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Abstract

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ANALYSIS OF THE RISLEY PRISM DUCTION PROCEDURE FOR SOURCES OF ERROR

by

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Approved by
Niles Roth
Advisor

Niles Roth

DEDICATION

We dedicate this thesis to Maureen Cann for her help in its preparation.

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1. SUMMARY

The objective of this thesis was to elucidate the various sources of error, including procedurally independent subjective behavior, associated with the standard duction measurement utilizing Risley prisms.

An apparatus was designed and fabricated incorporating an oscillographic recording system to monitor the movement of each of the two Risley prisms. The design also included a feature which enabled the patient to mark his own fusional changes by means of a push button. The Risley prisms were calibrated with a laser.

Experimentation was accomplished in three phases: 1) determination of time dependent patient behavior, 2) determination of variation among clinicians, and 3) evaluation of procedural parameters. Each phase was designed experimentally to permit statistical analysis of results.

A minority of subjects exhibited procedurally independent behavioral changes from 2^{Δ} to 3^{Δ}. The majority were within 1^{Δ} over periods of hours and days. The reproducibility error among clinicians was approximately 1.5^{Δ}, part of which possibly may be attributed to differences in duction velocity.

Duction velocity affects the break and recovery values probably because of the constancy of the response lag of the subject. Increased velocity increases the break reading and decreases the recovery reading by about $1^{\Delta}/\Delta \text{sec.}^{-1}$.

No significant correlations were observed between break or recovery value and procedural parameters such as asymmetry of duction movement, non-linearity of duction movement, and time interval between the break and the start of prism reversal towards recovery.

Recommendations for future research included the design and fabrication of a completely automated duction measurement system to facilitate control of procedural parameters and enable their evaluation.

2. INTRODUCTION

The authors hope that through our research the profession of Optometry and the vision care of the public will be promoted and served. It is our belief that through more accurate measurement of the parameters of the visual system the patient's interests will be served by more adequate vision analysis and the resulting better remedial prescriptions.

Our study was premised with the hypothesis that in this day of modern technology, an economical method could easily be devised that would allow the vision care practitioner to more adequately measure the ductions and phorias that are basic in the understanding of the patient's needs. Great emphasis has always been placed on a thorough analysis before prescription. It is our belief that thorough analysis can only be as good and thorough as the accuracy of the data from the system that is being analyzed. The purpose of this study is to determine whether there is a need for the research and development of an adequate, accurate device that can precisely measure the visual ductions and phorias with respect to time, direction and limits. Our research was not directed to developing instrumentation, but only to ascertain whether the development is needed. Such instrumentation could incorporate motorized Risley prisms with a digital read-out that would automatically combine the readings of the left and right prisms and allow the patient to record, with a button, the readings (such as blur, break and recovery) that are necessary for vision analysis. If a need for better analysis equipment is found, the optometrists should present to the equipment manufacturers the specifications as to what is necessary and allow the mechanical, electrical and electronic engineers to develop the equipment that we must have to better serve the public.

One automated prism system was developed and utilized by William L. Larson of the School of Optometry, University of Montreal, Montreal, Quebec, Canada. He developed a new type of rotary prism called a stepping prism and is, in essence, a rotary prism driven by a stepping motor. He believes that this prism makes possible the refinement of optometric tests which make use of prisms (8). In using this stepping prism, the number of steps made and their direction are controlled by a digital computer. With this system, he was able to change the prism's value continuously or in steps of as many diopters as he desired (9). His studies showed that convergence break values are much more variable than the divergence break values. This was another reason this thesis study used the divergence system in our research. Larson used a prism in his study similar

to that originated by von Graefe (3). It was his conclusion that more information could be gained by using the accurate stepping prism (10). In our investigation we sought to find out if the present clinical techniques and the data gained in these procedures were firm and adequate enough to warrant the conclusions that are being made in present methods of vision analysis. The research sought to find the possible errors that are currently being introduced into the vision analysis by the possible inaccuracy of the equipment being used or the inadequate understanding of the innate variables of the human visual system within the unique individual as well as the variance between individuals.

About 40 years ago Verhoeff suggested that the process of unification should not be considered as an additive effect of the retinas of the two eyes to the perceived image (14). On the contrary he regarded the whole process as one of reciprocal replacement. If the images become disparate, then he referred to the process as "quasi unification" and the disappearance of one of the images occurred by total replacement. If Verhoeff's suggestion is true, then it is reasonable to believe that it will only be through very accurate subjective testing when the brain is involved in the image perception that adequate analysis information of the visual system can be measured. If the positions of the eyes are recorded photographically or observed with a telescope during the process of making a horizontal vergence movement, it can be demonstrated that the record of the relative positions of the lines of sight of the two eyes may differ from the convergence angles of the test targets during single binocular fixation (5, 12). The exact amount of this disparity differs according to the subject and the test conditions, but there is fairly good agreement that the order of magnitude is several degrees, i.e. much larger than the size usually postulated for Panum's fusional areas (11). On the basis of such evidence Tani, Ogle, Weaver and Martens have questioned the validity of optical measurements of eye movements by photographic or telescopic observation of details on the eyes themselves or of images from light reflected from the corneas (13). In the light of this evidence, the authors of this thesis also believe better subjective methods of detecting eye position and movement must be developed to overcome the difficulties encountered in the objective approach. The patient's observations must be recorded more accurately.

This study looked into the significance of the possible errors that occur in current clinical data gathering. Some past studies of eye movements indicate that convergence relaxation required a longer period of time for both the

reaction and the response durations as compared with that required for convergence (15). To avoid as many of these variables as possible our studies were restricted to base-in prism. Since a lot of research has been done with eye movements, we selected a very narrow aspect of these movements to investigate an area of needed improvement. Breinin, testing vergences by electromyography, held that no simultaneous contraction of the recti took place (4). The innervation of opposing forces was centrally adjusted and integrated, and the outflow was a vector resultant of innervation. The final common path was expressed as a reciprocity mechanism. Alpern and Walter also believed that common paths for saccadic movements were formed by the thick somatic nerve fibers, while the common final path for the vergence movements was formed by thin autonomic nerve fibers (1). This permitted vergence and saccadic movements to both occur during a single change in fixation and explained the very close similarity in the velocity characteristics of vergence movements and of autonomically innervated intraocular muscles. This is evidence that accurate subjective testing is an important route to the understanding of an individual visual system.

3. APPARATUS AND PROCEDURE

The recording device was a dual-beam oscilloscope made by Tektronix. The cathode-ray tube (CRT) had electrostatic-deflection and an 8 x 10 division (one-half inch per division) internal black graticule. This oscilloscope had Dual Beam Storage Display (D-13) unit, two differential amplifiers (5A21N) and a time base amplifier (5B10N). To record our findings we used Polaroid film type 107 with an ASA 3000 panchromatic that yields paper prints with Tektronix C-5 oscilloscope camera.

The subject in the testing procedure held a push button in his hand which recorded his break and recovery responses on the oscilloscope screen. The position of the Risley prisms was shown on the screen by the relative voltage drop across two ten-turn precision potentiometers of 2000 ohms each. The mounting of the potentiometers on the Greens phoropter is shown in Figure 2. The long rods connect the Risley prisms directly to the potentiometers. The potentiometers (box 1 and box 2, R 1 and R 2, see Figure 1), which indicated the position of the Risley prisms, had voltage potentials established by coarse potentiometers R 4 and R 5 and five adjustment potentiometers R 6 and R 7. This network of resistors received its power source from a Heathkit regulated power supply (Figure 1, box IV), model IP-18 set for ten volts. With proper

