

VERTICAL VERGENCE DEMAND:
AN ANALYSIS OF FIXATION DISPARITY AND ADAPTATION

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ABSTRACT

Vertical fixation disparity introduced into the binocular visual system of most patients has been shown to change with time as the result of adaptation to the new vergence demand. The purpose of this study was to determine the extent to which the parameters of the vertical fixation disparity curve are related to the ability to adapt to new vertical vergence demands. Clinical implications of this relationship are discussed.

KEY WORDS

vergence adaptation, vergence demand, vertical fixation disparity, vertical prism

INTRODUCTION

Vertical fixation disparity introduced into the binocular visual system of most patients has been shown to change with time as the result of adaptation to the new vergence demand.

Ellerbrock and Fry¹ demonstrated that some patients adapted to the vertical vergence demand induced by wearing anisometric ophthalmic lenses. Ogle and others² reported that a reduction in an induced vertical fixation disparity may occur in as little as 3 to 10 minutes. Sethi and Henson³ more recently suggested that such adaptation may take a much longer period of time to occur completely. They felt that by using a technique that measured the rate at which an induced phoria changed with additional disparity, the adaptation process was much slower than when measured by a phoria or fixation disparity technique alone.

Rutstein and Eskridge⁴⁻⁸ studied vertical fixation disparity extensively, and concluded that the slope of the vertical fixation disparity curve may suggest the degree to which adaptation will occur. While no overall correlation was found between the fixation disparity curve slope and the ability to adapt to an induced vertical prism, it was determined that patients with the greatest adaptation ability generally had flatter slopes than patients who showed the least adaptation ability. Eskridge⁹ later found, using a sample of eleven patients, a significant correlation between the slope of the vertical fixation disparity curve and the ability to adapt to vertical prism. He suggested that patients with a hyperphoria who have steeper vertical fixation disparity slopes will more likely be successfully corrected with vertical prism.

The purpose of this study was to further determine the extent to which the parameters of the vertical fixation disparity curve are related to the ability to adapt to new vertical vergence demands. An understanding of such adaptation is important in the consideration of induced vertical prism imbalances associated with anisometric spectacle corrective lenses. It is also important in the prescribing of vertical prism for relieving asthenopic symptoms associated with hyperphoria. It was also hoped to determine the extent to which the measurement of vertical fixation disparity curves is clinically relevant.

METHODS

Twenty patients with healthy oculomotor systems participated in this study. The criteria for patient selection were that the patient: (1) be between 18 and 35 years of age, (2) have a lateral heterophoria less than 5 exo or 5 eso at distance, and less than 10 exo and 6 eso at near ¹⁰ as measured by the objective cover test, (3) have visual acuity correctable to 20/20 (6/6) in each eye, (4) have at least 60 seconds of arc stereoscopic acuity as measured by the Titmus Stereo Reindeer test, (5) have zero vertical heterophoria as measured by the Maddox rod, and (6) have no symptoms of asthenopia.

The disparometer described by Sheedy ¹¹ was used to measure fixation disparity. Measurements were made in free space at a distance of 40 centimeters. A pair of polaroid spectacles were placed over the patient's habitual correction. Vertical fixation disparity was first measured without an induced vergence demand.

represents the fixation disparity present in the absence of any vergence demand. The horizontal intercept of this line represents the amount of vertical prism necessary to reduce the fixation disparity to zero, often referred to as the associated phoria.

To determine if the slope of the vertical fixation disparity curve changed while wearing vertical prism, a paired T-test was used to compare the slopes measured before wearing prism to the slopes measured at the various time intervals after the prism was inserted. There was no significant difference found at the 0.05 level for any of the measurements. In fact, the lowest value for alpha in any of the comparisons was 0.28. This indicates that the slope of the curve did not change when it shifted in position.

All the vertical fixation disparity slopes were then considered as one group of data and analyzed. A mean slope of -3.01 was found with a standard deviation of 1.21. The slopes ranged from -6.60 to -0.03. A frequency histogram of the slope distribution was made (Figure 2).

The group wearing base-down prism was compared to the group wearing base-up prism. Using the fixation disparity present in the absence of vergence demand (vertical intercept) at each of six measurement intervals, the two groups were compared using an unpaired T-test. While the results (Table 2) do reflect a difference that approaches the 0.05 level of significance for the slope measured before the prism was inserted, this could not have been a result of the prism orientation since the prism had not

yet been inserted. All other measurements were not significantly different, and the two groups were considered to be statistically the same. The data from the base-down group was then inverted around the measurements taken before the prism was introduced so the two groups could be analyzed together.

