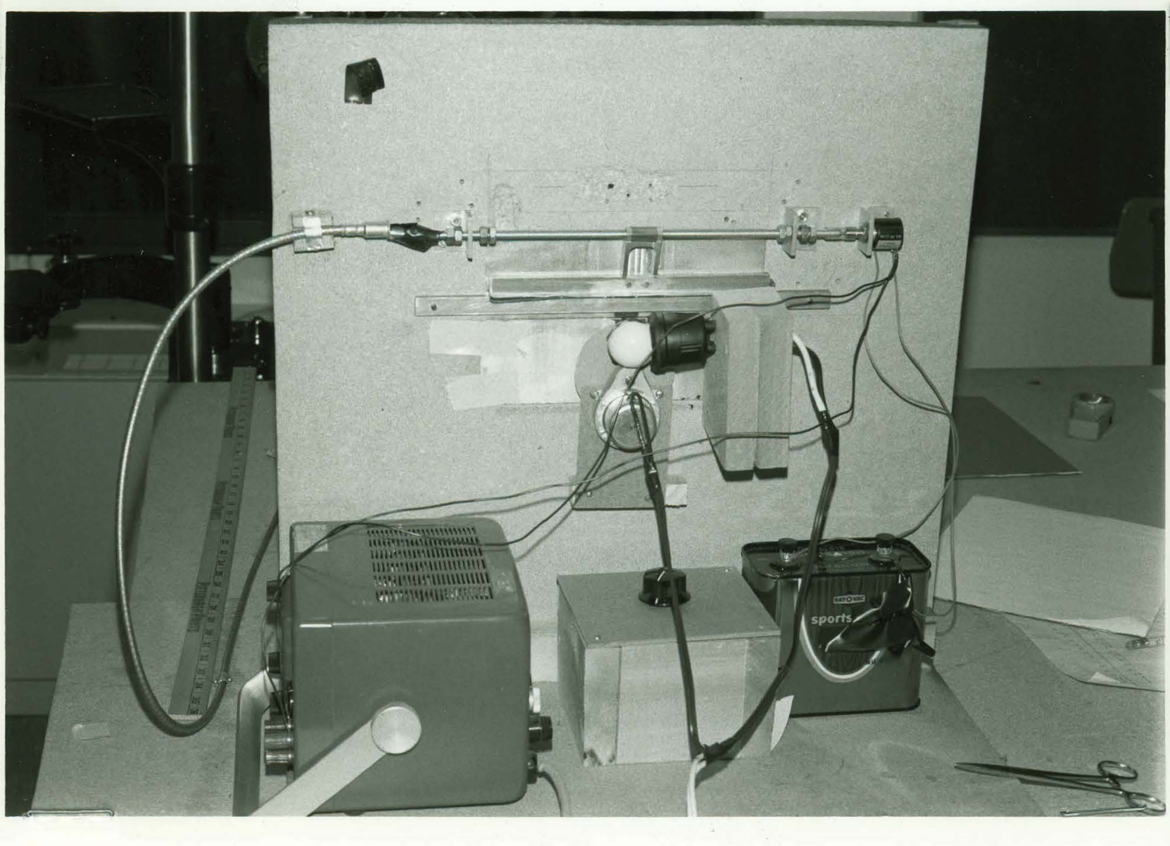
V. Shephard JS: A Study Of The Relationship Between Fixation Disparity And Target Size. Am. J. Optom. 28 391-404 1951.

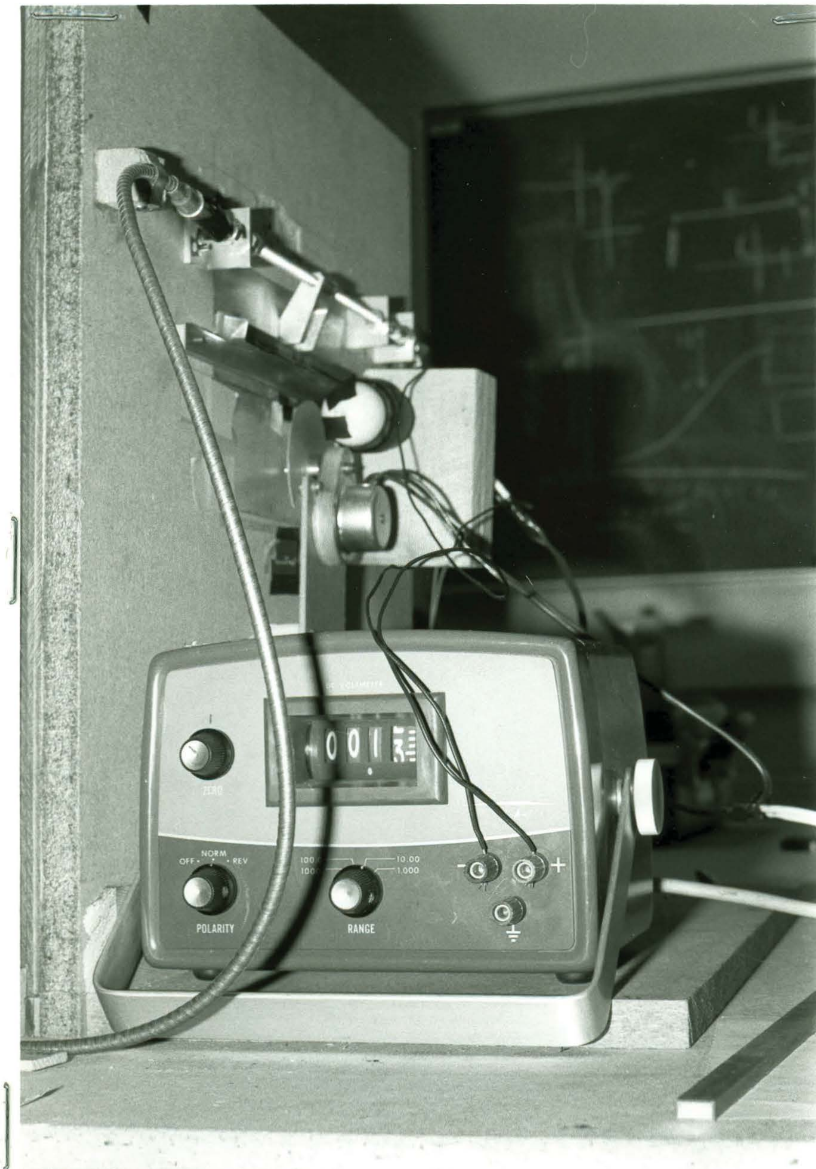


The Experimental Setup

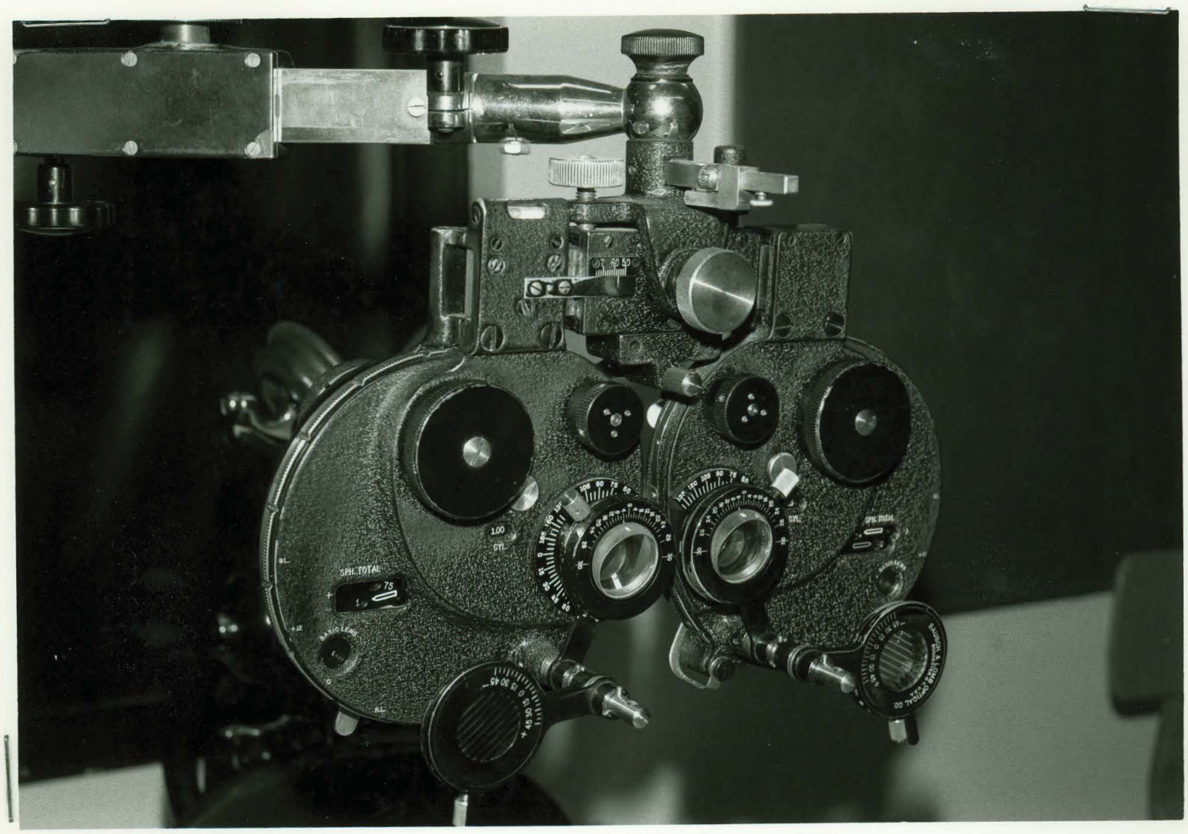
TARGET SHOWN UNDER FULL ILLUMINATION

TESTING APPARATUS SHOWN FROM BEHIND





VOLTMETER CALIBRATED FOR READING DISPARITY IN MINUTES OF ARC



PHOROPTER WITH RISLEY PRISMS IN POSITION

COMPARISON OF FOUR PERIPHERAL FUSION RINGS TESTED
.75°   1.5°   3.0°   6.0° ARC SUBTENDED

No Fusion Lock

Subject Number	Fixation Disparity	PRISM 0	4BI	4BO	8BI	8BO	12BI	12BO	20 B.O.
#1		4eso	7eso	3eso	10eso	0	dipl.	1exo	4exo
#2		1exo	0	1exo	1eso	1exo	dipl.	2exo	6,5exo
#3		3eso	10eso	0	dipl	1exo	dipl	2exo	11exo
#4		2eso	2eso	0	3,5eso	1exo	8eso	3exo	8,5exo
#5		1eso	1eso	1,5eso	2eso	0	7eso	2exo	6exo
#6		2,5eso	3eso	1eso	6,5eso	0	dipl	1exo	1exo
#7									
#8		0	5eso	2exo	8eso	3exo	dipl	3exo	3.5exo
#9		1exo	0	2exo	1eso	1exo	dipl	4exo	15exo
#10		0	1eso	0	6eso	1exo	dipl	1exo	7exo
#11		0	0	1exo	3eso	1exo	7eso	1,5exo	5,5exo
#12		4exo	2eso	3exo	2eso	3exo	2eso	3exo	13exo
#13		0	2eso	2exo	3,5eso	2exo	dipl	5exo	dipl
#14		1exo	1,5exo	0	2,5eso	1,5exo	11eso	3,5exo	6exo
#15		1,5eso	7eso	1eso	17eso	2eso	20eso	2exo	5exo
#16		1eso	4eso	2eso	12eso	2,5eso	17eso	dipl	dipl
#17		2exo	3eso	3exo	12eso	16exo	dipl.	18exo	dipl
#18		0	2eso	5exo	7eso	7exo	dipl.	8exo	10exo
#19		1,5exo	3eso	5exo	5eso	11exo	dipl	5exo	8,5exo
#20		0	0	1exo	1eso	3exo	3,5eso	5exo	8exo
Mean		-.2	-2,5	+.8	-5,25	+2,4	-3.8	+3,5	+6,0

Smallest Fusion Lock

Subject Number	Fixation Disparity	PRISM							
		0	4BI	4BO	8BI	8BO	12BI	12BO	20B.O.
#1		5eso	10eso	5eso	dipl	1eso	dipl	.5exo	5exo
#2		1exo	0	1exo	1,5eso	1exo	dipl	3exo	7exo
#3		5eso	15eso	4eso	16eso	3eso	dipl	0	6exo
#4		2,5eso	2eso	0	3eso	0	dipl	4exo	7exo
#5		1,5eso	2eso	1,5eso	2,5eso	0	7eso	0	6.5exo
#6		2eso	2eso	1eso	5,5eso	0	dipl	0	1exo
#7		—	—	—	—	—	—	—	—
#8		0	0	1exo	3eso	2exo	8eso	4exo	8exo
#9		1.5eso	6eso	2exo	dipl	2exo	dipl	3exo	4exo
#10		2exo	1,5exo	4,5exo	0	2exo	3,5eso	4exo	16exo
#11		0	1eso	1exo	7eso	1exo	dipl	1,5exo	7exo
#12		0	.5eso	.5exo	2eso	1exo	dipl	1,5exo	4,5exo
#13		3eso	3eso	4eso	6eso	4eso	10eso	4eso	2eso
#14		0	1eso	2exo	3eso	2exo	dipl	6exo	dipl
#15		1,5exo	2exo	0	2,5eso	0	12eso	4exo	7exo
#16		1eso	7eso	2eso	13eso	3eso	19eso	1,5exo	5exo
#17		1eso	5eso	2eso	12eso	1,5eso	18eso	dipl	dipl
#18		2exo	3eso	2exo	14eso	16exo	dipl	18exo	dipl
#19		0	3eso	5exo	7eso	7exo	dipl	8exo	13exo
#20		0	1eso	1,5exo	1eso	4exo	3,5eso	4exo	8exo
Mean		-.8	-2,6	0	-4.9	+1,3	-4.0	+2,9	+5.1

Second Smallest Fusion Lock

Subject Number	Fixation Disparity	PRISM							
		0	4BI	4BO	8BI	8BO	12BI	12BO	20 B.O.
#1		5eso	9eso	5.5eso	20eso	2eso	dipl	1eso	3exo
#2		1exo	1.5exo	1exo	2eso	2exo	dipl	2exo	7exo
#3		5eso	7.5eso	3eso	16eso	.5eso	dipl	2exo	3.5exo
#4		2eso	2eso	1exo	3.5eso	1.5exo	dipl	4exo	8exo
#5		1eso	3eso	1eso	2.5eso	1exo	7eso	1exo	7exo
#6		2.5eso	2.5eso	1eso	5eso	0	dipl	.5exo	1.5exo
#7		0	0	1exo	3eso	2exo	8eso	4exo	8exo
#8		.5exo	1eso	1exo	9eso	1exo	dipl	4exo	5exo
#9		3exo	3exo	4exo	1exo	5exo	1exo	8exo	18exo
#10		1exo	1eso	1eso	7eso	1eso	16eso	1exo	7exo
#11		.5exo	.5exo	2exo	3.5eso	2exo	dipl	3exo	7exo
#12		2exo	0	3exo	2eso	2exo	5eso	3exo	15exo
#13		0	2eso	2exo	3eso	2exo	dipl	dipl	dipl
#14		1exo	2eso	0	3eso	1.5exo	12eso	3exo	6exo
#15		1.5eso	7eso	1eso	14eso	2eso	20eso	1exo	3.5exo
#16		1.5eso	5.5eso	2eso	12eso	1eso	16eso	.5eso	5exo
#17		2exo	3eso	2exo	dipl	16exo	dipl	18exo	dipl
#18		1eso	2.5eso	3.5exo	7eso	7exo	dipl	8exo	8exo
#19		2exo	3eso	5exo	4eso	3.5exo	dipl	7exo	10exo
#20		0	0	1eso	2eso	3exo	5eso	5exo	10exo
Mean		-.3	-2.3	+.5	-6	+2.15	dipl	+3.7	+6.7