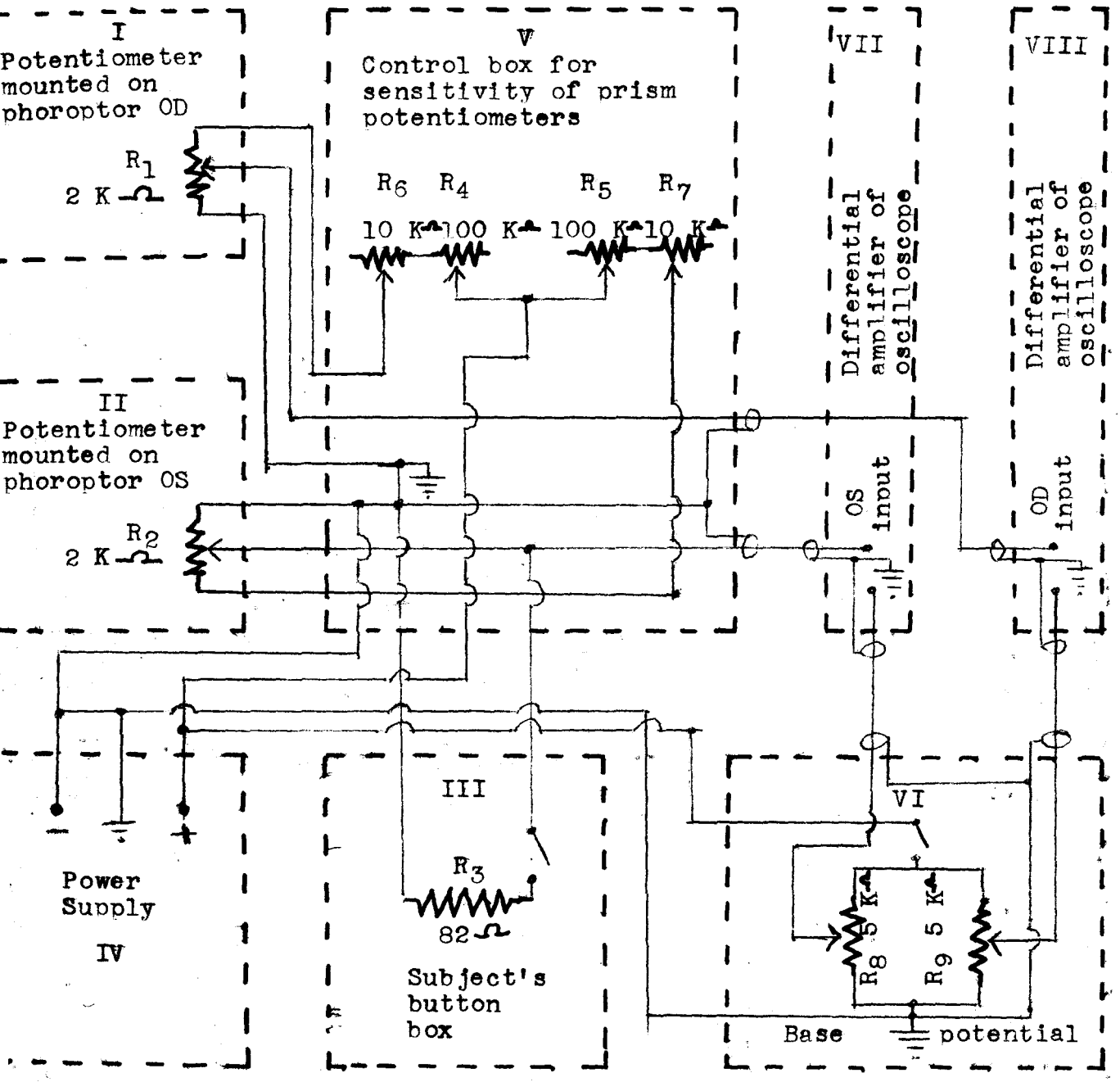


Figure 1

SCHEMATIC OF APPARATUS

adjustment of potentiometers R 4, R 5, R 6 and R 7, the voltage potential sensitivity of the Risley prism potentiometers R 1 and R 2 (boxes I and II of Figure 1) was controlled to give the correct voltage charge required to deflect the CRT beam over the face of the oscilloscope at the selected sensitivity of vertical deflection of ten millivolts per half inch.

When the subject indicated a response (either break or recovery), he pushed a button and said "now." The pressing of the button effectively shorted out the OS Risley prism potentiometer and was indicated on the screen as a rapid downward sweep of the trace. The 82~ resistor R 3 in box III (Figure 1) was a safety resistor. It was necessary to place a base potential at the negative input of the oscilloscope's vertical amplifiers to properly place the starting point of the two beams at the top and bottom of the screen to gain maximum use of the entire screen area for both the OS and the OD inputs. This base potential (box VI of Figure 1) derived its power from the same Heathkit power supply. The wiring schematic hookup is indicated in Figure 1. The picture of this group of equipment is in Figure 3. The power supply (box IV, Figure 1) is center top, the base potential (box VI, Figure 1) is in the center of the picture with two controls on top to adjust the starting point of each prism on the oscilloscope screen. We had the zero point for the left prism at the bottom on the screen and increased in prism diopters as the beam moved toward the top. The right Risley prism had its zero point at the top of the screen and increased in prism diopters as the beam moved toward the bottom.

At the bottom center of Figure 3 is the control box for sensitivity of the Risley potentiometers. Its schematic hookup is indicated in box V of Figure 1. Two control knobs on this box allowed the sensitivity of the movements of the Risley prism potentiometers to be increased or decreased by varying the voltage drop across R 1 in box I and R 2 in box II of Figure 1. The push button box (box III of Figure 1) is shown to the left of Figure 3.

The equipment that we designed for this project could accurately display on the oscilloscope screen to one-half diopter for each Risley prism. The calibration of the oscilloscope CRT display included the use of a laser (light amplification by stimulated emission of radiation) so that the light beam of intense, coherent radiation could be deflected by the Risley prisms across the room and show its position on a meter stick. Using the definition of the prism diopter of one centimeter of deflection for every meter of distance, we found the calibration markings on the Bausch and Lomb's Greens refractor surprisingly

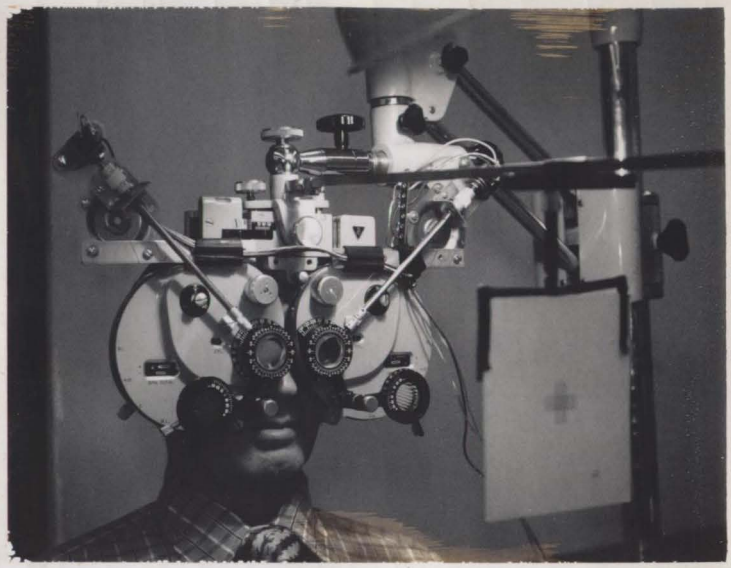


Figure 2

The potentiometers mounted on the phoropter connected to the Risley prisms.

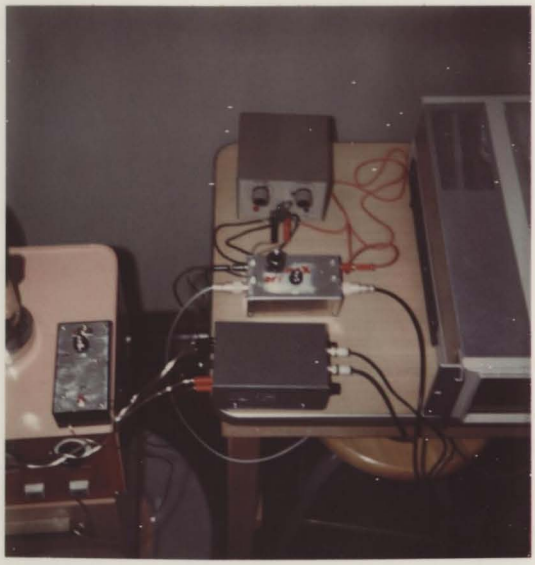


Figure 3

On the left is the subject's button box, on the right is the oscilloscope. At top center is the power supply, in the middle center is the prism sensitivity control box.

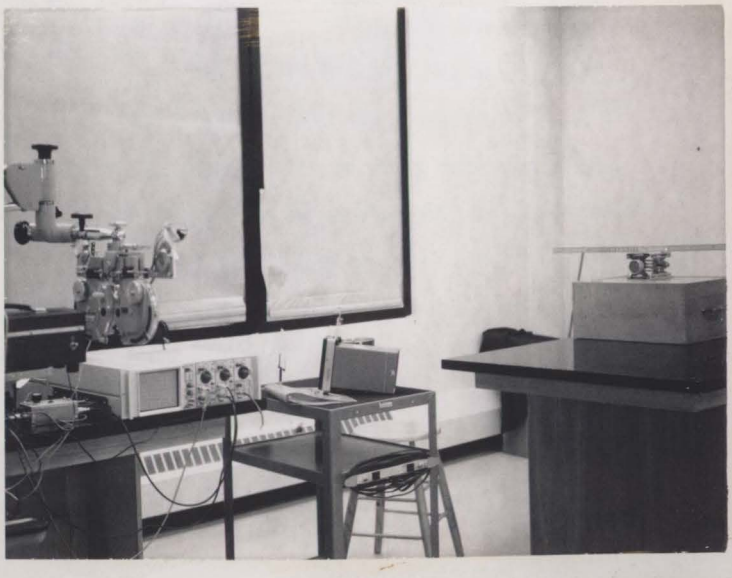


Figure 4

The laser generator is seen at left behind the phoropter with the laser beam about in the center of the meter stick on the right.

accurate. The only observable defect was the close proximity of the scale divisions and the play in the gears that could mislead the clinician into believing there was a prism diopter figure represented when it was actually slightly high or low. Figure 4 shows the laser generator on the left behind the phoropter and the spot of the laser in about the center of the meter stick across the room on the right of the picture. Although the calibration on the Risley prism was substantially accurate, we always used the meter stick laser calibration in setting up the calibration of the CRT display.

After firmly establishing the position of the Risley prism to be a particular prism diopter reading, we would trigger the oscilloscope trace to record on the screen the position of each of the following diopter readings: 2, 4, 6, 8, 10, 12, 14, 16, 18. First we went through this procedure for the left Risley prism from the bottom of the CRT to the top as shown in Figure 5. Then we repeated the operation for the right Risley prism as shown in Figure 6.

From Figures 5 and 6 transparent overlays were made in order to record the values of clinical findings for our data collection. We were able to use the vertical lines on the graticule of the cathode-ray tube for our time measurements, but the lines displayed on the CRT by the Risley prism tracings were nonlinear and would not allow the use of the horizontal lines of the graticule. We were required to make our own transparent overlays for the purpose of recording the vertical trace of the CRT electron beam. We made two different sets of two. One set that could be placed over the face of the CRT for direct reading and one set that could be placed over the photographs of the CRT tracings. Both methods were used in the collection of our data.

Our study sought to determine the significance of testing variables and methods in compiling data for vision analysis. We restricted our study to one simple aspect of the visual system. We selected for our study the maximum ability of the fusion reflex to maintain single binocular vision with prisms base-in while the subject is fixating at sixteen inches (40 centimeters). We are testing a host of complex variables in the visual system even when limiting the testing to this one test. This test showed the ability of accommodation to maintain its stimulation while we increased base-in prism. The convergence support to accommodation is removed as the eyes slowly (sometimes rapidly with some clinicians) diverge behind these base-in prisms. The accommodation is left more and more to its own resources for the maintenance of accurate stimulation. In this test we evaluate the ability of the brain to stimulate accommodation

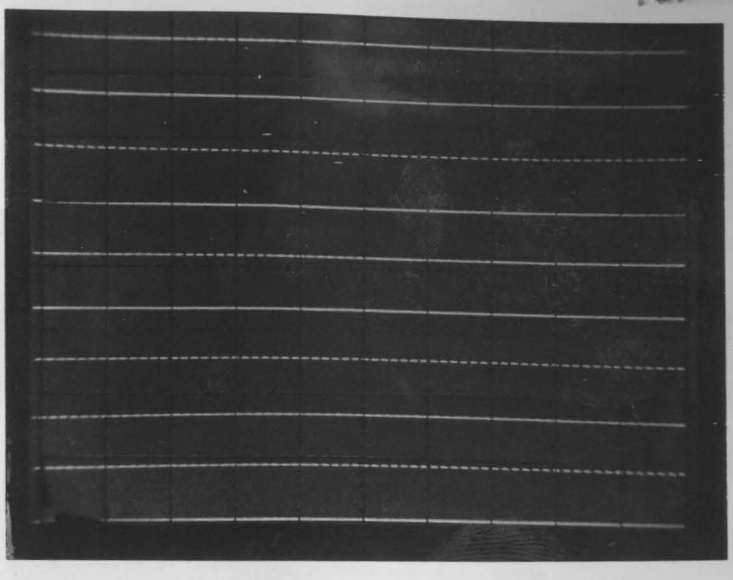


Figure 5

Calibration for the left Risley prism. Calibration is from the bottom to the top in two diopter steps.