Following the methods of previous studies⁴⁻⁹, the computer-generated vertical intercept was used to determine the rate and extent of adaptation to vertical prism. The change in the vertical intercept was plotted as a function of time, both individually, and as an average of all the patients (Figure 3, Table 3). On an individual basis, while some patients showed adaptation as expected, many patients showed a great deal of variability (Figure 4). Because of this variability, a coefficient of adaptation based on the change in vertical intercept as used by previous investigators⁴⁻⁹ was not found to be a useful piece of information.

It was also noted that for some individuals, there was considerable variation in the slope of the six curves plotted. To determine if steeper slopes tended to be more variable, for each person the standard deviation of the six slopes was plotted as a function of the mean of the six slopes (Figure 5). A computer analysis of this relationship yielded a correlation coefficient of -0.3815. This was significant at the 0.1 level, suggesting only a limited relationship.

DISCUSSION

Because the vertical intercept for each patient's measurements at the various time intervals was found to fluctuate considerably, this study was unable to compare the slope of the

vertical fixation disparity curve with a meaningful coefficient of adaptation as Eskridge and Rutstein did. It would appear that it is difficult to measure the vertical fixation disparity curve to a level of accuracy necessary to make such a comparison using the methods of this study.

There were several ways in which the design of this study differed from the work of Eskridge and Rutstein. All of their fixation disparity measurements were taken through a phoropter instead of in free space. In measuring the vertical fixation disparity curve, they used one-half prism-diopter steps of vergence demand instead of full prism-diopter steps. Further, and perhaps most significant, they did not alternate between base-up and base-down vergence demand, but rather continued to present increasingly greater vergence demands in a given direction until fusion was lost. It is likely that adaptation to the vergence demand induced by the measurement may have occurred.

In recent years it has been found increasingly useful to employ control system theory in considering the binocular visual system. This has especially been used in horizontal vergence models¹³⁻¹⁵. To apply this theory to a vertical vergence model, a similar form of this model is presented in Figure 6. Because accommodation is not linked to vertical vergence eye movements, this model is greatly simplified from its horizontal counterpart. The fast vergence adaptation mechanism serves as a forward controller, detecting vertical disparity, either right hyper or right hypo, and sending innervation to the extraocular muscles in the form of right supraduction or right infraduction to achieve

or maintain fusion. It must be kept in mind that even though disparity and duction movements are specified in terms of their relationship to the right eye, this is only for purposes of simplicity of explanation. In reality, disparity and eye movements are divided between the eyes. While the fast vergence adaptation mechanism has a short time constant, it also has a low gain. In other words, there is a very short latency time, but a relatively large disparity is required to drive the system to fusion. Therefore, the slow vergence adaptation mechanism becomes important. Although the slow vergence adaptation mechanism has a high gain, it has a long time constant. In other words, it effectively amplifies the signal put out by the fast vergence adaptation mechanism allowing a much smaller disparity to drive the system to fusion, but it requires time to become operational. Throughout this process, a negative feedback system allows the disparity detectors to constantly monitor the need for greater or lesser innervation.

This study once again demonstrated the fact that adaptation to vertical prism occurs. Following an increase in vertical fixation disparity following the insertion of vertical prism, the amount of vertical fixation disparity decreases over time. Initially the fast vergence adaptation mechanism allows fusion to occur when prism is inserted. As time passes the slow vergence adaptation mechanism becomes functional, causing the amount of fixation disparity to decrease. Thus, the slow vergence adaptation mechanism is responsible for the adaptation to vertical prism that occurs.

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It has been shown that the flat portion around the center

of symmetry of the horizontal fixation disparity curve reflects the ability of the slow vergence adaptation mechanism to function. Since the vertical fixation disparity curve is represented by a straight line without any central flattening, it might be assumed that a slow vergence adaptation mechanism for the vertical does not exist in the same way it does for the horizontal. However, since some work^{6,9} has shown a relationship between the slope of the vertical fixation disparity curve and the ability to adapt to vertical prism, it is proposed that the vertical slow vergence adaptation mechanism is present but not as well developed as the horizontal slow vergence adaptation mechanism. Therefore, the slope of the central area of the vertical fixation disparity curve is steeper than that horizontal, making it difficult to differentiate the central portion of the curve from the asymptotic tails of the curve. Thus, it has been represented in its entirety by a straight line.