Second Largest Fusion Lock

Subject Number	Fixation Disparity	PRISM 0	4BI	4BO	8BI	8BO	12BI	12BO	20BO
#1		4eso	10eso	4eso	dipl	2eso	dipl	0	5exo
#2		0	1.5eso	0	1eso	2exo	dipl	3exo	7exo
#3		1.5eso	1eso	1.5eso	15.5eso	0	dipl	2exo	3.5exo
#4		2.5eso	2.5eso	0	4eso	1exo	dipl	3.5exo	7exo
#5		1eso	2.5eso	1eso	3eso	0	7eso	1exo	7.5exo
#6		3eso	4eso	.5eso	6eso	0	dipl	1exo	2exo
#7		0	.5eso	1exo	3eso	2exo	10eso	4exo	10exo
#8		2exo	0	2exo	8eso	2exo	dipl	4.5exo	6exo
#9		4exo	0	2exo	0	4exo	12eso	6exo	20exo
#10		0	0	0	7eso	1exo	18eso	2exo	6.5exo
#11		.5exo	2eso	2exo	2eso	1exo	dipl	3.5exo	7exo
#12		1eso	3eso	2exo	5eso	0	14eso	0	10exo
#13		0	1.5eso	1eso	3.5eso	2exo	dipl	5exo	dipl
#14		1exo	0	1exo	3eso	2exo	10eso	5exo	6exo
#15		1eso	7eso	1eso	17eso	2eso	20eso	2exo	4exo
#16		2eso	4eso	1eso	9eso	1eso	16eso	1eso	5.5exo
#17		2exo	3eso	2exo	dipl	15exo	dipl	18exo	dipl
#18		1eso	1.5eso	3.5exo	5.5eso	7exo	dipl	8exo	10exo
#19		1.5exo	3eso	5exo	5eso	5exo	dipl	7exo	7exo
#20		1exo	1eso	2exo	1eso	2.5exo	3eso	5exo	8exo
Mean		-.2	-2.4	+.6	-4.9	+2.0	-8	+4	+6.6

Largest Fusion Lock

Subject Number	Fixation Disparity	Prism 0	4BI	4BO	8BI	8BO	12BI	12BO	20B.O.
#1		5.5eso	9eso	3eso	18eso	1exo	dipl	1exo	6exo
#2		1exo	1exo	1exo	0	1exo	dipl	2exo	7exo
#3		2eso	5.5eso	.5eso	9eso	1exo	20eso	2exo	5.5exo
#4		2eso	2eso	0	4eso	0	dipl	3exo	7.5exo
#5		1.5eso	2eso	1eso	2eso	0	8eso	.5exo	6exo
#6		2eso	2eso	.5eso	3eso	0	dipl	1exo	1exo
#7		1exo	.5eso	1exo	2eso	2exo	8eso	4exo	8exo
#8		4exo	2,5eso	2exo	12eso	1exo	dipl	1exo	1,5exo
#9		2exo	2exo	4exo	1exo	4exo	1eso	5exo	18exo
#10		1eso	0	0	7eso	0	17eso	1.5exo	6.5exo
#11		1exo	1exo	2exo	2,5eso	1.5exo	dipl	3exo	5.5exo
#12		5exo	0	1exo	1eso	4exo	8eso	4exo	10exo
#13		0	1eso	2exo	3eso	2exo	10eso	6exo	dipl
#14		0	2eso	1exo	2eso	2exo	12eso	4exo	7.5exo
#15		1eso	7eso	1eso	18eso	0	20eso	1.5exo	4exo
#16		1eso	6eso	1.5eso	12eso	0	18eso	0	5exo
#17		1.5exo	4eso	3exo	dipl	15exo	dipl	22exo	dipl
#18		1eso	3eso	3exo	7eso	8exo	dipl	8exo	10exo
#19		.5exo	1eso	7exo	6eso	5exo	dipl	7exo	9exo
#20		0	1eso	0	3eso	2exo	4eso	6exo	8exo
Mean		0	-2.2	+1	-5.5	+2.3	-6.3	+4.1	+6.3

1

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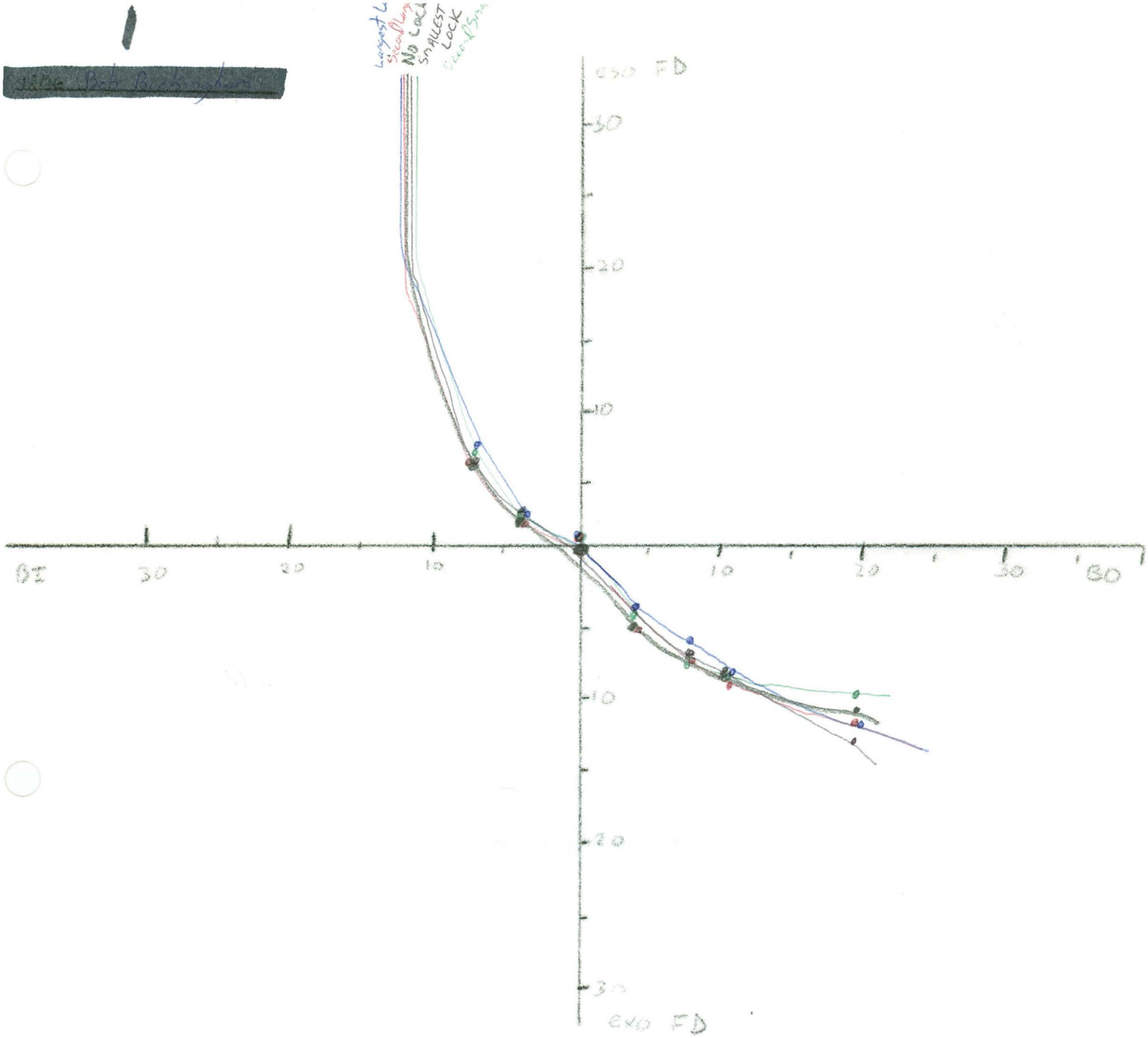

SUMMARY

NO FUSION LOCK	SMALLEST FUSION LOCK	Second Smallest Lock	Second Largest Lock	Largest Fusion Lock
0Δ Φ	0Δ Φ	0Δ 1eso	0Δ 1eso	0° 1eso
4BI 2eso	4BI 3eso	4BI 2,5eso	4BI 1,5eso	4BI 3eso
8BI 7eso	8BI 7eso	8BI 7 eso	8BI 5.5eso	8BI 7eso
12 BI Diplopia	12 BI Diplopia	12 BI Diplopia	12 BI Diplopia	12 BI Diplopia
4BO 5exo	4BO 5exo	4BO 3.5exo	4BO 3.5exo	4BO 3exo
[illegible]BO 7exo	8BO 7exo	8BO 7.0 exo	8BO 7 exo	8BO 6exo
12 BO 8exo	12BO 8exo	12BO 8,0 exo	12BO 8exo	12BO 8exo
20 BO 10 exo	20 BO 13exo	20 BO 8.0 exo	20 BO 10exo	20BO 10exo

2

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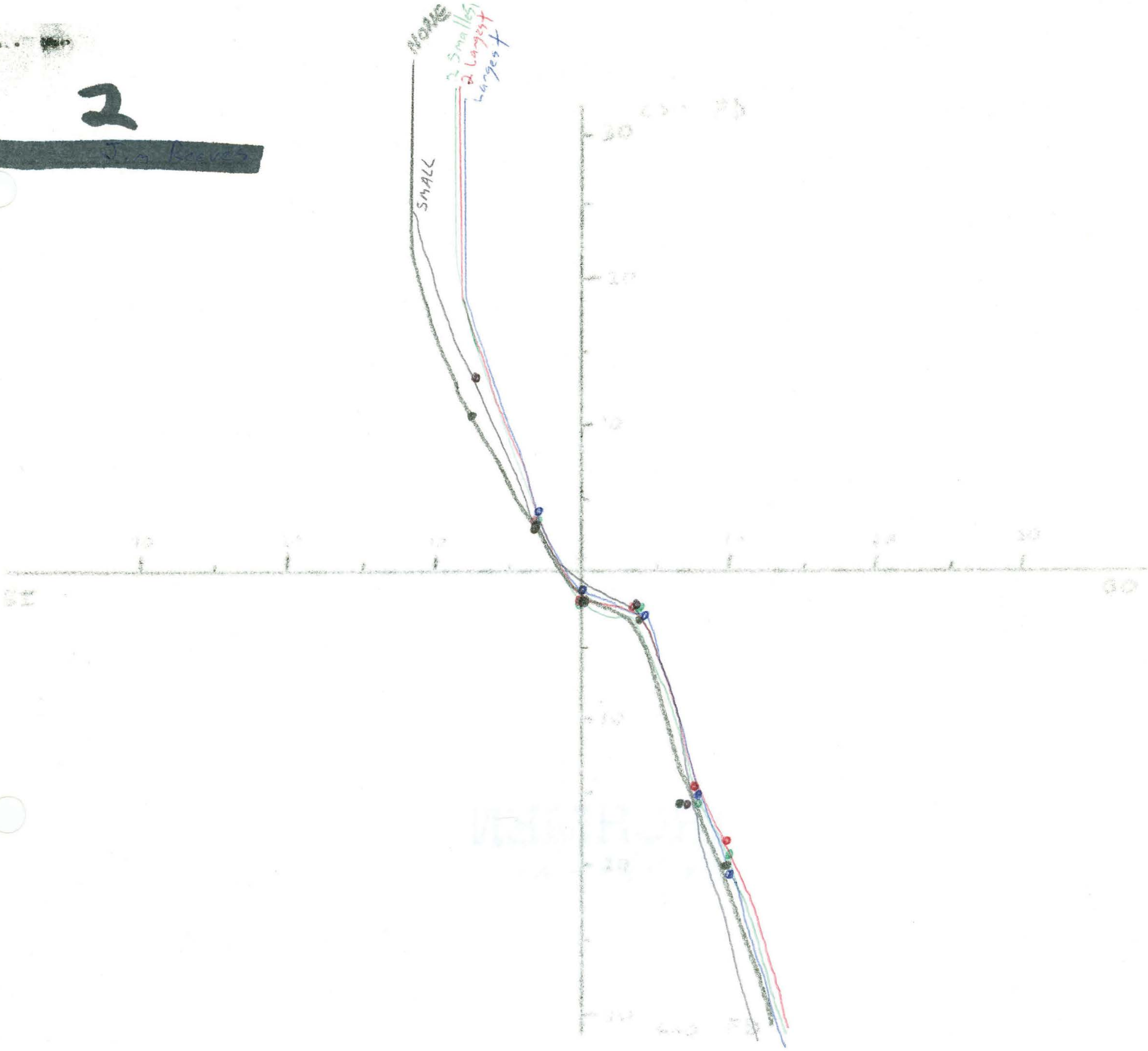

SUMMARY

NO FUSION LOCK	SMALL FUSION LOCK	SECOND SMALLEST LOCK	Second Largest Lock	Largest Fusion Lock
0 2 exo	0 2 exo	0 2 exo	0 2 exo	0 1.5 exo
4 BI 3 eso	4 BI 3 eso	4 BI 3 eso	4 BI 3 eso	4 BI 4.0 eso
8 BI 12 eso	8 BI 14 eso	8 BI Diplopia	8 BI Diplopia	8 BI Diplopia
12 BI Diplopia	12 BI Diplopia	12 BI Diplopia	12 BI Diplopia	12 BI Diplopia
4 BO 3 exo	4 BO 2 exo	4 BO 2 exo	4 BO 2 exo	4 BO 3 exo
8 BO 16 exo	8 BO 16 exo	8 BO 16 exo	8 BO 15 exo	8 BO 15 exo
12 BO 18 exo	12 BO 18 exo	12 BO 18 exo	12 BO 18 exo	12 BO 22 exo
BO Diplopia	20 BO Diplopia	20 BO Diplopia	20 BO Diplopia	20 BO Diplopia

3

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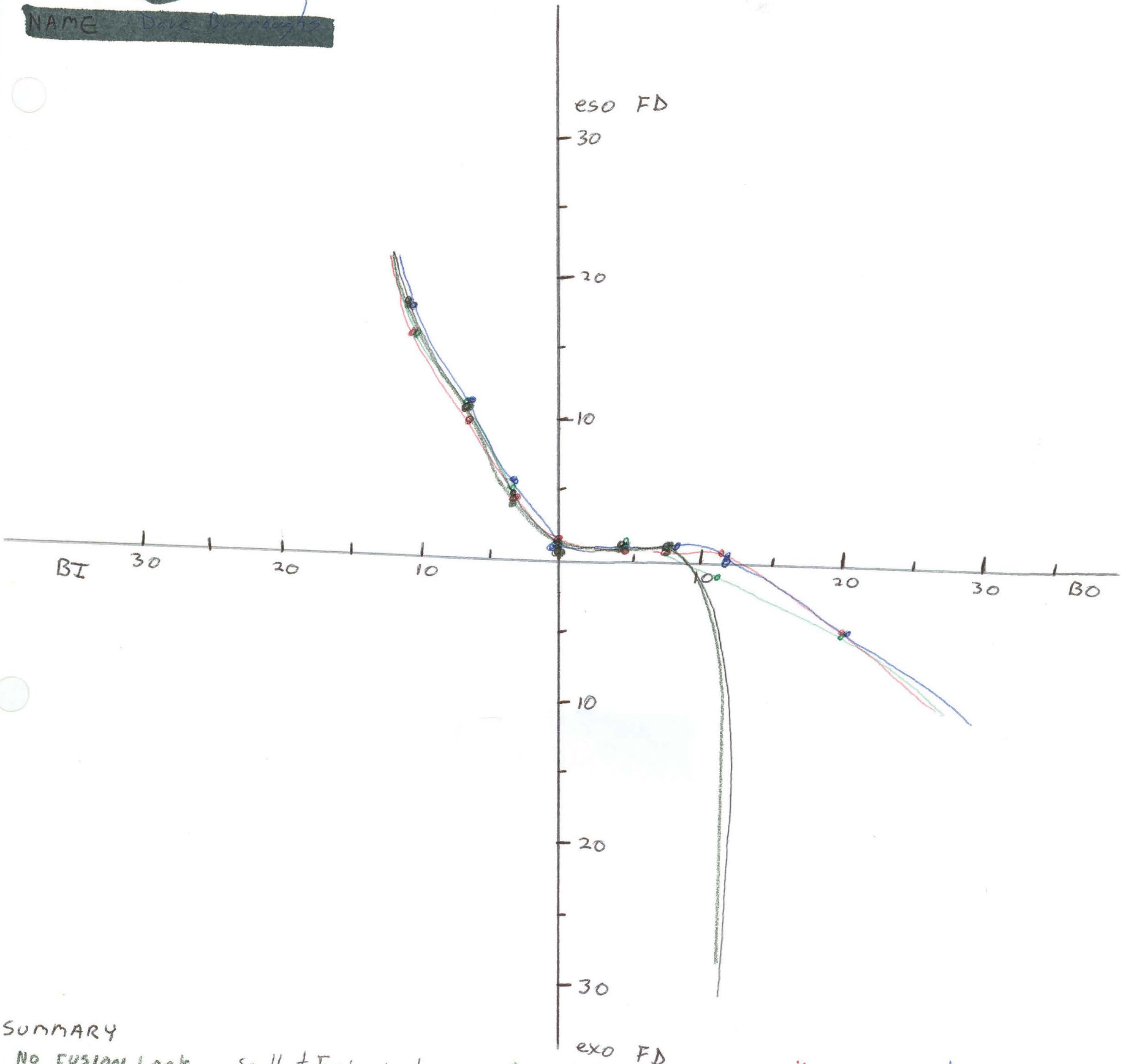