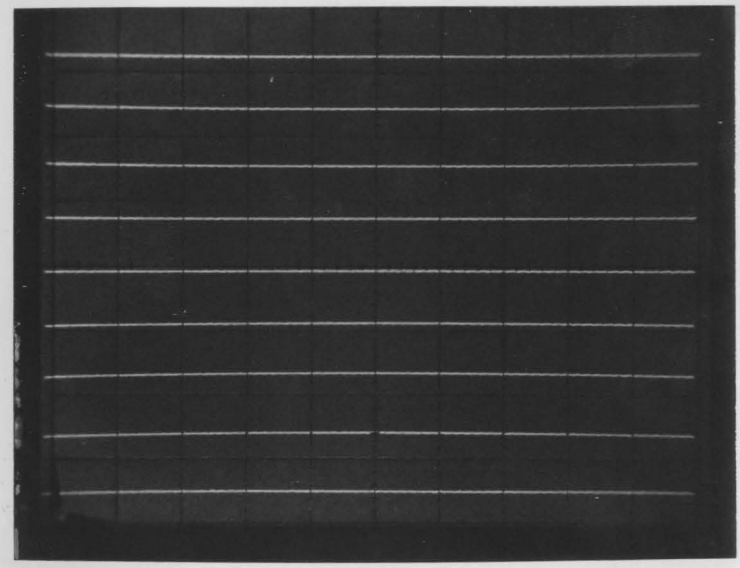


Figure 6

Laser calibration of the right Risley prism. Calibration is from top to bottom of the photograph in two diopter steps.

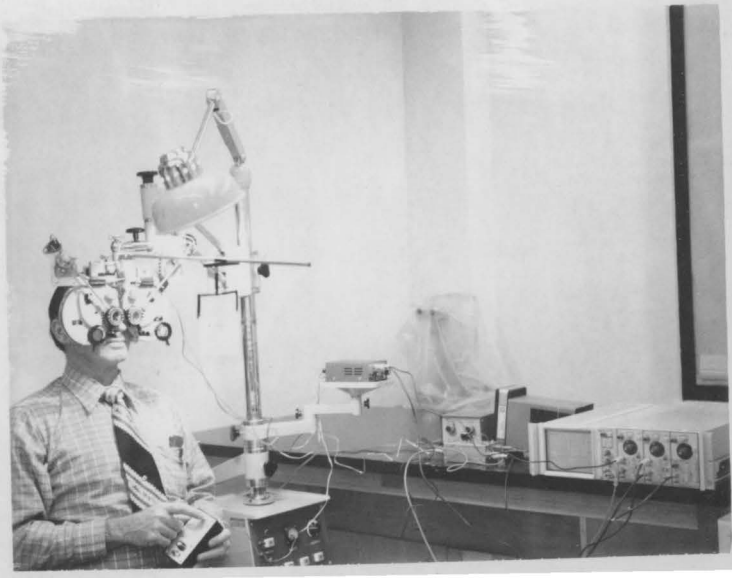


Figure 7

A subject ready for testing with the button box in hand.

under adverse stimulating conditions. The accommodative system is paramount in our diagnosis and regimens in vision care. Because of the wide differences in technique among clinicians with respect to speed, asymmetry and preset, we suspected that variations in measurement among clinicians could be sufficient to cause a difference in prescriptions. Consequently, our study was directed to determine whether these variations are significant to identify the various sources of variation; and if significant variations are found, propose methods by which optometrists can minimize the variations to gain maximum accurate data for adequate vision analysis.

4. EXPERIMENTAL

The instrumentation described above was designed to enable measurement of the primary parameters suspected of contributing to error in the duction measurement by the Von Graefe procedures. Probable sources of error are asymmetry in prismatic effect between the two Risley prisms, variation in prism velocity, non-linearity of prism movement, and with respect to the fusion recovery point the delay in time between the fusion break to the start of prism reversal (eg. recovery direction), which is termed herein the pause.

4.1. APPROACH. Because the emphasis was on the analysis of the method rather than on subjective behavior, the initial experimental effort was restricted to two subjects (patients). Concomitantly the number of examiners (clinicians) was extended to 29 in order to gain insight into parameter ranges that could be anticipated over a wide population. Despite utilizing only two subjects, extreme care was required in establishing the experimental design to permit the statistical separation of subjective and procedural effects. Such a design necessitated division of the study into two tasks: determination of the time dependent characteristics of the base-in duction of each subject and the evaluation of the procedural sources of error over the examiner population. Presumably this technique would enable compensation of effects for accountable subject temporal behavior.

Later in the program a third phase of study was initiated to more accurately evaluate the effect of variations in prism velocity and to ascertain any differences between experienced and naive subjects with respect to visual training. The two subjects of the first study have undergone training. Each of three examiners was trained to operate the prisms at one of the three levels of velocities required for the experiment in order to minimize the variation about each velocity level.

The experimental program was thus separated into three phases: patient temporal behavior study, the clinician variability study, and the parametric study.

4.2. STATISTICAL DESIGN. To assure quantitative separation of the various experimental effects factorial designs were employed. Statistical manipulation via analysis of variance enables the quantitative evaluation of the different effects of these various parameters. Therein the significance of each effect can be determined with the aid of the F ratio and appropriate published tables of F values, and the variance of each effect estimated (2, 6, 7).

In the patient temporal behavior study the original intent was to employ a three-component factorial design analyzing for the effects of days of testing, time periods within each day of testing, and the method of recording employed (patient pushing the button to mark the oscillographic trace or the examiner observation). In the course of the study circumstances prevented the testing at one period thus upsetting the design. Consequently, the matrix was analyzed in three two-component units, which subsequently were summed to yield the desired result. Originally the procedural parameters were to be evaluated by generating multiple correlation coefficients by inversion of a matrix of simultaneous regressions. Unfortunately the computer at Pacific University could not be programmed in time for this thesis. Consequently, procedural parameter evaluation was restricted to single linear correlations for the clinician variability phase.

Patient effects (*eg.* differences) were incorporated into the experimental design of the clinician variability study yielding a three-component factorial matrix. The latter constitutes a more powerful approach to component evaluation than the compilation of several two-component matrices as employed in the patient temporal behavior phase. Experimentation was uneventful; therefore, the analysis proceeded as planned.

A repetitive Latin Square design was utilized for the parametric study with three levels each of prism velocity, patients, time of day, and days. Such a design is most efficiently used in experimental matrices where interactions among the different components may be ruled out.(6). The patient temporal behavior and clinician variability studies cited previously demonstrated the absence of interactions, thereby justifying the use of the Latin Square.

The experimental matrix was arranged in three Latin Square elements, one for each day of testing. After analyzing each of the three elements, their results were combined to yield a more powerful and sensitive analysis.

4.3. RESULTS. Each duction measurement was capable of yielding 15 bits of data: (1) the examiner recording, (2, 3, 4) the oscilloscopic recordings of total, right, and left prism values, (5) the velocity of prismatic movement, (6) maximum deviation from linearity of prism movement, (7) average deviation from linearity all concerning the fusion break; the same as the above concerning the fusion recovery (8, 9, 10, 11, 12, 13, 14); and the pause (time lapse between the break and prism reversal towards recovery) of the recovery.

Average deviation from linearity is determined by measuring with a planimeter the area under each curve of deviation from a straight line drawn on each oscilloscopic photograph from the start of prism movement to fusion change. Maximum deviation is taken as the maximum total deviation (both prisms) from the straight line. In actual data reduction the first few measurements were substantially less than 0.5^{Δ} indicating they probably did not constitute a primary parameter as compared to the other measurements. The effort required to integrate the area of the four traces of each of the 118 oscilloscopic recordings for the apparently secondary error source was adjudged beyond the scope of this thesis.

The data of the subjective temporal behavior study are reported in Table 1 for Patient #1 and Table 2 for Patient #2. With respect to Patient #1 data entries are inexplicably missing for the sixth series of the afternoon of the first day. To avert disruption of the statistical analysis, a substitute entry was made utilizing the means of the other five members of the series. The consequence of this alteration is anticipated to be insignificant. The results of the statistical analysis of these data are given in Tables 6, 7, 8, and 9 and will be discussed later in this report.

Tables 3, and 4 show the data obtained from the clinician variability study. Therein clinicians are designated by their first and last name initials, which can be coded with the original oscilloscopic photographs appended to the original of this thesis. The statistical results are presented in Table 10. Correlations were tested statistically between the base-in duction as recorded oscillographically and the asymmetry between prisms at break, the velocity of prismatic charge, and in the case of fusion recovery measurements, the pause (i.e. time lapse between the break and beginning of prism motion in the recovery direction). Findings regarding the latter are reported in Table 11.

Data for the parametric study are given in Table 5 whereas the results of the analyses of variance are provided in Table 12.

5. DISCUSSION

Because of the complexity and total mass of data reported herein, discussion is accomplished progressively through each of the three studies cited previously.

5.1. SUBJECTIVE TEMPORAL BEHAVIOR. A controlling factor of the manner in which the analysis of variance is performed is the presence or absence of interaction between the main effects (i.e. parameters). As indicated by the findings in Table 6 and 8 only one of the six two-component analyses of variance exhibited a significant interaction between method of recording breaks or recovery and time of day at the 80 percent level of confidence based on the tables of Fisher and Yates (7). Consequently, for the compilation of these results shown in Tables 7 and 9 interaction was adjudged to be absent.

For both patients the sensitivity of the experiment was sufficient to elicit significant errors attributable to both recording method and time of measurement. The magnitude of error (i.e. variance) for each source was computed in accordance with standard analysis of variance procedures (2, 6). The individual day substudies exhibited a fairly wide range in error; shown in Tables 6 and 8 the variance values from <0.3 to 9.4 for Patient #1 and from <0.3 to 15.8 for Patient #2. The error in prism diopters corresponds to the square root of the variance; therefore, the error ranges up to about 3 prism diopters.

The compilations of the analyses of variance from Tables 6 and 8 are presented in Tables 7 and 9, respectively. In the case of Patient #1 the largest error appears to arise from the day and time of day of testing rather than the method of recording. However, for Patient #2 the method of recording appeared to constitute the greatest source of error.

Despite the significance of temporal differences no definitive trend could be established for either patient. Consequently, this study suggests that determination of errors less than $1.8^{\triangle}$ for Patient #1 and less than $2.7^{\triangle}$ for Patient #2 would not be feasible because of the unpredictable time behavior. Regardless of this gloomy outlook testing was continued into the clinician variability phase.

5.2. CLINICIAN VARIATION STUDY. The analysis of variance of the clinician variation study is summarized in Table 10. Because the design incorporated

three main effects (i.e. parameters) there are three different two-factor interactions. In both break and recovery determinations none of these interactions were significant. With respect to the break variations attributable to patient, method, and clinician differences were all found significant but numerically relatively small. In the recovery measurement only patient differences were significant. It must be emphasized that patient differences are inconsequential relative to the procedure evaluation and their inclusion served only to enhance the power of the analysis. The largest error source was the residual which in this study for the most part is attributable to subjective behavioral variation (i.e. time or otherwise). The estimated variation of this residual amounted to approximately 1.9^{Δ} for the break and 3.4^{Δ} for the recovery. Again the difference between examiner and oscillographic measurements does not appear to be numerically significant (i.e. $<0.6^{\Delta}$). Surprisingly perhaps, the variation among clinicians was less than the residual error, amounting to approximately 1.3^{Δ} for the break and $<1.8^{\Delta}$ for the recovery.

Although significant procedural parametric effects should have appeared in the clinician effect, linear correlations were performed between the oscillographically recorded break/recovery and the three procedural parameters cited in prior discussion. The regression technique employed for this purpose is the standard statistical method (6). Both computed correlation coefficients and their square roots, which correspond to the percent of error that is accounted for by the regression, are reported in Table 11. Statistically no significant correlations were obtained. However, in the recovery data for Patient #1 there was an indication that differences in velocity may have accounted for as much as 25 percent of the total error.

Again this phase of the experimentation appears to confirm that the major variation in the duction measurement is the subjective fluctuations, which are not controllable by more accurate measurement techniques. However, no generalization of this conclusion can be made beyond the two patients tested. Subjective error appears to be 2.5 to 3.0^{Δ}, whereas clinician error amounts to only about 1.5^{Δ}.

5.3. PARAMETRIC STUDY. Although the prior correlation attempt suggests velocity differences may cause significant errors, there was no statistical evidence to that effect. However, the conditions of the clinician variability study were far from optimum to elicit procedural parameter effects. Therein ranges in these parameters were narrow and interaction effects of these parameters were probably significant. Consequently, a specific design was evolved to determine the influence of velocity. Three levels of velocity were

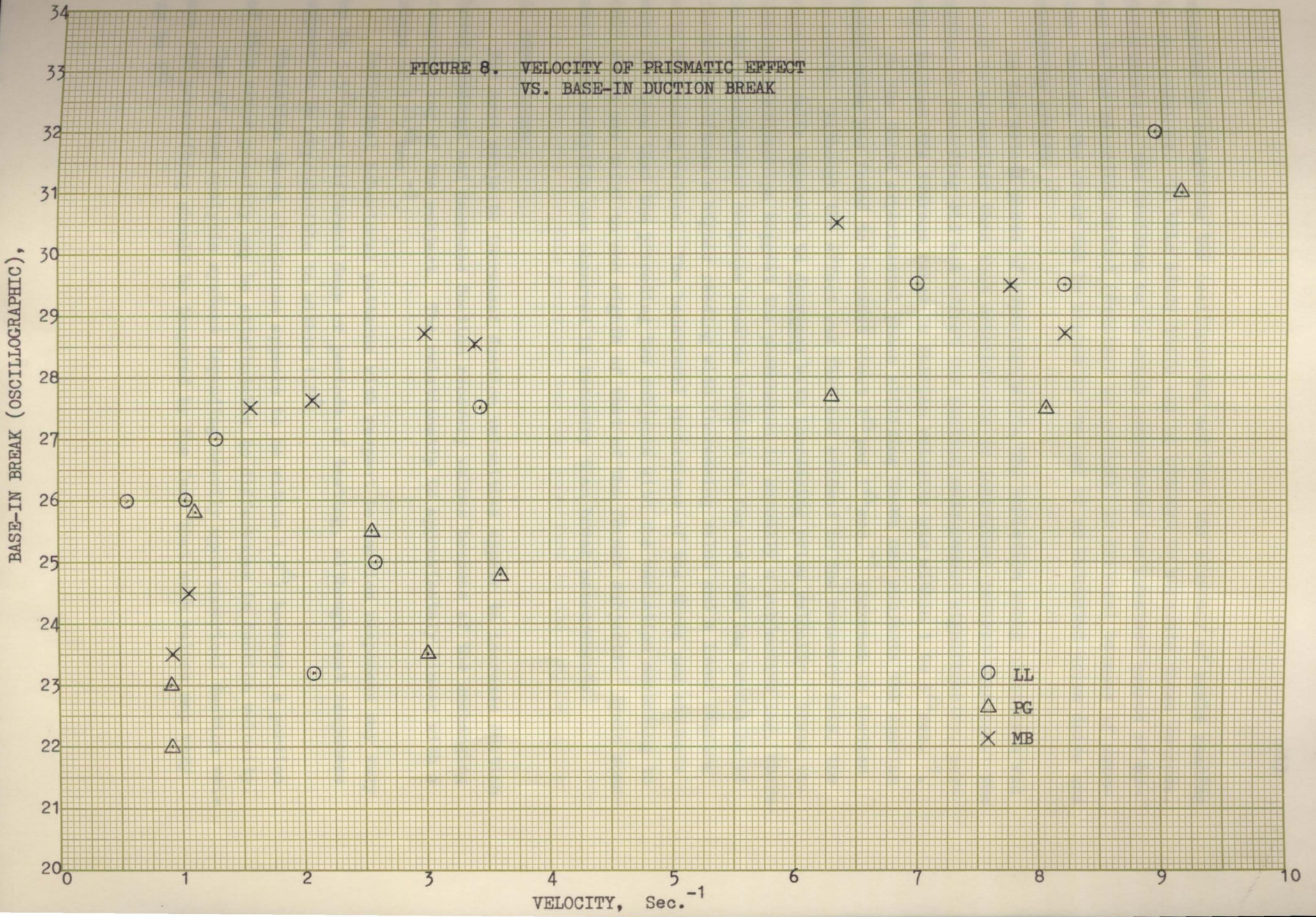
selected with the most rapid rate being about 8X the slowest rate. The parametric study utilized three new subjects who had no prior visual training, thus providing new information on subjective temporal behavior. The Latin square experimental design minimized prismatic training effects by allowing only one duction measurement at any one time per subject and requiring only 9 total duction measurements over three dispersed days. Only the oscillographically recorded breaks were utilized for the analysis.

The analyses of variance for the duction break are summarized in Table 12. In contrast to the previous study phases both residual error, which includes the non-temporal subjective variation, and the subjective temporal behavior, were very small. The residual error was approximately 0.55^{Δ} whereas day and time of test variations amounted to only 0.33^{Δ} and 0.42^{Δ}, respectively. Differences attributable to changes in velocity were highly significant with the average error amounting to about 1.45^{Δ}. In fact the velocity means reported in Table 12 strongly suggest a relationship. Consequently, a graphical representation was prepared and is shown by Figure 8. Because of the rather large variance, a regression analysis was not performed; however, these data indicate that the duction break point increases about one prism diopter for every velocity increase of one prism diopter per second.

Table 13 reports the analytical results for the duction recovery. Despite the fact that the influence was highly significant the trend was not as distinctive as that observed for the break. Therein the smallest velocity produced the highest recovery value, but there was no statistical difference between the largest and medium velocity levels. The overall variation as a result of velocity change was approximately 1.3^{Δ}. Again time of test and residual effects were numerically relatively small, although higher by a factor of about two than the corresponding levels in the results for the break.

5.4. OVERVIEW. The principal objective of this thesis was to quantitate the various sources of error of the duction procedure. In the first two phases of experimentation only two subjects were utilized. An attempt was made to establish a base-line behavior for each patient by performing repetitive tests over an extended period of time. The two subjects were found to differ with regard to primary source of error. With one subject the chief source was the test time, whereas with the other subject the method of recording appeared to be the major error source. Variation with respect to recording method arises actually from two sources: one, the subject with respect to his visual-motor

FIGURE 8. VELOCITY OF PRISMATIC EFFECT VS. BASE-IN DUCTION BREAK



response in triggering the oscilloscope, and two, the accuracy of scale reading by the examiner. In this study there was no attempt to separate these sources. Unfortunately, the decision as to which constitutes the greatest source of error in the recording method (examiner or patient) is critical because if examiner caused, the error can be abated by the use of an automated prism drive and recording system.

In the second phase of experimentation the variation among clinicians was found to be smaller than that attributable to individual patient behavior. The method of recording did not affect the duction measurement significantly, perhaps because the average range in duction velocity was within 1 to 3^{Δ} sec.$^{-1}$.

In the third experimental phase utilizing three new subjects the duction break value was found to increase about 1^{Δ} per 1^{Δ} sec.$^{-1}$ increase in duction velocity. Although the effect was far less evident in the recovery data, the recovery value appeared to decrease with increasing prism velocity. These velocity relationships suggest the phenomenon is actually a subjective lag, wherein the visual-motor response remains constant as far as time lag producing at faster velocities a higher reading with increasing value and a lower reading with decreasing values. The behavioral variations of the three new subjects were far less than the preceding two subjects with the variation amounting to only about one third to one eighth of that of the former subjects. Again somewhat more variation was observed in recovery than break measurements.