SUMMARY

No Fusion Lock		Smallest Fusion Lock		Second Smallest		Second Largest		Largest Fusion Ring	
0	1eso	0	1eso	0	1.5eso	0	2eso	0	1eso
4BI	4eso	4BI	5eso	4BI	5.5eso	4BI	4eso	4BI	6eso
8BI	12eso	8BI	12 eso	8BI	12 eso	8 BI	9eso	8 BI	12 eso
12 BI	17eso	12 BI	18 eso	12 BI	16 eso	12 BI	16eso	12 BI	18 eso
4 BO	2eso	4 BO	2eso	4 BO	2eso	4 BO	1eso	4 BO	1.5eso
8 BO	2.5eso	8 BO	1.5eso	8 BO	1 eso	8 BO	1eso	8 BO	1eso
12 BO	Diplopia	12 BO	Dipl.	12 BO	.5eso	12 BO	1eso	12 BO	ϕ
20 BO	Diplopia	20 BO	Diplo	20 BO	5exo	20 BO	5.5exo	20 BO	5exo

4

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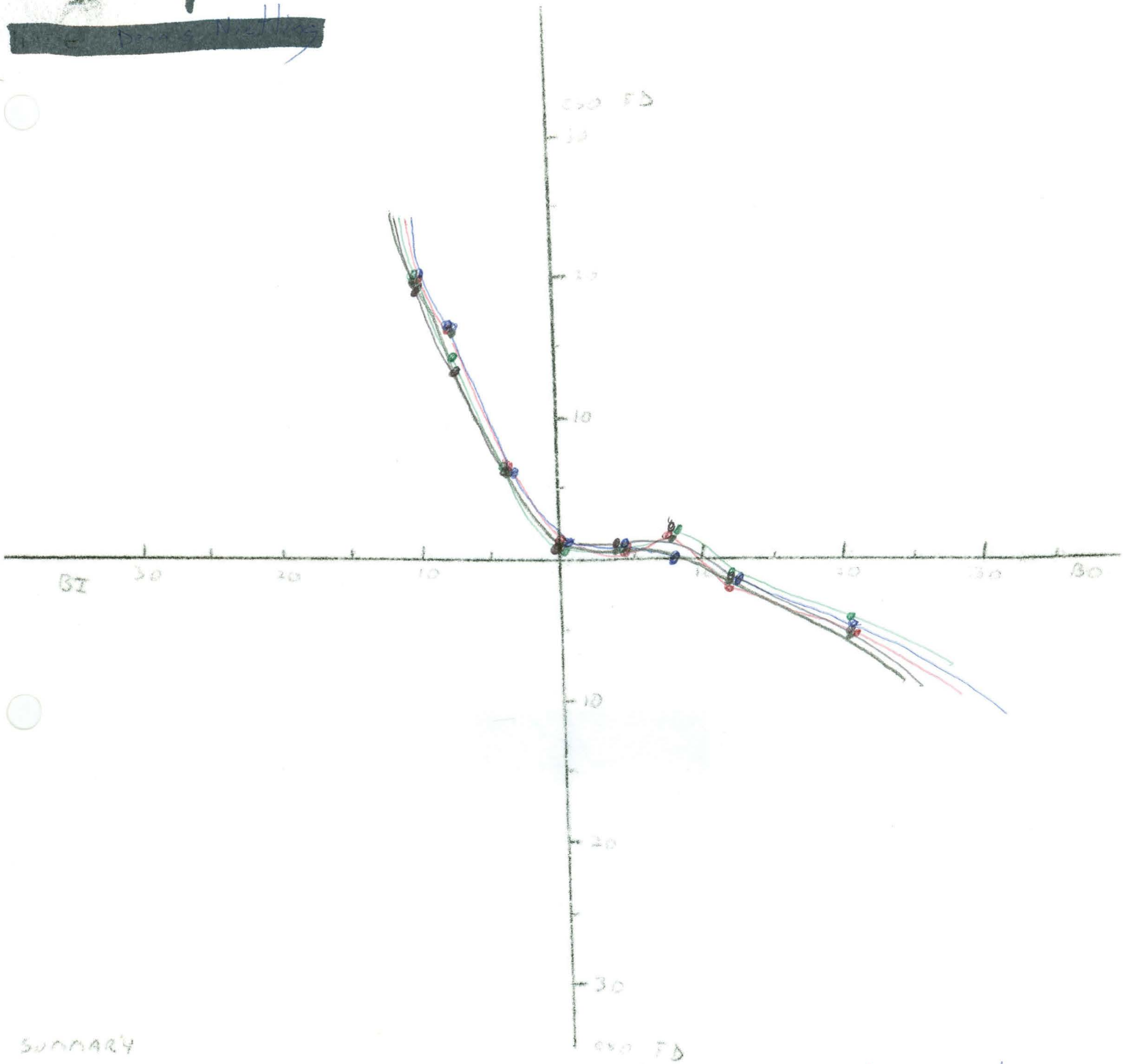

SUMMARY

NO FUSION LOCK		Smallest Fusion Lock		Second Smallest		Second Largest		Largest Fusion Lock	
0^{Δ}	1,5 eso	0	1eso	0	1,5eso	0	1eso	0	1eso
4BI	7 eso	4BI	7eso	4BI	7eso	4BI	7eso	4BI	7 eso
8 BI	17eso	8BI	13eso	8BI	14eso	8BI	17eso	8BI	18 eso
12 BI	20eso	12BI	19eso	12BI	20eso	12BI	20eso	12BI	20
4BO	1eso	4BO	2eso	4BO	1eso	4BO	1eso	4BO	1eso
8 BO	2eso	8 BO	3eso	8 BO	2eso	8 BO	2eso	8 BO	ϕ
12 BO	2exo	12 BO	1.5exo	12 BO	1exo	12 BO	2exo	12 BO	1,5exo
20 BO	5exo	20 BO	5exo	20 BO	3,5exo	20 BO	4exo	20 BO	4exo

5

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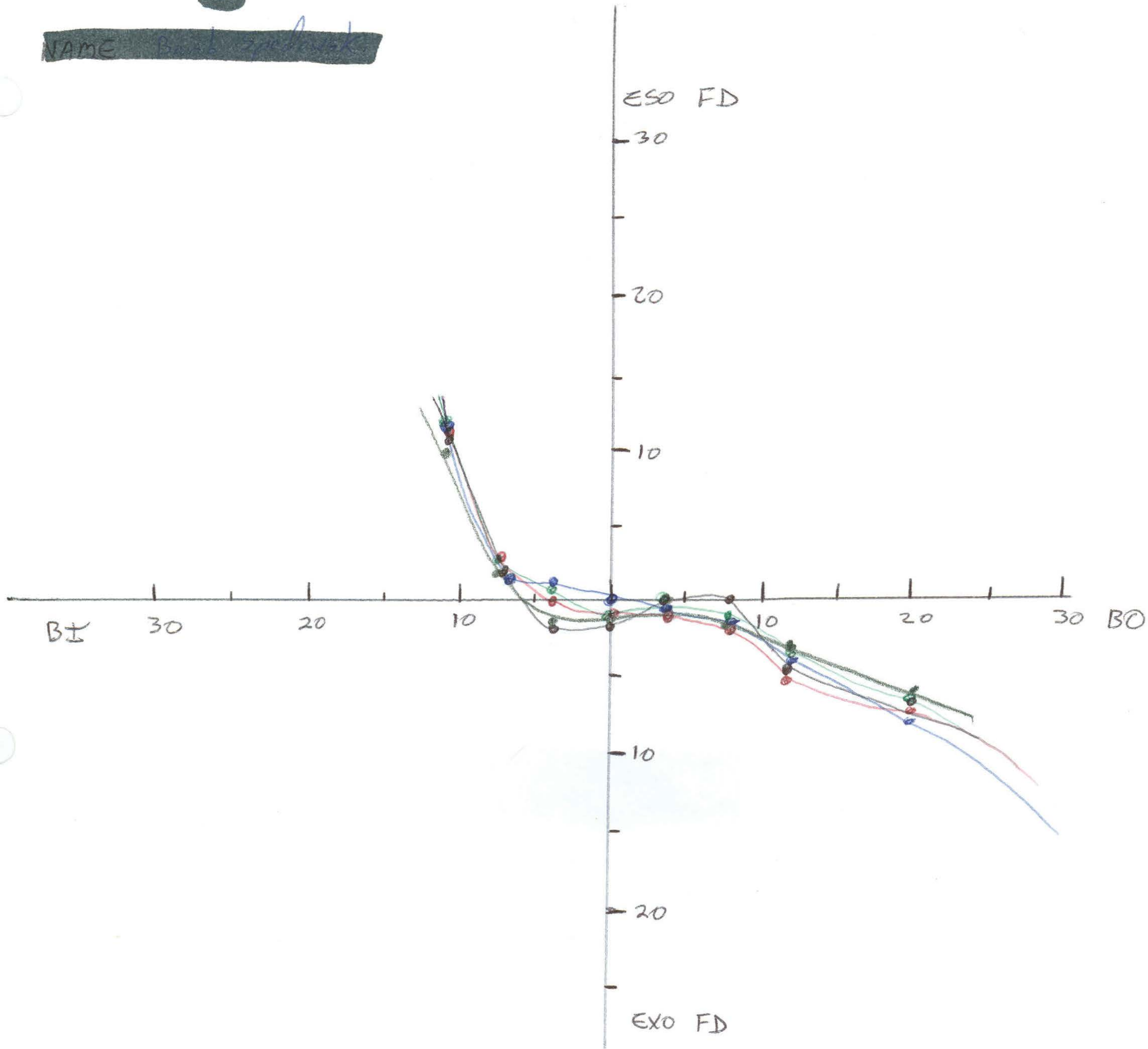
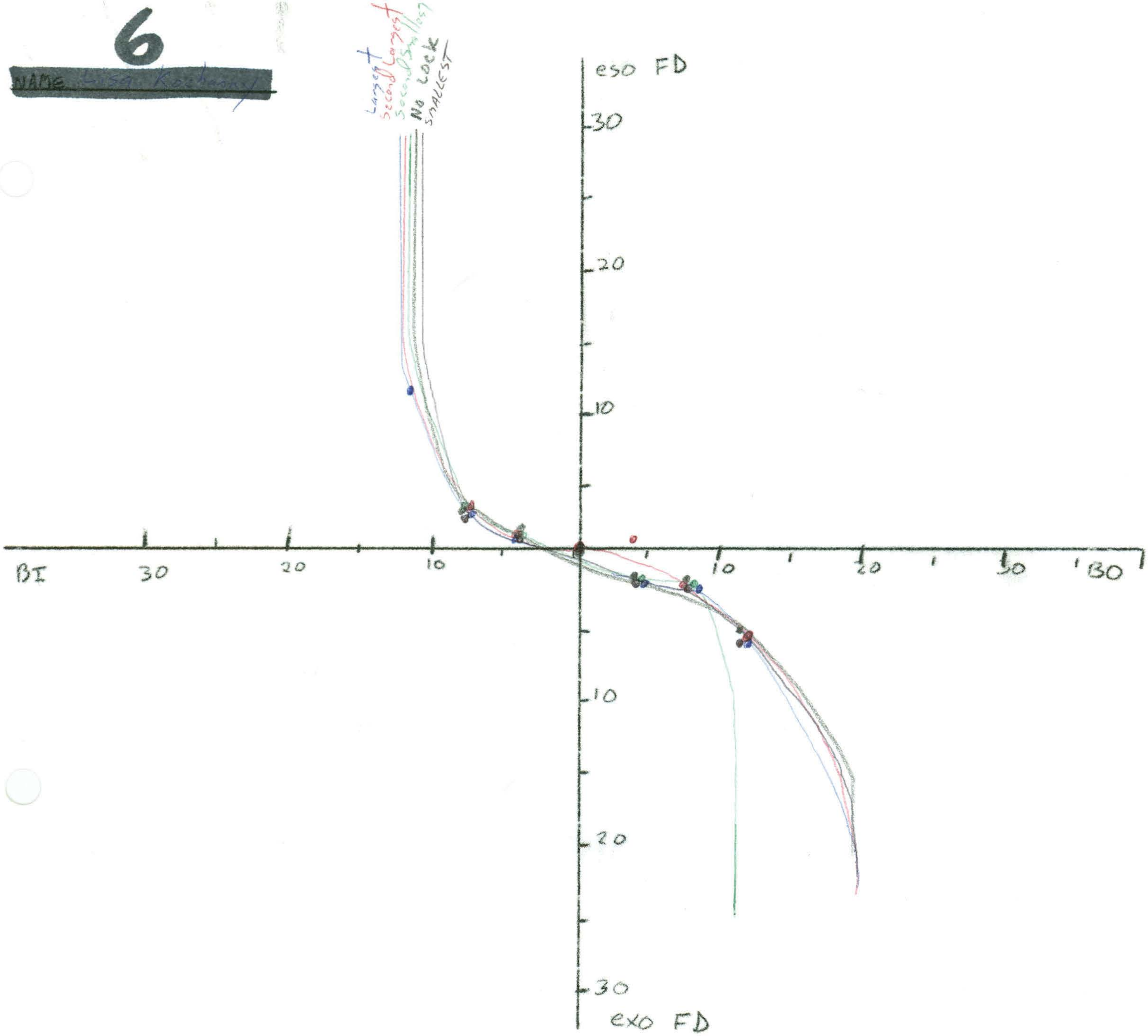


SUMMARY

	No Fusion Lock	Smallest Lock	Second Smallest	Second Largest	Largest Fusion Lock
0	1exo	1,5exo	1exo	1exo	ϕ
4BI	1.5exo	2exo	2eso	ϕ	2eso
8BI	2,5eso	2.5eso	3eso	3eso	2eso
12BI	11eso	12eso	12eso	10eso	12eso
4BO	ϕ	ϕ	ϕ	1exo	1exo
8BO	1.5exo	ϕ	1,5exo	2exo	2exo
12BO	3.5exo	4exo	3exo	5exo	4exo
20BO	6exo	7exo	6exo	6exo	7,5exo

6

NAME [redacted]



SUMMARY

No Fusion Lock	Smallest Fusion Lock	Second Smallest	Second Largest	Largest Fusion Lock
0Δ Φ	0 Φ	0 Φ	0 Φ	0 Φ
4BI 2eso	4BI 1eso	4BI 2eso	4BI 1.5 eso	4BI 1eso
8BI 3.5eso	8BI 3eso	8BI 3eso	8BI 3.5 eso	8BI 3eso
12 BI Diplopia	12 BI Diplopia	12 BI Diplopia	12 BI Diplopia	12 BI 10eso
4BO 2exo	4 BO 2exo	4BO 2 exo	4BO 1eso	4BO 2exo
8 BO 2exo	8 BO 2exo	8BO 2exo	8BO 2exo	8 BO 2exo
12 BO 5exo	12 BO 6exo	12 BO Diplopia	12BO 5exo	12 BO 6exo
[illegible] BO Diplopia	20BO Diplopia	20 BO Diplopia	20BO Diplopia	20 BO Diplopia

7

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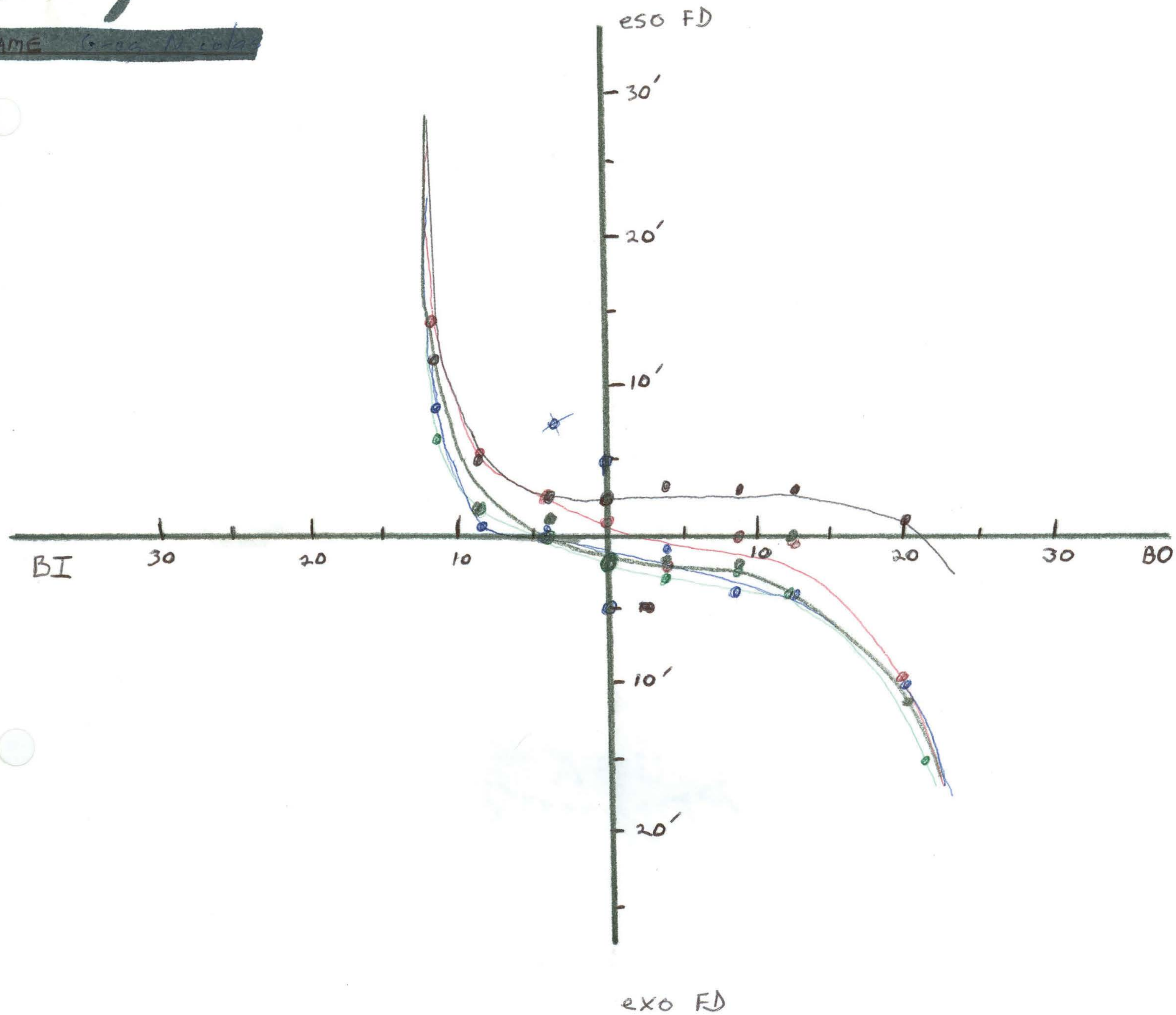

Summary

	No Fusion Lock	Smallest Ring Fusion Lock	Second Smallest	Second Largest	Largest Fusion Ring
0^Δ	4 exo	3 eso	2 exo	1 eso	5 exo
4 BI	2 eso	3 eso	0	3 eso	0
8 BI	2 eso	6 eso	2 eso	5 eso	1 eso
12 BI	Diplopia	10 eso	5 eso	14 eso	8 eso
4 BO	3 exo	4 eso	3 exo	2 exo	1 exo
8 BO	3 exo	4 eso	2 exo	0	4 exo
12 BO	3 exo	4 eso	3 exo	0	4 exo
20 BO	13 exo	2 eso	15 exo	10 exo	10 exo

8

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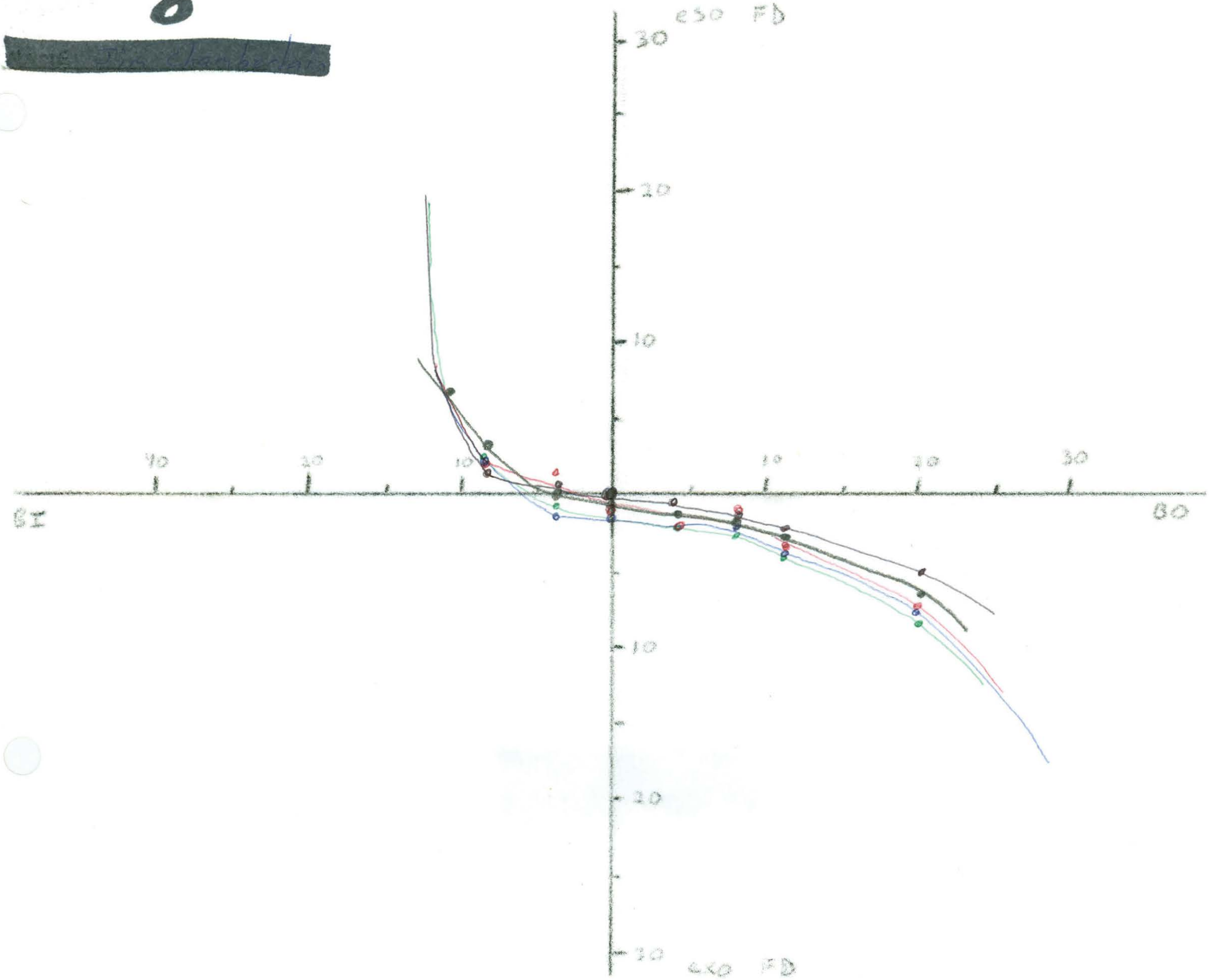

SUMMARY

NO FUSION LOCK		SMALLEST FUSION RING		Second Smallest Ring		Second Largest Ring		Largest Ring	
0	0	0	0	0	.5exo	0	.5exo	0	1exo
4BI	0	4BI	.5eso	4BI	.5exo	4BI	2eso	4BI	1exo
8BI	3eso	8BI	2eso	8BI	3.5eso	8BI	2eso	8BI	2.5eso
12BI	7eso	12BI	Diplopia	12BI	Diplopia	12BI	Diplopia	12BI	Diplopia
4BO	1exo	4BO	.5exo	4BO	2exo	4BO	2exo	4BO	2exo
8BO	1exo	8BO	1exo	8BO	2exo	8BO	1exo	8BO	1.5exo
12BO	1.5exo	12BO	1.5exo	12BO	3exo	12BO	3.5exo	12BO	3exo
20BO	5.5exo	20BO	4.5exo	20BO	7exo	20BO	7exo	20BO	5.5exo

9

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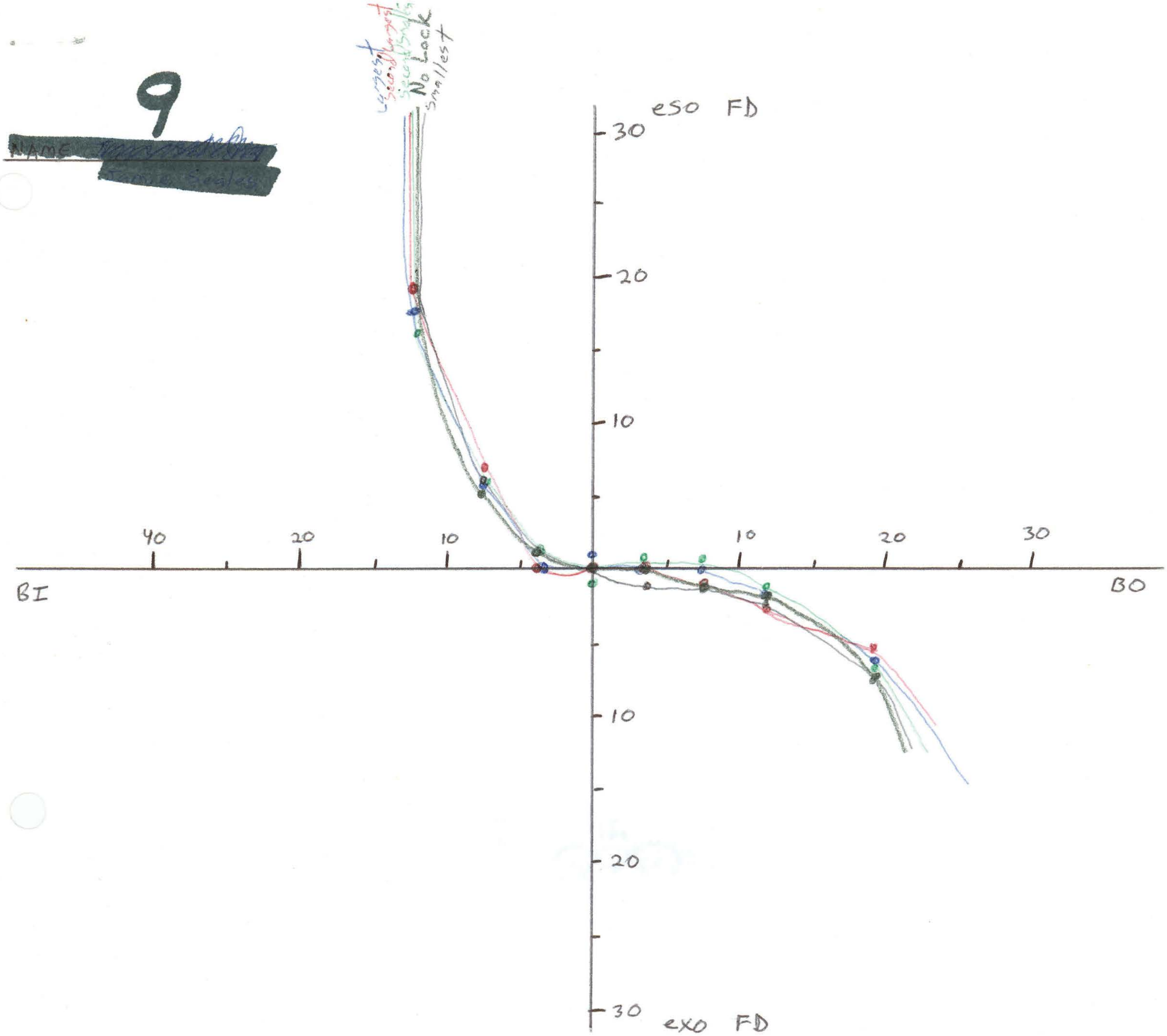
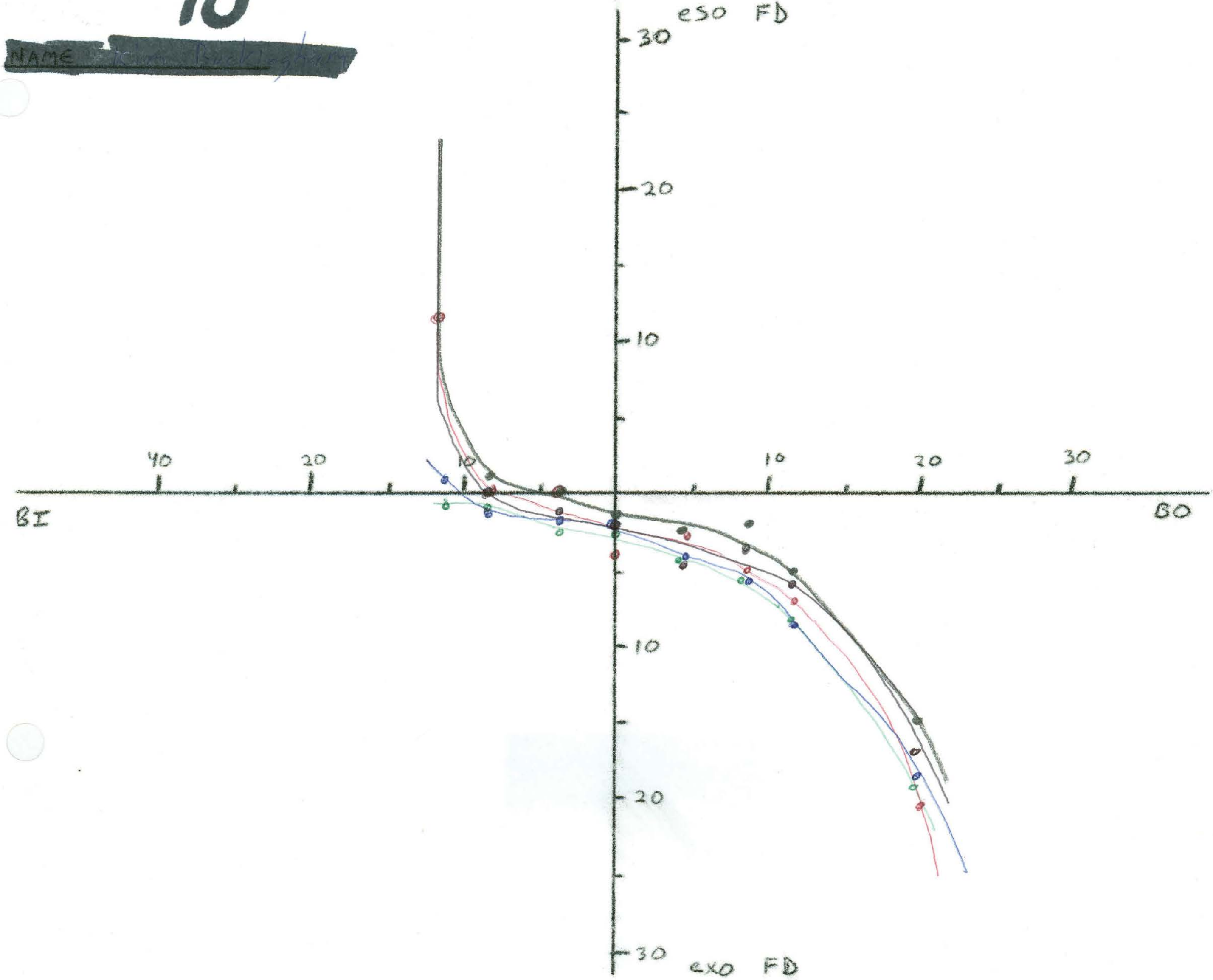