6. CONCLUSIONS

For most subjects increased duction velocities appear to increase duction break readings and decrease duction recovery values because of the unchanging response lag of the subject. The relationship is approximately linear with a slope of $1.^{\Delta}/^{\Delta}$ sec.$^{-1}$.

Individual behavioral patterns with respect to duction responses may vary up to 3.5^{Δ} over different days or periods of testing, although most responses appear to be reproducible to within 1.0^{Δ}.

Variation among clinicians appears to be within 1.5^{Δ}; however, a portion of this error possibly may be attributable to differences in duction velocity.

Use of case analysis systems depending heavily upon numerical duction values for prescribing should be tempered by the fact that such values may vary up to 3^{Δ}.

Where there is a need for duction measurement accuracy better than 2.5 to 3^{Δ}, the use of a system incorporating an automated prism drive and subjective recording is recommended. An alternative is to judiciously employ a relatively constant duction velocity in taking duction measurements.

Although in this work there appeared to be no significant correlation between duction measurement error and asymmetry of duction movement, non-linearity of duction movement, or with respect to the recovery the time interval between the break and start of prism reversal towards recovery, a carefully designed experiment utilizing an automated system would be required to simultaneously evaluate these parameters.

7. RECOMMENDATION FOR FUTURE RESEARCH

This work suggests there is a need for an automated duction measurement system on the basis of the error induced by variations in duction velocity. However, additional research utilizing such instrumentation is needed in order to provide adequate control and manipulation of the procedural parameters of duction movement asymmetry, non-linearity of duction movement, and time lapse between the break and start of recovery motion. Appropriate evaluation can be achieved by perturbing each of these parameters in a carefully designed experiment which would be a Latin square or Greco-Latin square matrix and solving simultaneously for the multiple correlation coefficients with the aid of a computer. A program for this procedure has been submitted to the computer group at Pacific University.

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TABLE 1

SUBJECTIVE TEMPORAL BEHAVIOR OF PATIENT #1

DAY	TIME	SERIES	BREAK, prism diopters							RECOVERY, prism diopters							
			EXAMINER	TOTAL	O.D.	O.S.	OSCILLOSCOPE VELOCITY[1]	NON-LINEARITY[2] MAX.	NON-LINEARITY[2] AVE.	EXAMINER	TOTAL	O.D.	O.S.	OSCILLOSCOPE VELOCITY[1]	OSCILLOSCOPE PAUSE[3]	NON-LINEARITY[2] MAX.	NON-LINEARITY[2] AVE.
1	A.M.	1	28	25.6	12.6	13.0	5.75	-	-	22	21.3	9.9	11.4	-	-	-	-
		2	28	26.4	12.4	14.0	5.28	-	-	20	19.1	9.0	10.1	-	-	-	-
		3	30	28.6	12.6	16.0	5.15	-	-	22	22.8	10.3	12.5	-	-	-	-
		4	28	27.0	13.0	14.0	6.59	-	-	24	19.7	10.5	9.2	-	-	-	-
		5	30	27.7	12.9	14.8	5.43			20	20.6	9.6	11.0	7.54	1.5		
		6	30	28.4	13.5	14.9	6.31			20	19.5	9.5	10.0	7.20	1.9		
	N	1	26	23.6	12.1	11.5	7.38	-	-	16	15.0	7.5	7.5	-	-	-	-
		2	26	22.4	11.1	11.3	6.33			16	17.5	8.5	9.0	13.0	2.3		
		3	26	24.9	13.5	11.4	6.55	-	-	18	17.1	9.0	8.1	-	-	-	-
		4	28	25.8	13.3	12.5	5.61	-	-	18	17.3	8.5	8.8	-	-	-	-
		5	26	23.8	11.9	11.9	6.10			18	18.5	9.0	9.5	5.06	2.7		
		6	28	24.8	12.8	12.0	5.17	-	-	20	19.4	8.7	10.7	-	-	-	-
	P.M.	1	26	25.5	13.6	11.9	6.22	-	-	20	19.2	9.5	9.7	-	-	-	-
		2	28	27.3	13.9	13.4	5.46			18	17.8	8.8	9.0	8.05	2.2		
		3	28	26.3	12.8	13.5	4.92	-	-	18	19.0	8.5	10.5	-	-	-	-
		4	28	28.5	13.9	14.6	5.00	-	-	18	21.1	8.6	12.5	-	-	-	-
		5	28	30.4	15.2	15.2	4.98			20	22.0	10.4	11.6	4.61	1.6		
2	A.M.	1	28	24.8	12.3	12.5	7.29	-	-	20	20.4	9.0	11.4	-	-	-	-
		2	28	24.8	12.4	12.4	7.75	-	-	20	19.0	9.2	9.8	-	-	-	-
		3	28	27.6	13.0	14.6	5.11	-	-	20	20.9	9.4	11.5	-	-	-	-
		4	28	25.5	13.0	12.5	5.80	-	-	20	20.7	9.3	11.4	-	-	-	-
		5	28	27.5	13.5	14.0	7.05			20	19.6	9.1	10.5	7.60	1.3		
		6	28	27.4	13.8	13.6	6.77			20	19.6	9.4	10.2	4.48	1.7		
	N	1	28	24.7	12.7	12.0	8.23	-	-	18	18.9	9.5	9.4	-	-	-	-
		2	26	23.5	12.0	11.5	6.03			20	20.5	9.4	11.1	6.14	1.3		
		3	26	24.4	11.6	12.8	5.08	-	-	18	21.2	9.3	11.9	-	-	-	-
		4	28	26.7	12.7	14.0	6.07	-	-	18	20.5	9.0	11.5	-	-	-	-
		5	28	29.3	13.8	15.5	5.43			20	19.6	9.5	10.1	5.45	1.8		
		6	28	27.9	13.7	14.2	6.98	-	-	18	19.2	9.5	9.7	-	-	-	-

TABLE 1 (cont.)

DAY	TIME	SERIES	BREAK, prism diopters							RECOVERY, prism diopters						
			EXAMINER	OSCILLOSCOPE TOTAL	O.D.	O.S.	VELOCITY[1]	NON-LINEARITY[2] MAX.	AVE.	EXAMINER	OSCILLOSCOPE TOTAL	O.D.	O.S.	VELOCITY[1]	PAUSE[3]	NON-LINEARITY[2] MAX.	AVE.
2	P.M.	1	26	24.7	12.5	12.2	6.86			18	21.3	9.9	11.4				
		2	28	24.3	12.5	11.8	6.08			22	21.0	10.8	10.2	7.50	1.8		
		3	28	27.3	13.7	13.6	6.50			18	18.5	8.7	9.8				
		4	30	29.3	14.3	15.0	6.04			22	21.2	10.5	10.7				
		5	28	26.8	14.0	12.8	6.31			20	20.6	10.6	10.0	6.21	1.5		
		6	26	27.5	12.9	14.6	6.88			18	20.0	9.2	10.8				
3	A.M.	1	32	28.1	13.5	14.6	6.94			20	20.0	9.3	10.7				
		2	28	27.5	13.7	13.8	6.63			20	19.6	9.6	10.0	6.33	1.5		
		3	28	27.2	12.9	14.3	6.63			18	20.2	9.0	11.2				
		4	28	28.0	13.0	15.0	6.09			16	19.3	8.8	10.5				
		5	28	28.0	13.3	14.7	7.57			18	19.4	9.5	9.9	6.58	1.1		
		6	28	26.9	13.5	13.4	6.56			18	17.3	8.5	8.8				
	P.M.	1	30	29.0	13.5	15.5	5.32			22	22.8	11.3	11.5				
		2	30	29.7	14.2	15.5	5.71			20	20.1	9.5	10.6	9.06	1.5		
		3	28	28.4	13.6	14.8	6.53			18	20.5	10.0	10.5				
		4	30	30.2	14.6	15.6	5.12			20	21.1	10.4	10.7				
		5	32	29.8	15.3	14.5	5.18			24	22.3	11.8	10.5	5.83	1.3		
		6	32	31.8	15.8	16.0	8.05			20	21.9	12.0	9.9				

1. Velocity in prism diopters per second.
2. Non-linearity in prism diopters represents deviation from constant velocity from the start of motion to fusion change in the specified direction of motion.
3. Pause in seconds is the time interval between the break and the beginning of the decrease in prismatic effect towards recovery.