SUMMARY

No Fusion Lock	Smallest Fusion Lock	Second Smallest	Second Largest	Largest Fusion Lock
0^{Δ} ϕ	0^{Δ} 0	0 1exo	0 ϕ	0 1eso
4^{Δ}BI 1eso	4^{Δ}BI 1 eso	4BI 1eso	4BI ϕ	4BI 0
8^{Δ} BI 6eso	8^{Δ} BI 7eso	8 BI 7eso	8 BI 7eso	8 BI 7eso
12^{Δ} BI Diplopia	12^{Δ} BI Dipopia	12 BI 16eso	12 BI 18eso	12 BI 17eso
4 BO ϕ	4 BO 1exo	4 BO 1eso	4 BO ϕ	4 BO ϕ
8 BO 1exo	8 BO 1exo	8 BO 1eso	8 BO 1exo	8 BO ϕ
12 BO 1exo	12 BO 1.5exo	12 BO 1exo	12 BO 2exo	12 BO 1.5exo
20 BO 7exo	20 BO 7exo	20 BO 7exo	20 BO 6.5exo	20 BO 6.5exo

10

NAME [redacted]

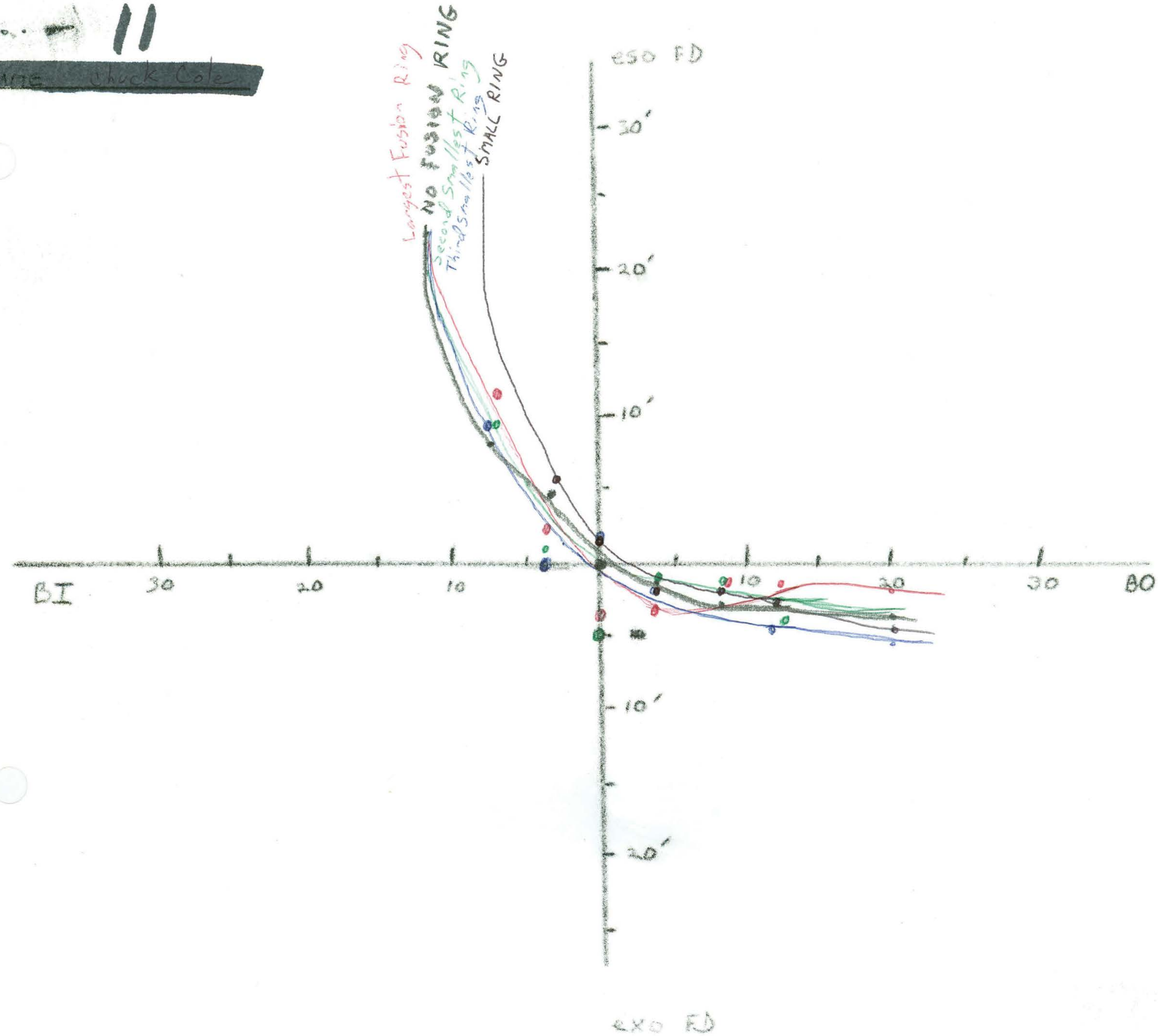


SUMMARY

NO FUSION LOCK		SMALLEST FUSION RING		Second Smallest Ring		Second Largest Ring		Largest Ring	
0	1exo	0	2exo	0	3exo	0	4exo	0	2exo
4BI	0	4BI	1,5exo	4BI	3exo	4BI	0	4BI	2exo
8BI	1eso	8BI	0	8BI	1exo	8BI	0	8BI	1exo
12BI	Diplopia	12BI	3,5eso	12BI	1exo	12BI	12eso	12BI	1eso
4BO	2exo	4BO	4,5exo	4BO	4exo	4BO	2exo	4BO	4exo
8BO	1exo	8BO	2exo	8BO	5exo	8BO	4exo	8BO	
12BO	4exo	12BO	4exo	12BO	8exo	12BO	6exo	12BO	5exo
20BO	15exo	20BO	16exo	20BO	18exo	20BO	20exo	20BO	18exo

11

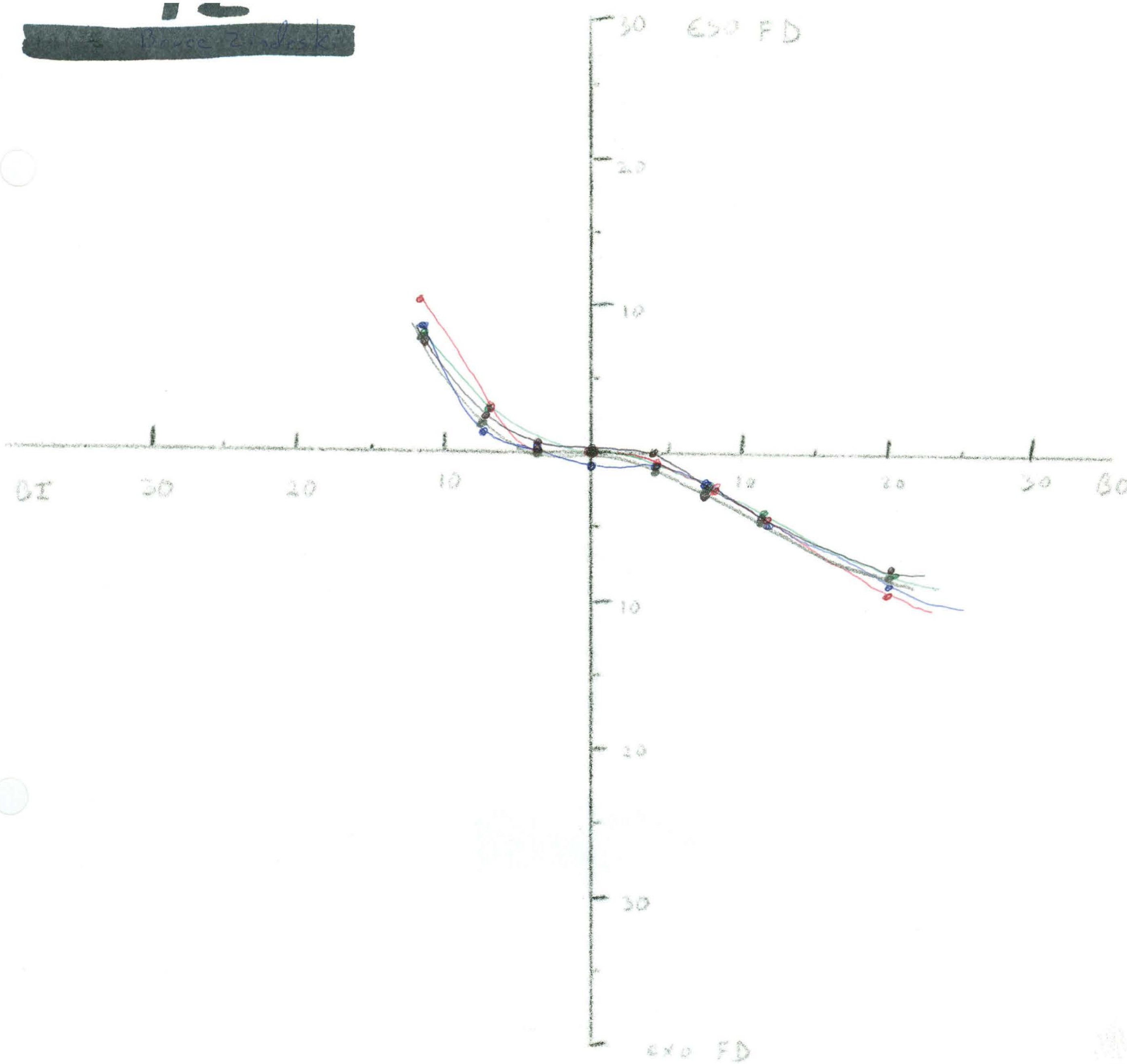
NAME [redacted]



SUMMARY

Prism	NO FUSION RING	Small Ring	2nd Smallest Ring	2nd Largest Ring	Largest Ring
0^Δ	0	1.5eso	.5exo	2exo	4exo
4BI	5eso	6eso	1eso	0	2.5eso
4BO	2exo	2exo	1exo	2exo	2exo
8BI	8eso	Diplopia	9eso	8eso	12eso
8BO	3exo	2exo	1exo	2exo	1exo
12BI	diplopia	Diplopia	Diplopia	Diplopia	Diplopia
12BO	3exo	3exo	4exo	4.5exo	1exo
20BO	3.5exo	4exo	5exo	6exo	1.5exo

[redacted]



SUMMARY

NO FUSION LOCK
0Δ
4BI
8 BI
12 BI

Smallest Fusion Lock
0Δ
4 BI
8 BI
12 BI
4BO
8BO
12BO
20BO

Second Smallest

0	ϕ
4BI	ϕ
8 BI	3eso
12BI	8eso
4BO	1exo
8BO	2exo
12BO	4exo
20BO	8exo

Second Largest

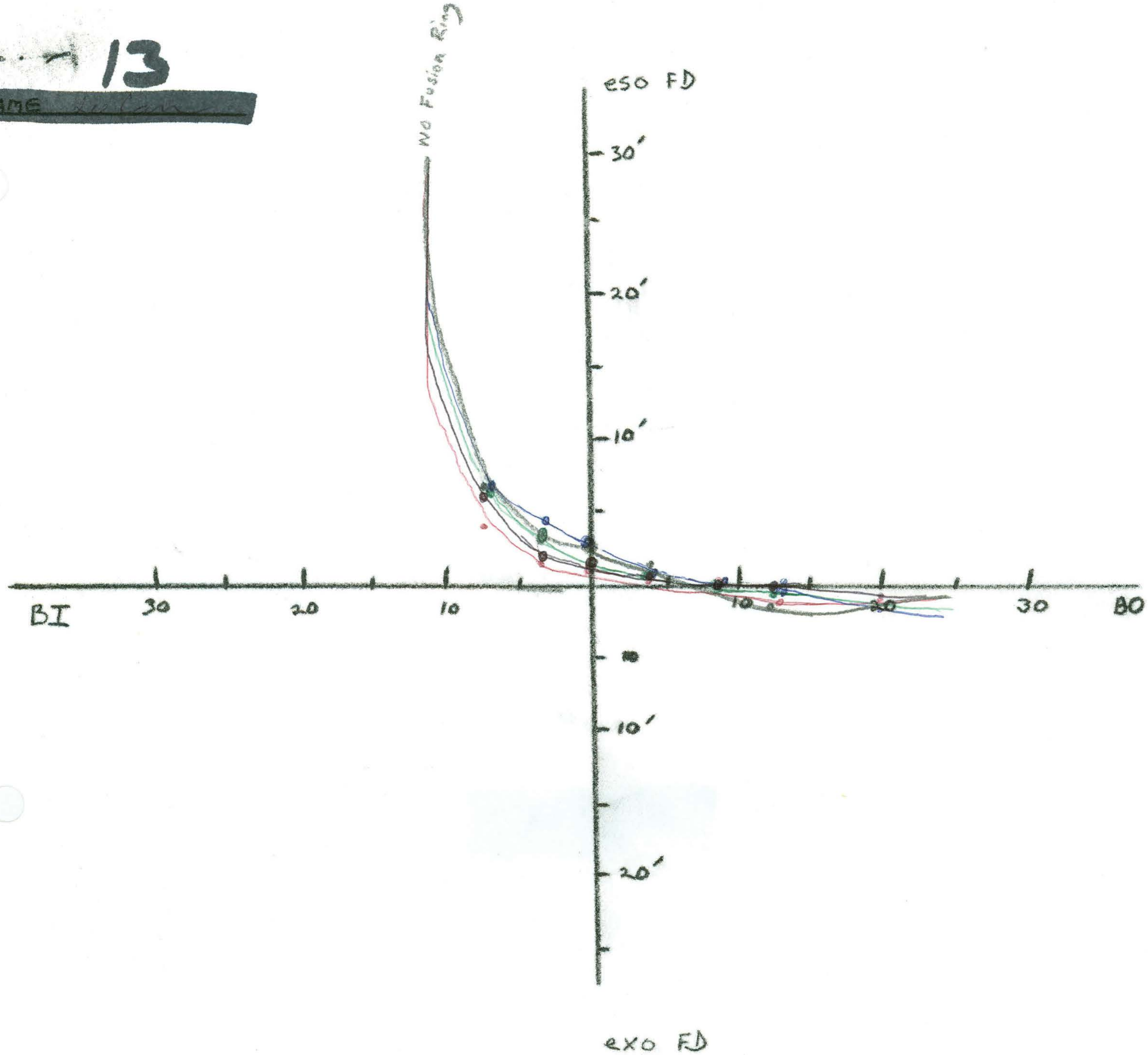
0	ϕ
4BI	.5eso
8 BI	3eso
12 BI	10eso
4 BO	1exo
8 BO	2exo
12 BO	4exo
20 BO	10exo

Largest Fusion Ring

0	1exo
4BI	.5eso
8 BI	2eso
12 BI	8eso
4BO	1exo
8BO	2exo
12BO	4exo
20 BO	8exo

13

NAME [redacted]



SUMMARY

No Fusion Ring		Smallest Fusion Ring		2nd Smallest Ring		2nd Largest Ring		Smallest Ring	
0^Δ	2.5eso	0^Δ	2eso	0^Δ	2.5eso	0^Δ	3eso	0^Δ	2eso
4BI	3.0eso	4BI	2eso	4BI	2.5eso	4BI	4 eso	4BI	2eso
4BO	1eso	4BO	1eso	4BO	1eso	4BO	.5eso	4BO	.5eso
8BI	6.5eso	8BI	5.5eso	8BI	5eso	8BI	6eso	8BI	3eso
8BO	0	8BO	0	8BO	0	8BO	0	8BO	0
12BI	Diplopia	12BI	Diplopia	12BI	Diplopia	12BI	Diplopia	12BI	Diplopia
12BO	1exo	12BO	0	12BO	.5exo	12BO	1exo	12BO	1exo
20BO	1exo	20BO	1exo	20BO	1.5exo	20BO	2exo	20BO	1exo

14

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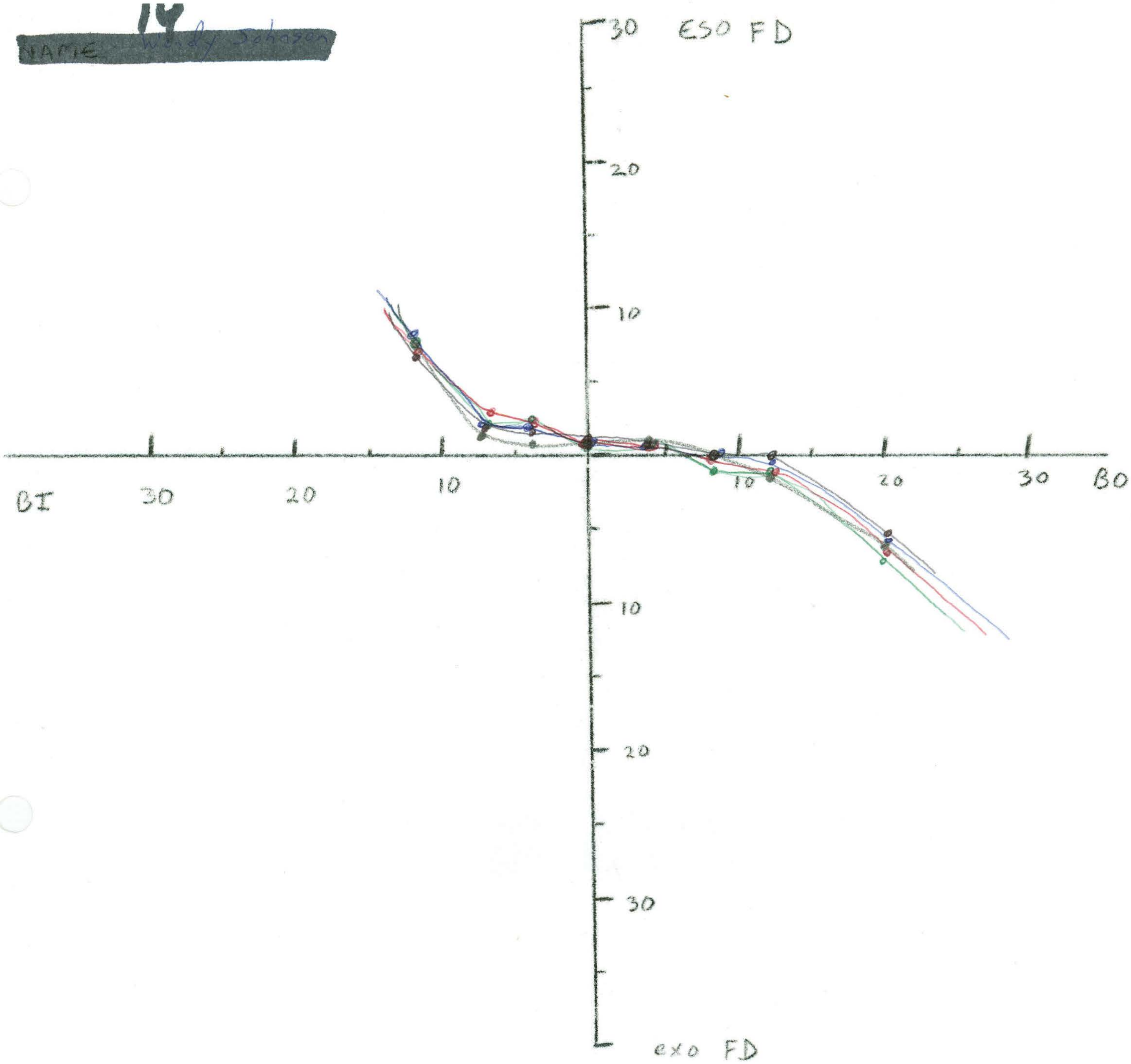
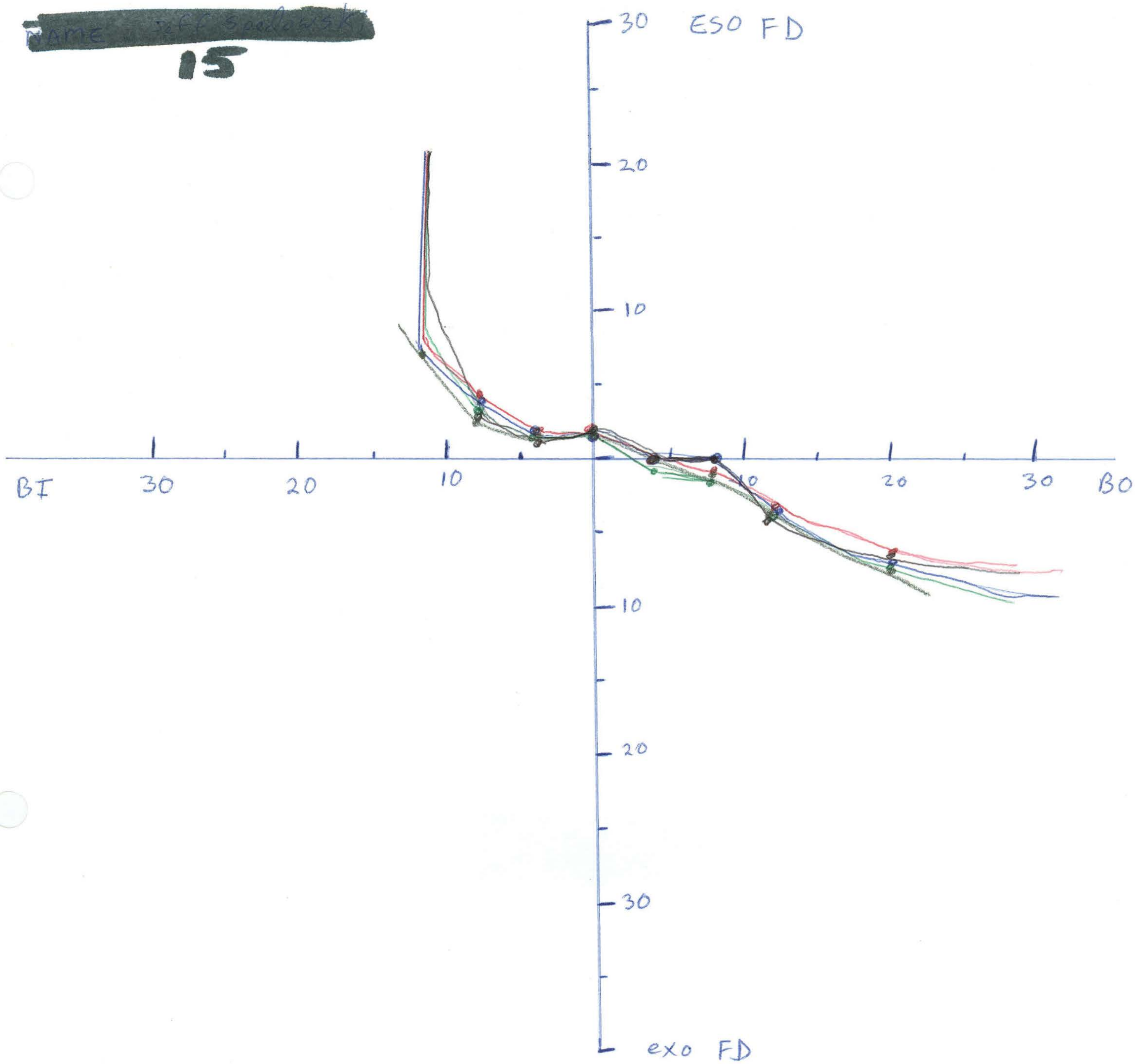


SUMMARY

	NO FUSION LOCK	Smallest Fusion Lock	Second Smallest	Second Largest	Largest Fusion Ring
0	1 eso	1.5 eso	1 eso	1 eso	1.5 eso
4 BI	1 eso	2 eso	3 eso	2.5 eso	2 eso
8 BI	2 eso	2.5 eso	2.5 eso	3 eso	2 eso
12 BI	7 eso	7 eso	7 eso	7 eso	8 eso
4 BO	1.5 eso	1.5 eso	1 eso	1 eso	1 eso
8 BO	ϕ	ϕ	1 exo	ϕ	ϕ
12 BO	2 exo	ϕ	1 exo	1 exo	.5 exo
20 BO	6 exo	6.5 exo	7 exo	7.5 exo	6 exo

[redacted]

15

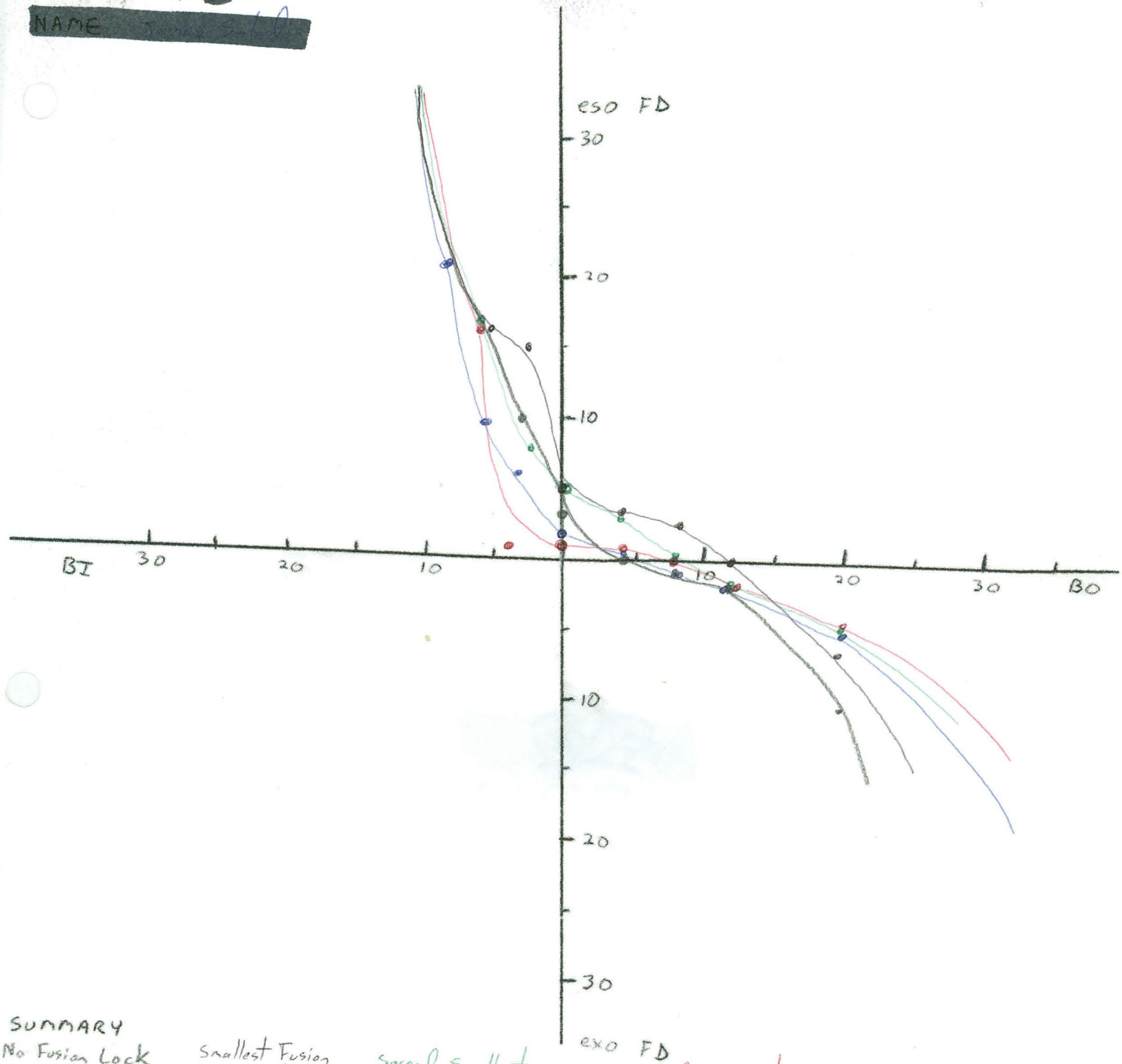


SUMMARY

	No Fusion Lock	Smallest Fusion Lock	Second Smallest Lock	Second Largest Lock	Largest Fusion Lock
0	2 eso	2.5 eso	2 eso	2.5 eso	2 eso
4 BI	2 eso	2 eso	2 eso	2.5 eso	2 eso
8 BI	3.5 eso	3 eso	3.5 eso	4 eso	4 eso
12 BI	8 eso	Diplopia	Diplopia	Diplopia	Diplopia
4 BO	ϕ	ϕ	1 exo	ϕ	ϕ
8 BO	1 exo	ϕ	1.5 exo	1 exo	ϕ
12 BO	3 exo	4 exo	4 exo	3.5 exo	3 exo
20 BO	8.5 exo	7 exo	8 exo	7 exo	7.5 exo

16

[redacted]