TABLE 2

SUBJECTIVE TEMPORAL BEHAVIOR OF PATIENT #2

DAY	TIME	SERIES	BREAK, prism diopters							RECOVERY, prism diopters							
			EXAMINER	TOTAL	OSCILLOSCOPE O.D.	O.S.	VELOCITY[1]	NON-LINEARITY[2] MAX.	AVE.	EXAMINER	TOTAL	OSCILLOSCOPE O.D.	O.S.	VELOCITY[1]	PAUSE[3]	NON-LINEARITY[2] MAX.	AVE.
1	A.M.	1	32	32.0	17.0	15.0	6.81	-	-	32	31.5	13.5	18.0	-	-	-	-
		2	30	29.0	14.5	14.5	6.59	-	-	30	30.5	14.5	16.0	-	-	-	-
		3	32	29.0	13.5	15.5	6.59			32	29.5	14.0	15.5	8.8	1.8		
		4	32	31.8	15.0	16.8	5.48	-	-	32	30.5	13.5	17.0	-	-	-	-
		5	32	32.0	15.0	17.0	6.15	-	-	30	28.5	12.5	16.0	-	-	-	-
		6	32	30.5	15.0	15.5	6.49			32	27.5	12.0	15.5	5.6	2.1		
	N	1	32	33.5	16.0	17.5	5.98	-	-	32	30.5	13.0	17.5	-	-	-	-
		2	32	29.0	14.5	14.5	5.00	-	-	32	29.5	13.5	16.0	-	-	-	-
		3	28	27.0	13.5	13.5	5.29			28	30.0	14.0	16.0	4.1	3.5		
		4	32	31.5	16.0	15.5	5.63	-	-	32	29.0	13.5	15.5	-	-	-	-
		5	32	30.5	15.0	15.5	5.08			30	30.0	13.5	16.5	4.9	1.8		
		6	28	27.0	13.5	13.5	7.11	-	-	32	28.3	12.0	16.3	-	-	-	-
	P.M.	1	32	25.5	10.5	15.0	6.71	-	-	30	26.5	11.5	15.0	-	-	-	-
		2	32	29.5	14.0	15.5	7.56			28	29.0	13.5	15.5	5.5	1.5		
		3	28	26.5	13.0	13.5	8.28	-	-	28	27.5	13.5	14.0	-	-	-	-
		4	32	31.0	14.0	17.0	5.74	-	-	32	30.0	14.0	16.0	-	-	-	-
		5	32	29.0	13.0	16.0	7.44			36	31.0	13.0	18.0	7.4	2.5		
2	A.M.	1	24	22.3	12.0	10.3	7.96	-	-	24	23.5	11.8	11.7	-	-	-	-
		2	30	25.5	11.5	14.0	8.79			30	26.8	12.5	14.3	9.3	1.7		
		3	24	24.5	13.0	11.5	9.42	-	-	28	26.5	13.5	13.0	-	-	-	-
		4	28	24.8	10.8	14.0	6.89	-	-	32	25.1	9.3	15.8	-	-	-	-
		5	28	24.5	12.0	12.5	9.42			28	26.0	12.5	13.5	10.8	1.6		
		6	24	24.3	11.8	12.5	8.10	-	-	28	26.5	12.0	14.5	-	-	-	-
	N	1	28	28.5	13.8	14.7	8.91	-	-	28	26.0	12.0	14.0	-	-	-	-
		2	32	27.2	11.7	15.5	7.56			32	26.8	10.8	16.0	7.1	1.4		
		3	32	31.2	14.5	16.7	6.64	-	-	32	30.2	14.0	16.2	-	-	-	-
		4	28	26.0	12.0	14.0	8.39	-	-	28	28.2	14.0	14.2	-	-	-	-
		5	34	29.0	12.5	16.5	6.04			32	27.0	10.8	16.2	7.3	1.6		
		6	28	24.6	11.0	13.6	9.11	-	-	32	26.0	10.5	15.5	-	-	-	-

TABLE 2 (cont.)

DAY	TIME	SERIES	BREAK, prism diopters							RECOVERY, prism diopters							
			EXAM-INER	OSCILLOSCOPE TOTAL	O.D.	O.S.	VELOCITY[1]	NON-LINEARITY[2] MAX.	AVE.	EXAM-INER	OSCILLOSCOPE TOTAL	O.D.	O.S.	VELOCITY[1]	PAUSE[3]	NON-LINEARITY[2] MAX.	AVE.
2	P.M.	1	32	24.8	10.5	14.3	7.52	-	-	32	25.2	10.0	15.2	-	-	-	-
		2	34	29.2	13.2	16.0	6.21			32	27.3	12.5	14.8	5.4	1.8		
		3	32	27.7	12.3	15.4	5.23	-	-	32	28.5	12.7	15.8	-	-	-	-
		4	32	30.2	15.5	14.7	6.57	-	-	28	27.3	14.5	12.8	-	-	-	-
		5	30	27.3	12.4	14.9	6.50			30	24.7	10.0	14.7	7.0	2.2		
		6	32	32.4	16.4	16.0	7.12	-	-	32	30.1	13.8	16.3	-	-	-	-
3	A.M.	1	24	23.5	11.3	12.2	9.40	-	-	32	26.3	11.0	15.3	-	-	-	-
		2	32	26.4	12.6	13.8	7.14			28	26.3	13.3	13.0	7.5	1.7		
		3	32	27.3	11.3	16.0	6.66	-	-	32	27.3	12.0	15.3	-	-	-	-
		4	30	29.8	14.3	15.5	7.10	-	-	28	28.3	14.8	13.5	-	-	-	-
		5	28	25.0	12.1	12.9	6.25			32	27.6	12.0	15.6	6.9	2.0		
		6	32	28.3	12.6	15.7	7.08	-	-	32	27.9	12.0	15.9	-	-	-	-
	P.M.	1	28	27.8	14.0	13.8	7.72	-	-	28	25.3	11.5	13.8	-	-	-	-
		2	30	27.5	13.7	13.8	5.73	-		28	26.5	13.3	13.2	4.7	1.6		
		3	30	26.1	12.2	13.9	6.69	-	-	28	23.4	10.3	13.1	-	-	-	-
		4	32	29.5	14.4	15.1	5.27	-	-	30	28.4	12.7	15.7	-	-	-	-
		5	28	26.0	12.0	14.0	5.65			28	24.8	11.0	13.8	6.0	1.2		
		6	28	28.2	15.7	12.5	9.56	-	-	28	25.0	12.7	12.3	-	-	-	-

1. Velocity in prism diopters per second; recovery data accurate only to 0.1 sec. because extrapolation was required.
2. Non-linearity in prism diopters represents deviation from constant velocity from the start of fusion motion to fusion change in the specified direction of motion.
3. Pause in seconds is the time interval between the break and the beginning of the decrease in prismatic effect towards rocovery.

TABLE 5

CLINICIAN VARIABILITY STUDY OF PATIENT #1

CLINICIAN	DAY	TIME	BREAK, prism diopters						RECOVERY, prism diopters						
			EXAMINER	OSCILLOSCOPE TOTAL	O.D.	O.S.	VELOCITY[1]	NON-LINEARITY[2] MAX.	AVE.	EXAMINER	OSCILLOSCOPE TOTAL	O.D.	O.S.	VELOCITY[1]	PAUSE[3]	NON-LINEARITY[2] MAX.	AVE.
LR	1	A.M.	24	23.0	11.0	12.0	1.92			18	16.5	8.5	8.0	4.03	2.0		
LD			26	24.5	11.5	13.0	2.36			20	20.5	10.5	10.5	1.84	2.0		
RT			26	23.5	12.5	11.0	3.01			20	19.0	10.0	9.0	4.67	2.4		
DO			27	25.5	13.0	12.5	3.27			23	19.0	9.5	9.5	3.65	2.2		
TM			28	24.2	11.5	12.7	2.24			24	21.5	11.5	10.0	2.71	2.2		
HD			26	28.0	14.0	14.0	4.67			20	22.0	10.0	12.0	4.08	4.4		
SB			28	27.0	11.5	15.5	2.93			20	21.5	9.5	12.0	2.40	2.4		
RA		N	28	27.8	14.0	13.8	3.23			23	22.5	11.0	11.5	2.48	3.6		
DP			30	27.3	13.5	13.8	2.07			26	24.0	12.5	11.5	1.45	2.8		
NR			29	28.2	14.0	14.2	3.36			22	21.5	11.0	10.5	2.54	3.2		
MH			28	27.0	13.0	14.0	1.59			26	24.5	12.0	12.5	1.80	3.0		
JH			28	28.7	13.5	15.2	2.76			24	23.5	11.5	12.0	2.16	4.4		
DH			28	30.5	15.5	15.0	2.46			24	25.8	12.8	13.0	2.00	2.0		
DD	2	A.M.	24	24.2	12.0	12.2	2.63			20	19.0	10.0	9.0	2.91	4.4		
CD			28	24.0	12.5	11.5	2.22			18	18.2	9.0	9.2	2.02	3.2		
MA			24	25.8	12.5	13.3	3.23			20	20.5	9.5	11.0	3.75	3.2		
RP			27	26.0	12.5	13.5	1.44			22	20.5	10.5	10.0	1.29	2.5		
JK			29	27.8	13.5	14.3	1.16			24	22.7	11.5	11.2	1.33	9.0		
RD			28	28.0	12.5	15.5	1.47			24	23.5	12.0	11.5	1.17	8.0		
HH			23	22.5	10.5	12.0	4.50			19	18.3	9.3	9.0	4.50	1.2		

TABLE 3 (cont.)

CLINICIAN	DAY	TIME	BREAK, prism diopters							RECOVERY, prism diopters						
			EXAMINER	OSCILLOSCOPE						EXAMINER	OSCILLOSCOPE					
				TOTAL	O.D.	O.S.	VELOCITY[1]	NON-LINEARITY[2] MAX.	AVE.		TOTAL	O.D.	O.S.	VELOCITY[1]	PAUSE[3]	NON-LINEARITY[2] MAX. AVE.
TZ	3	A.M.	28	25.0	12.5	12.5	3.13			20	20.0	10.5	9.5	3.45	3.2	
BD			28	26.6	12.3	14.3	2.89			24	23.2	12.0	11.2	3.18	3.2	
MJ			26	23.5	11.0	12.5	4.90			22	21.5	10.0	11.5	3.57	1.6	
JK			24	24.8	12.0	12.8	3.26			20	19.0	10.0	9.0	3.57	3.2	
W			25	26.0	12.0	14.0	3.10			23	22.8	9.8	13.0	3.60	2.0	
PA			26	22.8	12.0	13.5	2.11			22	21.7	10.2	11.5	2.82	2.0	
PC			28	27.0	13.5	13.5	2.14			20	20.5	10.5	10.0	1.87	3.8	
HB			28	27.5	13.5	14.0	3.44			24	22.5	10.0	12.5	2.95	1.2	
DS			30	27.3	12.3	15.0	2.63			24	21.3	8.3	13.0	3.09	3.2	

1. Velocity in prism diopters per second.
2. Non-linearity in prism diopters represents deviation from constant velocity from the start of motion to fusion change in the specified direction of motion.
3. Pause in seconds is the time interval between the break and the beginning of the decrease in prismatic effect towards recovery.