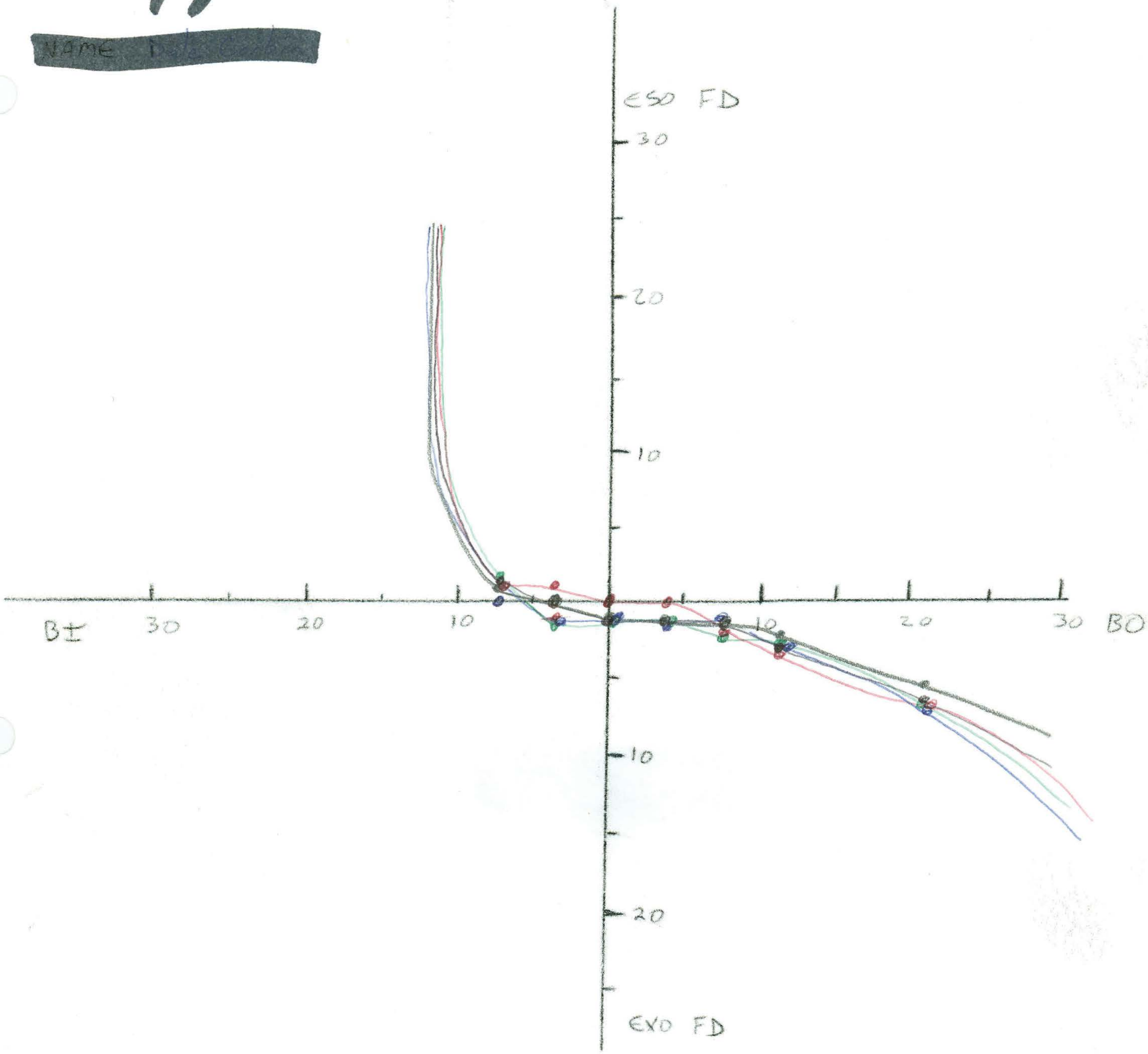


SUMMARY

	No Fusion Lock	Smallest Fusion Lock	Second Smallest	Second Largest	Largest Fusion Lock
0	3eso	5eso	5eso	1,5eso	2eso
4BI	10eso	15eso	7,5eso	1eso	5.5eso
8BI	Dipl	16eso	16eso	15.5eso	9eso
12BI	Dipl	Dipl	Dipl	Dipl	20eso
4BO	ϕ	4eso	3eso	1,5eso	.5eso
8BO	1exo	3eso	.5eso	ϕ	1exo
12BO	2exo	ϕ	2exo	2exo	2exo
20BO	11exo	6exo	3,5exo	3.5exo	5,5exo

17

NAME [redacted]

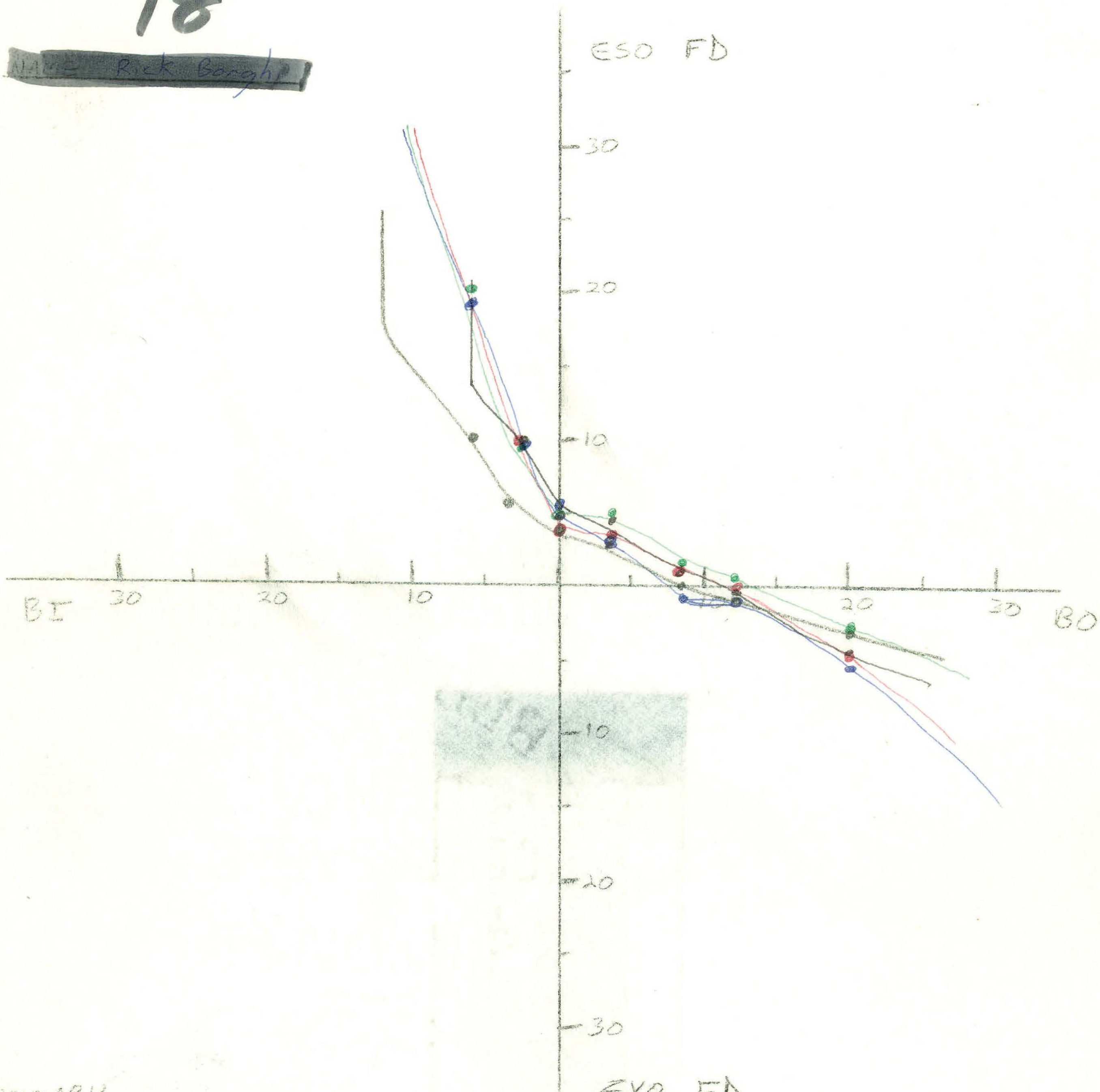


SUMMARY

Prism	No Fusion Lock	Smallest Fusion Lock	Second Smallest	Second Largest	Largest Fusion Lock
0	1exo	1exo	1exo	ϕ	1exo
4BI	ϕ	ϕ	1,5exo	1,5eso	1exo
8BI	1eso	1,5eso	2eso	1eso	ϕ
12 BI	Diplopia	Dipl.	Dipl.	Dipl	Dipl
4 BO	1exo	1exo	1exo	ϕ	1exo
8 BO	1exo	1exo	2exo	2exo	1exo
12 BO	2exo	3exo	2exo	3exo	2exo
20 BO	6,5exo	7exo	7exo	7exo	7exo

18

[redacted]

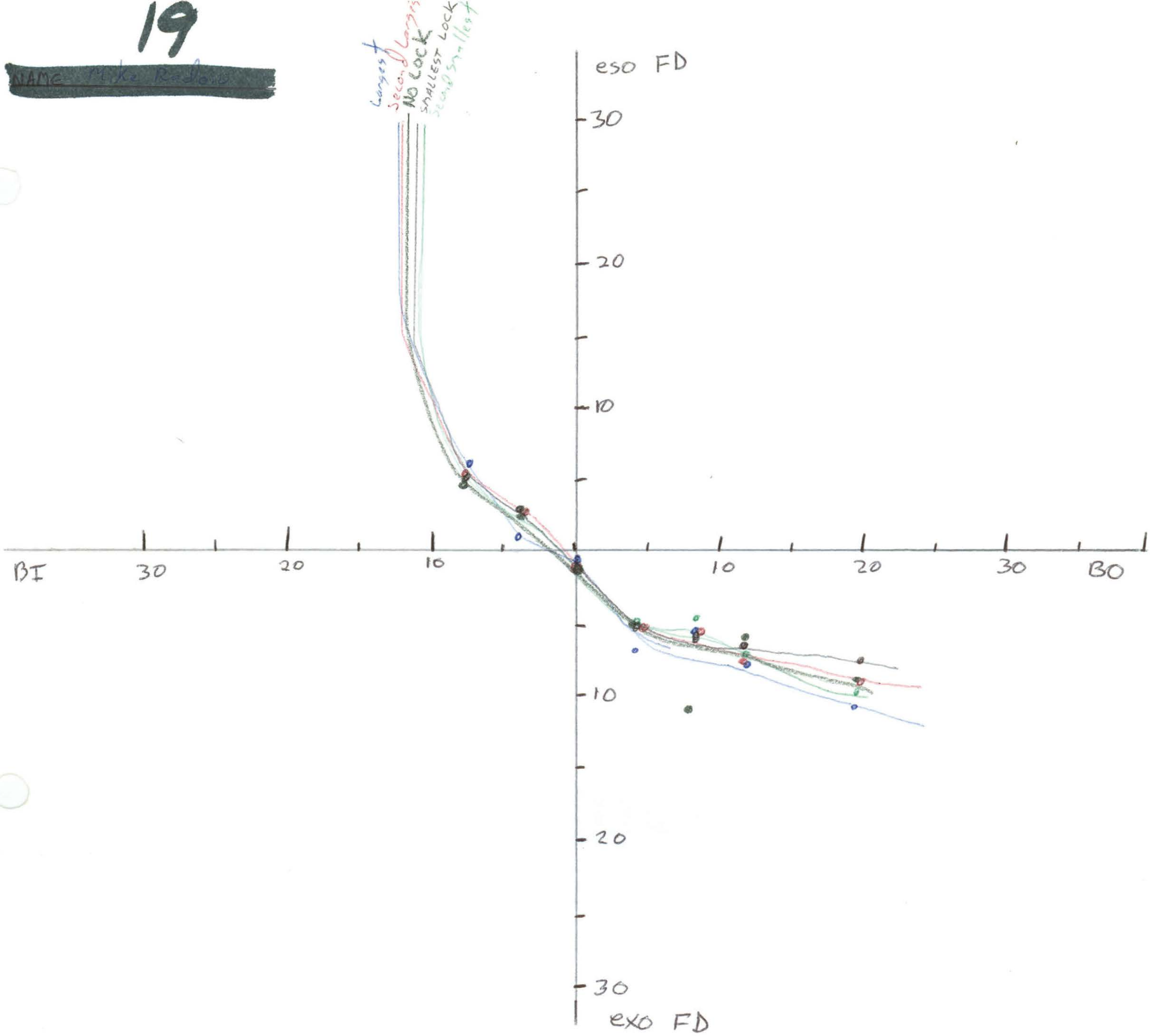


SUMMARY

No Fusion Lock	Smallest Fusion Lock	Second Smallest	Second Largest	Largest Fusion Lock
0 4eso	0 5eso	0 5eso	0 4eso	0 5,5eso
4BI 7eso	4BI 10eso	4BI 9eso	4BI 10eso	4BI 9eso
8BI 10eso	8BI dipl.	8BI 20eso	8BI dipl	8BI 18eso
12BI diplopia	12BI dipl.	12BI dipl	12BI dipl	12BI dipl.
4BO 3eso	4BO 5eso	4BO 5,5eso	4BO 4eso	4BO 3eso
8BO ϕ	8BO 1eso	8BO 2eso	8BO 2eso	8BO 1exo
12BO 1exo	12BO .5exo	12BO 1eso	12BO ϕ	12BO 1exo
[illegible] BO 4exo	20BO 5exo	20BO 3exo	20BO 5exo	20BO 6exo

19

[redacted]

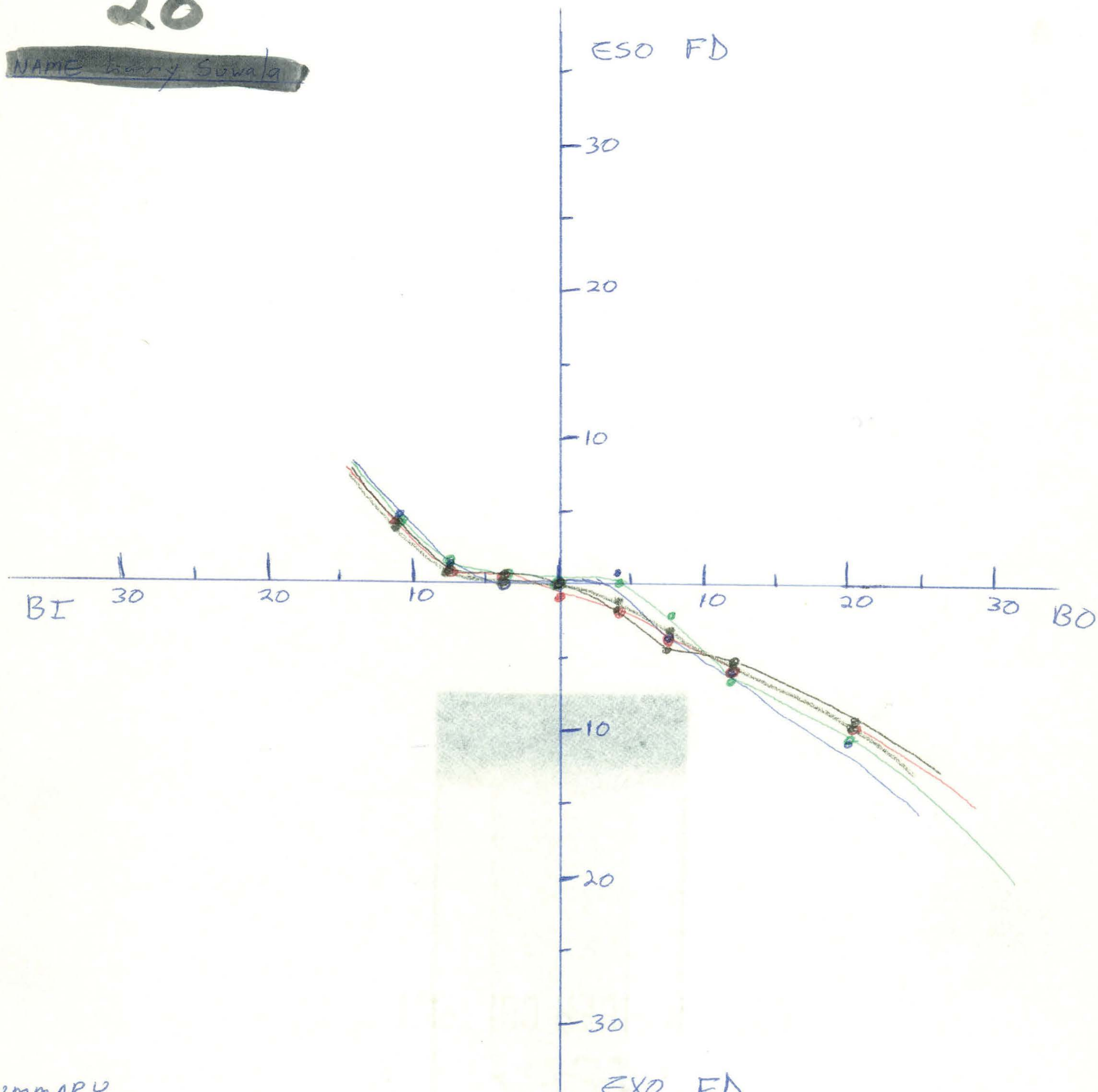


SUMMARY

NO FUSION LOCK	SMALLEST FUSION LOCK	Second Smallest Lock	Second Largest Lock	Largest Fusion Lock
0Δ 1.5exo	0Δ 1exo	0Δ 2exo	0 1.5exo	0Δ .5exo
4 BI 3eso	4BI 3eso	4BI 3eso	4BI 3eso	4BI 1eso
8 BI 5eso	8 BI 5eso	8 BI 4eso	8 BI 5eso	8BI 6eso
12 BI Diplopia	12 BI Diplopia	12 BI Diplopia	12 BI Dipopia	12 BI Diplopia
4BO 5exo	4 BO 5exo	4 BO 5exo	4BO 5exo	4BO 7exo
8BO 11exo	8 BO 4 exo	8 BO 3.5exo	8 BO 5exo	8 BO 5exo
[illegible]BO 5exo	12 BO 5exo	12 BO 7exo	12 BO 7exo	12 BO 7exo
20 BO 8.5exo	20 BO 7exo	20 BO 10exo	20 BO 7exo	20 BO 9exo

20

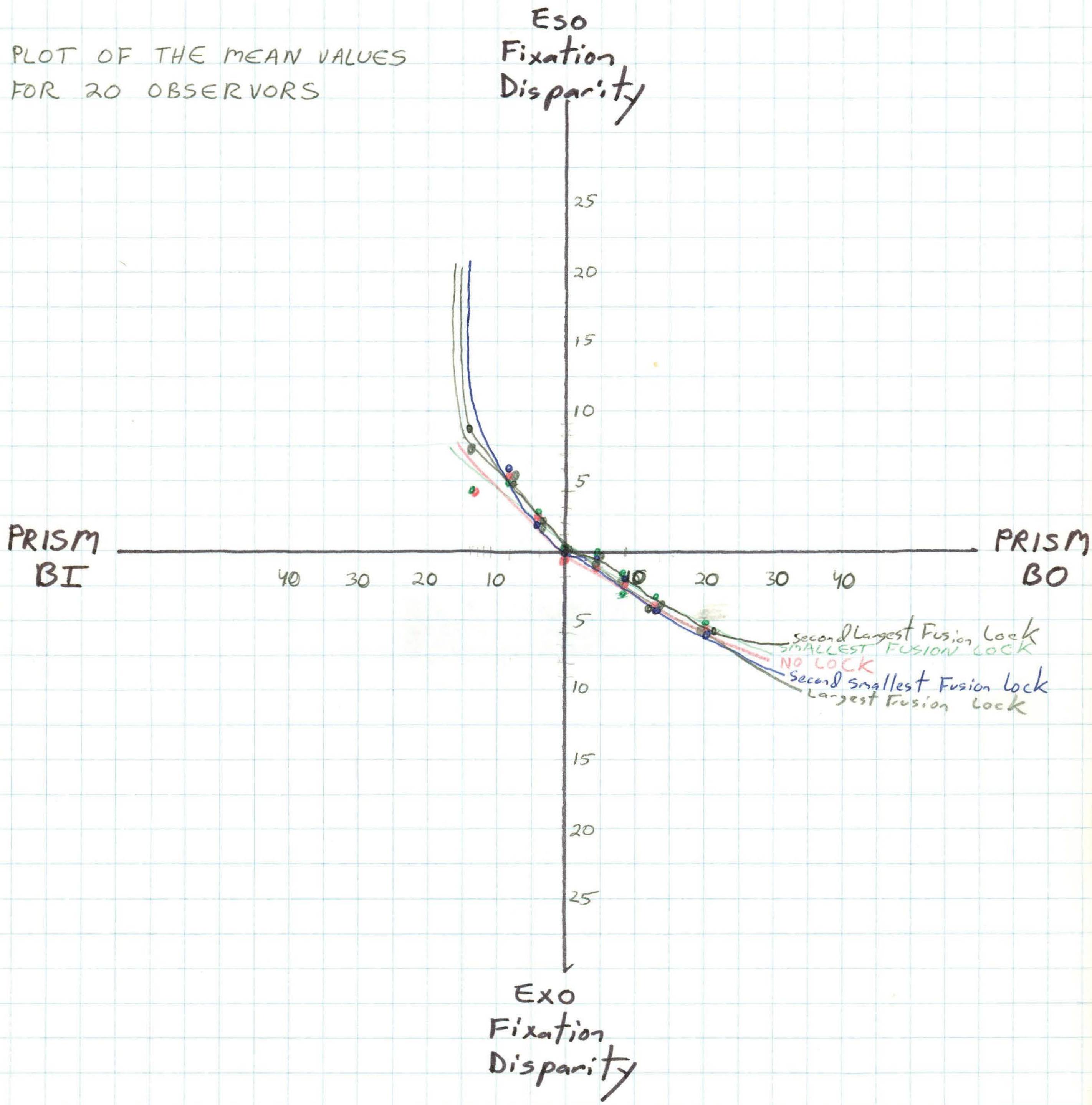
NAME [redacted]



SUMMARY

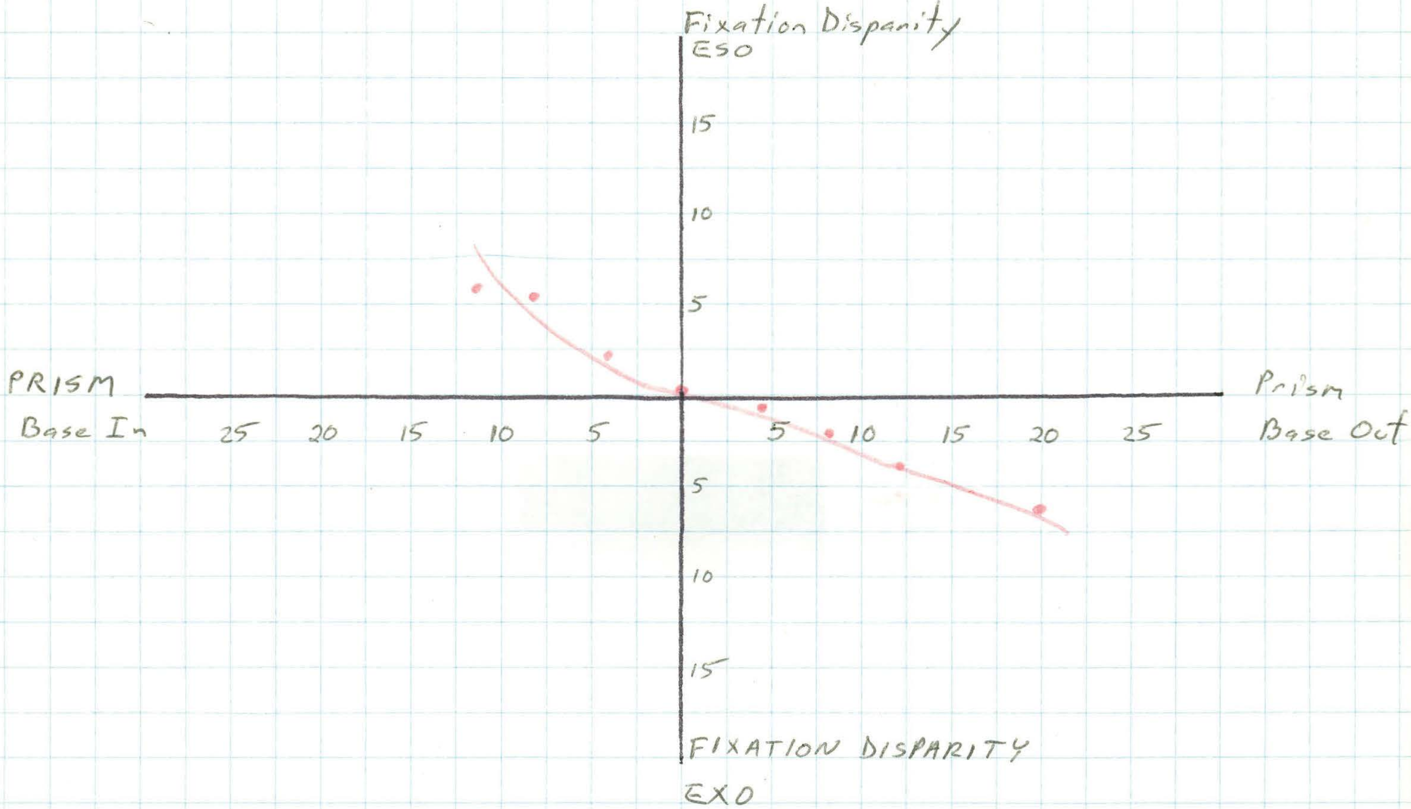
NO FUSION LOCK		Small Fusion Lock		Second Smallest		Second Largest		Largest Fusion Ring	
0	Φ	0	Φ	0	Φ	0	1exo	0	Φ
4BI	Φ	4BI	1eso	4BI	Φ	4BI	1eso	4BI	1eso
8BI	1eso	8BI	1eso	8BI	2eso	8BI	1eso	8BI	3eso
12 BI	3.5eso	12 BI	3.5eso	12 BI	5eso	12 BI	3eso	12 BI	4eso
4BO	1exo	4BO	1.5exo	4BO	1eso	4BO	2exo	4BO	Φ
8BO	3exo	8BO	4exo	8BO	3exo	8BO	2.5exo	8BO	2exo
BO	5exo	12BO	4exo	12BO	5exo	12BO	5exo	12BO	6exo
20BO	8exo	20BO	8exo	20BO	10exo	20BO	8exo	20BO	8exo

PLOT OF THE MEAN VALUES FOR 20 OBSERVORS



MEAN OF THE MEANS

Fusion Ring	PRISM							
	0	4BI	4BO	8BI	8BO	12BI	12BO	20BO
None	.2eso	2.5eso	.8exo	5.25eso	2.4exo	3.8eso	3.5exo	6exo
Smallest	.8eso	2.6eso	0	4.9eso	1.3exo	4.0eso	2.9exo	5.1exo
Second Smallest	.3eso	2.3eso	.5exo	6eso	2.15exo	dipl	3.7exo	6.7exo
Second Largest	.2eso	2.4eso	.6exo	4.9eso	2.0exo	8eso	4.0exo	6.6exo
Largest	0	2.2eso	1.0exo	5.5eso	2.3exo	6.3eso	4.1exo	6.3exo
Mean Of Means	.3eso	2.4eso	.6exo	5.3eso	2.0exo	5.5eso	3.6exo	6.1exo



Effect Of Differential Treatment On Subgroup Means For Subject #1

PRISM	No Fusion Lock	Small	2 Small	2 Large	Largest
0	4 eso	-5	-5	-4	-5.5
4BI	7 eso	-10	-9	-10	-9
4BO	3 eso	-5	-5.5	-4	-3
8BI	10 eso	dipl	-20	dipl	-18
8BO	0	-1	-2	-2	+1
12 BI	dipl	dipl	dipl	dipl	dipl
12 BO	1exo	+.5	-1	0	+1
20 BO	4exo	+5	+3	+5	+6
MEAN	-2.7	-2.6	-5.6	-2.5	-3.9

Within-Groups Variance Estimate: 38.21

Among-Groups Variance Estimate: 14.08

$$F_{calculated} = \frac{\text{Among-Groups Var. Est.}}{\text{Within-Groups Var. Est.}} = .37$$

$F_{critical}$ = 4.12 at 5% level
7.85 at 1% level

$F_{calc} < F_{crit}$

so accept null hypothesis that size of fusion lock did <u>not</u> significantly alter results

Effect Of Differential Treatment On Subgroup Means For Subject #2

PRISM	No Fusion Lock	Small	2 Small	2 Large	Largest
0	+1	+1	+1	0	+1.0
4BI	0	0	+1.5	-1.5	+1.0
4BO	+1	+1	+1	0	+1.0
8BI	-1	-1.5	-2	-1	0
8BO	+1	+1	+2	+2	+1.0
12BI	dipl	dipl	dipl	dipl	dipl
12BO	+2	+3	+2	+3	+2.0
20BO	+6.5	+7	+7	+7	+7.0
Mean	+1.5	+1.6	+1.78	+1.4	+1.8

Within-Groups Variance Estimate: 6.0

Among-Groups Variance Estimate: .62

$F(\text{calculated}) = \frac{\text{Among-Groups Est}}{\text{Within-Groups Est}} = .10$

F(critical) = 4.12 at 5% level
7.85 at 1% level

Fcal < Fcrit

So Accept Null Hypothesis That Size Of Fusion Lock Did Not Significantly Alter Results

Effect Of Differential Treatment On Subgroup Means For Subject #3

PRISM	No Fusion Lock	Smallest	2 Small	2 Large	Largest
0	-3	-5	-5	-1	-2
4BI	-10	-15	-7.5	-1.5	-5.5
4BO	0	-4	-3	-1.5	-.5
8BI	dipl	-16	-16	-15.5	-9
8BO	+1	-3	-.5	0	+1
12BI	dipl	dipl	dipl	dipl	-20
12BO	+2	0	+2	+2	+2
20BO	+11	+6	+3.5	+3.5	+5.5
	+.17	-5.28	-3.78	-2.0	-3.56

Within-Groups Variance Estimate: 46.00

Among-Groups Variance Estimate: 30.05

$F(\text{calculated}) = \frac{\text{Among Groups Var.}}{\text{Within Groups Var.}} = .65$

F(critical) = 4.12 at 5% level
7.85 at 1% level

$F_{calc} > F_{crit}$ at 5%
$F_{calc} < F_{crit}$ at 1%

Since $F_{calc} < F_{crit}$ Can Accept Null Hypothesis That Size Of Fusion Lock Did Not Significantly Alter The Results

Effect Of Differential Treatment On Subgroup Means For Subject #4

PRISM	No Fusion Lock	Smallest	2 Small	2 Large	Largest
0	-2	-2.5	-2	-2.5	-2
4BI	-2	-2	-2	-2.5	-2
4BO	0	0	+1	0	0
8BI	-3.5	-3	-3.5	-4	-4
8BO	+1	0	+1.5	+1	0
12BI	-8	dipl	dipl	dipl	dipl.
12 BO	+3	+4	+4	+3.5	+3
20 BO	+8.5	+7	+8	+7	+7.5
MEAN	-.38	+.5	+1	+.36	+.36

Within-Groups Variance Estimate: 16.86

Among-Groups Variance Estimate: 1.84

$$F(\text{calculated}) = \frac{\text{Among-Groups Est}}{\text{Within-Groups Est}} = \frac{1.84}{16.86} = .11$$

F(crit) = 4.12 at 5% level
7.95 at 1% level

Fcal < Fcrit so accept null hypothesis that size of fusion lock did not significantly alter results

Effect Of Differential Treatment On Subgroup Means
For Subject #5

PRISM	No Fusion Lock	Smallest	2 Small	2 Largest	Largest
0	-1	-1.5	-1	-1	-1.5
4BI	-1	-2	-3	-2.5	-2
4BO	-1.5	-1.5	-1	-1	-1
8BI	-2	-2.5	-2.5	-3	-2
8BO	0	0	+1	0	0
12BI	-7	-7	-7	-7	-8
12BO	+2	0	+1	+1	+.5
20BO	+6	+6.5	+7	+7.5	+6
Mean	-.56	-1	-.69	-.75	-1

Within-Groups
Variance Estimate: 13.03

Among-Groups
Variance Estimate: .30

$$F_{calculated} = \frac{\text{Among Groups Est}}{\text{Within Groups Est}} = \frac{.3}{13.03} = .02$$

F_{crit} = 4.12 at 5% level
7.95 at 1% level

Since $F_{cal} < F_{crit}$ accept null hypothesis that size of fusion lock did not significantly alter results