TABLE 4

CLINICIAN VARIABILITY STUDY OF PATIENT #2

CLINICIAN	DAY	TIME	BREAK, prism diopters						RECOVERY, prism diopters						
			EXAMINER	OSCILLOSCOPE TOTAL	O.D.	O.S.	VELOCITY[1]	NON-LINEARITY[2] MAX. AVE.	EXAMINER	OSCILLOSCOPE TOTAL	O.D.	O.S.	VELOCITY[1]	PAUSE[3]	NON-LINEARITY[2] MAX. AVE.
LR	1	A.M.	24	24.5	11.0	13.5	4.54		26	25.5	12.5	13.0	4.63	1.8	
LD			32	28.8	13.8	15.0	1.95		28	26.3	13.0	13.3	1.86	2.8	
RT			30	29.4	15.2	14.2	1.99		28	27.5	14.5	13.0	3.00	3.2	
DO			26	25.0	13.0	12.0	2.60		24	24.0	12.0	12.0	4.25	3.0	
TM			40	29.7	15.0	14.7	3.09		32	26.2	13.0	13.2	2.73	1.6	
HD			28	30.5	14.0	16.5	3.24		26	29.0	13.5	15.5	3.50	3.8	
SB			31	30.5	13.0	17.5	2.31		27	29.0	12.5	16.5	2.14	2.4	
RA		N	30	30.0	14.5	15.5	3.00		28	28.0	14.0	14.0	2.50	2.4	
DP			32	30.0	15.5	14.5	1.74		30	28.5	14.0	14.5	1.72	2.4	
NR			32	31.0	15.5	15.5	2.50		28	27.0	13.5	13.5	3.42	2.0	
MH			32	30.6	15.0	15.6	1.53		28	25.7	12.2	13.5	1.93	3.0	
JH			26	27.3	13.0	14.3	2.07		26	26.5	12.2	14.3	2.43	3.6	
DH			28	28.0	13.5	14.5	2.09		26	26.5	13.0	13.5	2.56	2.2	
DD	2	A.M.	28	24.5	12.0	12.5	2.66		28	24.5	12.5	12.0	2.54	4.6	
TZ			30	29.4	15.4	14.0	3.00		30	28.5	14.5	14.0	3.06	2.2	
CD			28	28.0	14.0	14.0	2.80		28	25.0	12.0	13.0	2.54	1.6	
MA			26	29.0	14.0	15.0	2.90		26	27.0	13.0	14.0	3.70	2.0	
RP			26	24.5	11.5	13.0	1.63		28	28.0	13.5	14.5	1.30	5.0	
JK			26	25.5	12.5	13.0	1.21		28	27.5	14.5	13.0	1.80	8.0	
RD			30	25.5	11.0	14.5	1.59		28	26.5	13.0	13.5	1.17	5.0	
HH			27	26.5	11.0	15.5	3.40		22	25.3	11.3	14.0	7.00	1.2	

TABLE 4 (cont.)

CLINICIAN	DAY	TIME	BREAK, prism diopters							RECOVERY, prism diopters						
			EXAMINER	TOTAL	OSCILLOSCOPE O.D.	O.S.	VELOCITY[1]	NON-LINEARITY[2] MAX.	AVE.	EXAMINER	TOTAL	OSCILLOSCOPE O.D.	O.S.	VELOCITY[1]	PAUSE[3]	NON-LINEARITY[2] MAX.	AVE.
BD	3	A.M.	31	31.0	15.0	16.0	2.77			25	26.5	13.5	13.0	2.22	3.6		
MJ			28	28.5	14.0	14.5	5.09			28	29.5	14.5	15.0	3.54	1.6		
JK			28	29.3	13.3	16.0	3.05			28	28.5	14.5	14.0	4.55	4.4		
DW			26	29.8	13.5	16.3	2.71			24	27.0	11.5	15.5	3.65	2.2		
PA			30	29.7	15.5	14.2	2.56			28	28.5	15.0	13.5	2.25	3.6		
PC			28	26.0	13.0	13.0	2.20			28	27.0	13.5	13.5	0.00*	1.0		
HB			30	29.9	14.5	15.4	2.27			28	26.5	12.5	14.0	1.95	0.8		
DS			30	29.4	13.2	16.2	3.59			28	28.5	12.0	16.5	3.57	2.4		

1. Velocity in prism diopters per second.
2. Non-linearity in prism diopters represents deviation from constant velocity from the start of motion to fusion change in the specified direction of motion.
3. Pause in seconds is the time interval between the break and the beginning of the decrease in prismatic effect towards recovery.

* Patient fused with no movement of prism

TABLE 5

PARAMETRIC STUDY

PATIENT	DAY	TIME	PRISM VELOCITY CLASS	BREAK, prism diopters					RECOVERY, prism diopters					
				EXAMINER	TOTAL	OSCILLOSCOPE O.D.	OSCILLOSCOPE O.S.	OSCILLOSCOPE VELOCITY[1]	EXAMINER	TOTAL	OSCILLOSCOPE O.D.	OSCILLOSCOPE O.S.	OSCILLOSCOPE VELOCITY[1]	PAUSE[2]
LL	1	A.M.	fast	32	32.0	16.5	15.5	9.41	24	19.5	8.5	11.0	5.17	1.4
PG			slow	26	25.8	12.5	13.3	1.17	16	19.5	12.0	7.5	1.13	1.0
MB			med.	28	27.6	14.0	13.5	2.03	22	19.5	8.5	11.0	1.84	1.4
LL		N	med.	24	23.2	11.2	12.0	2.07	14	14.5	7.0	7.5	2.62	2.0
PG			fast	32	27.7	13.0	14.7	6.30	8	8.5	4.5	4.0	6.42	1.3
MB			slow	26	27.5	13.5	14.0	1.57	18	17.5	9.0	8.5	1.63	1.5
LL		P.M.	slow	28	27.0	13.5	13.5	1.29	23	22.5	11.5	11.0	1.25	2.0
PG			med.	26	25.5	12.0	13.5	2.55	9	6.0	3.5	2.5	2.67	2.0
MB			fast	32	30.5	14.0	16.5	6.35	24	20.5	9.0	11.5	5.53	2.0
LL	2	A.M.	med.	26	25.0	13.0	12.0	2.60	18	19.5	10.5	9.0	4.05	1.6
PG			fast	28	27.5	13.2	14.3	8.09	16	11.0	4.0	7.0	6.95	1.7
MB			slow	26	24.5	12.0	12.5	1.07	24	22.5	11.0	11.5	1.48	3.0
LL		N	slow	26	26.0	12.5	13.5	1.04	24	23.5	11.5	12.0	1.20	1.5
PG			med.	24	23.5	11.5	12.0	3.01	6	5.0	3.0	2.0	3.26	1.4
MB			fast	32	29.5	14.0	15.5	7.76	20	17.5	8.0	9.5	6.47	1.8
LL		P.M.	fast	29	29.5	15.0	14.5	8.19	16	16.0	7.5	8.5	7.52	1.8
PG			slow	24	22.0	11.0	11.0	0.92	12	10.2	5.5	4.7	0.94	2.0
MB			med.	28	28.7	15.0	13.7	2.99	18	19.0	9.8	9.2	3.61	1.8
LL	3	A.M.	slow	27	26.0	13.0	13.0	1.08	19	19.0	10.0	9.0	1.34	2.0
PG			med.	24	24.8	12.0	12.8	3.65	8	7.6	3.8	3.8	3.66	2.6
MB			fast	32	28.7	13.3	15.4	8.20	24	22.0	9.5	12.5	8.32	1.7
LL		N	fast	32	29.5	15.0	14.5	7.02	20	18.3	8.5	9.8	7.96	1.4
PG			slow	25	23.0	11.5	11.5	0.92	4	3.0	2.0	1.0	0.98	2.0
MB			med.	26	28.5	14.0	14.5	3.39	19	19.0	9.0	10.0	5.17	1.6
LL		P.M.	med.	28	27.5	14.0	13.5	3.44	18	18.0	8.5	9.5	6.08	2.0
PG			fast	34	31.0	14.0	17.0	9.69	4	2.5	0.5	2.0	8.29	1.6
MB			slow	26	23.5	11.5	12.0	0.94	24	22.5	11.0	11.5	0.73	2.0

1. Velocity in prism diopters per second.
2. Pause in seconds is the time interval between the break and the beginning of the decrease in prismatic effect towards recovery.

TABLE 6

STATISTICAL SUMMARY OF INDIVIDUAL TWO-COMPONENT ANALYSES OF VARIANCE OF DATA REGARDING THE TEMPORAL BEHAVIOR OF PATIENT #1 IN BASE-IN DUCTION BREAK

DAY	COMPONENT	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE VALUE	MEAN SQUARE ESTIMATE OF	VARIANCE OF COMPONENT (Δ^2)
1	**Method**	12.358	1	17.36	$\sigma^2+6\sigma^2_I+18\sigma^2_M$	0.70
	Time Period	48.973	2	24.49	$\sigma^2+6\sigma^2_I+12\sigma^2_T$	1.65
	Interaction	9.487	2	4.74	$\sigma^2+6\sigma^2_I$	0.55
	Residual	43.396	30	1.447	σ^2	1.45
	Total	119.214	35			
	Grand Mean	27.061				
	Method Means	27.756	26.367			
	Time Means	28.142	25.442	27.600		
2	Method	16.005	1	16.01	$\sigma^2+3\sigma^2_M$	4.43
	Time Period	1.535	2	0.77	$\sigma^2+2\sigma^2_T$	Not significant
	Interaction	0.802	2	2.185*	σ^2	2.19
	Residual	69.107	30			
	Total	87.449	35			
	Grand Mean	27.000				
	Method Means	27.667	26.333			
	Time Means	27.133	26.708	27.158		
3	Method	3.686	1	3.69	$\sigma^2+2\sigma^2_M$	1.06
	Time Period	22.430	1	20.43	$\sigma^2+2\sigma^2_T$	9.43
	Interaction	0.427	1	1.576*	σ^2	1.58
	Residual	32.665	20			
	Total	59.207	23			
	Grand Mean	29.108				
	Method Means	29.500	28.717			
	Time Means	28.142	30.075			

* Interaction not significant; therefore, it was combined with residual to constitute total remainder of variance.

TABLE 7

COMPILATION OF STATISTICAL SUMMARIES CONCERNING THE TEMPORAL BEHAVIOR OF PATIENT #1

FUSIONAL CHANGE	COMPONENT	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE VALUE	MEAN SQUARE ESTIMATE OF	VARIANCE COMPONENT (Δ^2)
Break	Days	77.776	2	38.89	$\sigma^2+6\sigma^2_D$	6.19
	Time	72.938	2	36.47	$\sigma^2+6\sigma^2_T$	5.79
	Method	37.049	1	37.05	$\sigma^2+9\sigma^2_M$	3.92
	Residual	155.857	90	1.732	σ^2	1.73
	Total	343.62	95			
	Grand Mean	27.550				
	Day Means	27.061	27.000	29.108		
	Method Means	28.158	26.942			
	Time Means	27.764	26.075	28.053		
Recovery	Days	8.101	2	4.05	Same as	0.40
	Time	101.536	2	50.77	above	8.18
	Method	9.074	1	9.07		0.82
	Residual	150.099	90	1.668		1.67
	Total	268.810	95			
	Grand Mean	19.632				
	Day Means	19.264	19.797	19.938		
	Method Means	19.392	19.873			
	Time Means	20.054	18.446	20.024		

TABLE 8

STATISTICAL SUMMARY OF INDIVIDUAL TWO-COMPONENT ANALYSES OF VARIANCE OF DATA REGARDING THE TEMPORAL BEHAVIOR OF PATIENT #2 BASE-IN DUCTION RECOVERY

DAY	COMPONENT	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE VALUE	MEAN SQUARE ESTIMATE OF	VARIANCE OF COMPONENT (Δ^2)
1	Method	0.000	1	0.00	See Table 6	Not significant
	Time Period	67.368	2	33.68	Day 2	15.80
	Interaction	5.304	2	2.090		2.09
	Residual	61.591	30			
	Total	134.263	35			
	Grand Mean	19.264				
	Method Means	19.267	19.261			
	Time Means	20.917	17.567	19.308		
2	Method	4.480	1	4.48	Same as	1.08
	Time Period	4.017	2	2.01	above	0.39
	Interaction	2.487	2	1.234		1.234
	Residual	37.003	30			
	Total	47.987	35			
	Grand Mean	19.797				
	Method Means	19.444	20.150			
	Time Means	20.017	19.325	20.050		
3	Method	4.594	1	4.59	Same as	1.26
	Time Period	30.151	1	30.15	above	14.04
	Interaction	0.050	1	2.082		2.08
	Residual	43.664	20			
	Total	78.459	23			
	Grand Mean	19.938				
	Method Means	19.500	20.375			
	Time Means	18.817	21.058			

TABLE 9

COMPILATION OF STATISTICAL SUMMARIES CONCERNING THE TEMPORAL BEHAVIOR OF PATIENT #2

FUSIONAL CHANGE	COMPONENT	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE VALUE	ESTIMATE OF	VARIANCE COMPONENT (Δ^2)
Break	Days	101.868	2	50.93	Same as	7.82
	Time	173.954	2	86.98	in Table	13.83
	Method	120.806	1	120.81	7	12.98
	Residual	359.350	90	3.993		3.99
	Total	755.978	95			
	Grand Mean	29.054				
	Day Means	30.383	28.222	28.308		
	Method Means	30.150	27.958			
	Time Means	28.242	29.625	29.625		
Recovery	Days	79.692	2	39.85	Same as	6.12
	Time	80.572	2	40.29	above	6.19
	Method	146.874	1	146.87		15.97
	Residual	282.620	90	3.140		3.14
	Total	589.758	95			
	Grand Mean	29.054				
	Day Means	30.178	28.658	27.963		
	Method Means	30.256	27.852			
	Time Means	28.819	29.646	29.119		

TABLE 10

CLINICIAN VARIATION STUDY - ANALYSIS OF VARIANCE

FUSIONAL CHANGE	COMPONENT	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE VALUE	ESTIMATE OF	VARIANCE COMPONENT (Δ^2)
Break	Patient(P)	143.012	1	143.01	$\sigma^2+58\sigma^2_P$	2.40
	Method(M)	20.868	1	20.87	$\sigma^2+58\sigma^2_M$	0.30
	Clinicianc(C)	299.414	28	10.69	$\sigma^2+4\sigma^2_C$	1.77
	Interaction_{P-M}	0.399	1			
	Interaction_{C-P}	9.152	28	3.60	σ^2	3.60
	Interaction_{C-M}	174.488	28			
	Residual	122.101	28			
	Total	769.434	115			
	Grand Mean	27.593				
	Patient Names	26.483	28.703			
	Method Means	28.017	27.169			
Recovery	Patient(P)	899.388	1	899.39	Same as	15.3
	Method(M)	6.284	1	6.28	above	Not significant
	Clinicians(C)	211.858	28	7.57		Not significant
	Interaction_{P-M}					
	Interaction_{C-P}	1007.693	85	11.855		11.86
	Interaction_{C-M}					
	Residual					
	Total	2125.223	115			
	Grand Mean	24.388				
	Patient Means	21.603	27.172			
	Method Means	24.621	24.155			

TABLE 11

CORRELATION OF TECHNIQUE PARAMETERS WITH THE BASE-IN DUCTION VALUES IN THE CLINICIAN VARIABILITY STUDY

PARAMETER	LINEAR CORRELATION COEFFICIENT				PERCENT OF ERROR ACCOUNTED FOR BY LINEAR REGRESSION			
	BREAK		RECOVERY		BREAK		RECOVERY	
	PATIENT #1	PATIENT #2	PATIENT #1	PATIENT #2	PATIENT #1	PATIENT #2	PATIENT #1	PATIENT #2
Difference between OD and OS values at fusion change point	0.105	0.028	0.115	0.257	1.09	0.08	1.33	6.59
Velocity, $sec.^{-1}$	0.150	0.050	0.521	0.152	2.26	0.25	27.19	2.30
Pause, sec.	-	-	0.237	0.123	-	-	5.64	1.51

TABLE 12

PARAMETRIC STUDY ANALYSES OF VARIANCE - DUCTION BREAK

DAY	COMPONENT	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE VALUE	MEAN SQUARE ESTIMATE OF	VARIANCE OF COMPONENT (Δ^2)
1	Patient	7.262	2	3.63	$\sigma^2+9\sigma_P^2$	0.38
	Time	8.436	2	4.22	$\sigma^2+9\sigma_T^2$	0.44
	Velocity	34.136	2	17.07	$\sigma^2+9\sigma_V^2$	1.87
	Residual	5.042	20	0.252	σ^2	0.252
	Total	54.876	26			
	Grand Mean	27.42				
	Patient Means	27.40	26.33	28.53		
	Time Means	28.47	26.13	27.67		
	Velocity Means	30.07	26.77	25.43		
2	Patient	17.242	2	8.62	Same as	0.92
	Time	1.742	2	0.87	above	0.06
	Velocity	33.842	2	16.92		1.85
	Residual	6.176	20	0.309		0.309
	Total	59.002	26			
	Grand Mean	26.24				
	Patient Means	26.83	24.33	27.57		
	Time Means	25.67	26.33	26.73		
	Velocity Means	25.73	28.83	24.17		
3	Patient	2.949	2	1.47	Same as	0.10
	Time	1.056	2	0.58	above	Not significant
	Velocity	46.482	2	23.29		2.53
	Residual	11.215	20	0.561		0.561
	Total	61.702	26			
	Grand Mean	26.94				
	Patient Means	27.67	26.27	26.90		
	Time Means	26.50	27.00	27.33		
	Velocity Means	24.17	26.93	29.73		

TABLE 12 (cont.)

DAY	COMPONENT	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE VALUE	MEAN SQUARE ESTIMATE OF	VARIANCE OF COMPONENT (Δ^2)
Total	Days	6.316	2	3.16	$\sigma^2+27\sigma^2$	0.11
	Patient	27.453	2	13.73	$\sigma^2+27\sigma^2_P$	0.50
	Time	11.234	2	5.12	$\sigma^2+27\sigma^2_T$	0.18
	Velocity	114.460	2	57.23	$\sigma^2+27\sigma^2_V$	2.11
	Residual	22.433	72	0.312	σ^2	0.312
	Total	181.896	80			
	Grand Mean	26.87				
	Day Means	27.42	26.24	26.94		
	Patient Means	27.30	25.64	27.67		
	Time Means	26.88	26.49	27.24		
	Velocity Means	29.54	26.03	25.03		

TABLE 13

PARAMETRIC STUDY ANALYSES OF VARIANCE - DUCTION RECOVERY

DAY	COMPONENT	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE VALUE	MEAN SQUARE ESTIMATE OF	VARIANCE OF COMPONENT (Δ^2)
1	Patient	117.722	2	58.86	Same as in	6.41
	Time	54.056	2	27.03	Table 12	2.88
	Velocity	63.722	2	31.86		3.41
	Residual	22.722	20	1.136		1.136
	Total	258.222	26			
	Grand Mean	16.44				
	Patient Means	18.83	11.33	19.17		
	Time Means	19.50	13.50	16.33		
	Velocity Means	16.17	19.83	13.33		
2	Patient	239.076	2	119.54	Same as	13.19
	Time	12.276	2	6.14	above	0.59
	Velocity	33.242	2	16.62		1.75
	Residual	17.042	20	0.852		0.852
	Total	301.636	26			
	Grand Mean	16.02				
	Patient Means	19.67	8.73	19.67		
	Time Means	17.67	15.33	15.07		
	Velocity Means	14.50	14.83	18.73		
3	Patient	487.582	2	243.79	Same as	27.03
	Time	11.949	2	5.97	above	0.60
	Velocity	0.682	2	0.34		Not significant
	Residual	10.869	20	0.543		0.543
	Total	511.082	26			
	Grand Mean	14.66				
	Patient Means	18.43	21.37	21.17		
	Time Means	16.20	13.43	14.33		
	Velocity Means	14.83	14.87	14.27		

TABLE 13 (cont.)

DAY	COMPONENT	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE VALUE	ESTIMATE OF	VARIANCE OF COMPONENT (Δ^2)
Total	Days	15.739	2	7.87	Same as in	0.27
	Patient	844.380	2	422.19	Table 12	15.61
	Time	78.280	2	39.14		1.42
	Velocity	97.647	2	48.82		1.78
	Residual	50.633	72	0.703		0.703
	Total	1086.679	80			
	Grand Mean	13.42				
	Day Means	16.44	16.02	14.66		
	Patient Means	18.98	8.14	20.00		
	Time Means	17.79	14.09	15.24		
	Velocity Means	15.09	14.23	17.80		