This study indicates that the measurement of vertical fixation disparity curves is difficult clinically. It appears difficult to obtain a high level of accuracy in a single measurement. This may be related to the fact that the slow vergence adaptation mechanism is not highly developed in the vertical direction, causing the system to be much less stable than in the horizontal direction.

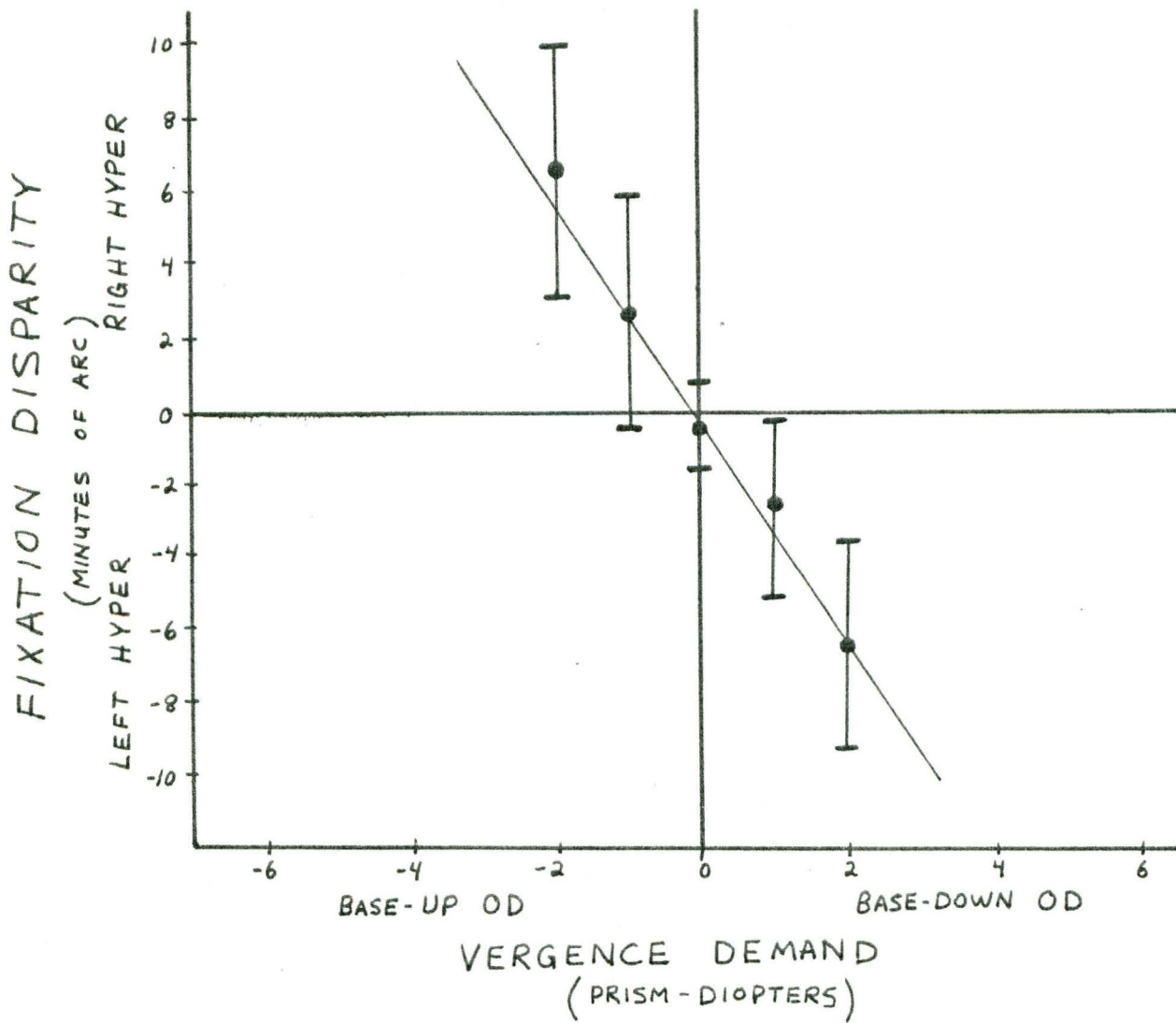


Figure 1. Average fixation disparity curve of twenty patients before vertical prism was worn.

Table 1. Vertical fixation disparity curves of twenty patients before vertical prism was worn.

Demand:	0	1 BD	1 BU	2 BD	2 BU
Mean	-0.50	-2.60	2.75	-6.42	6.61
S.D.	1.28	2.54	3.31	2.82	3.62

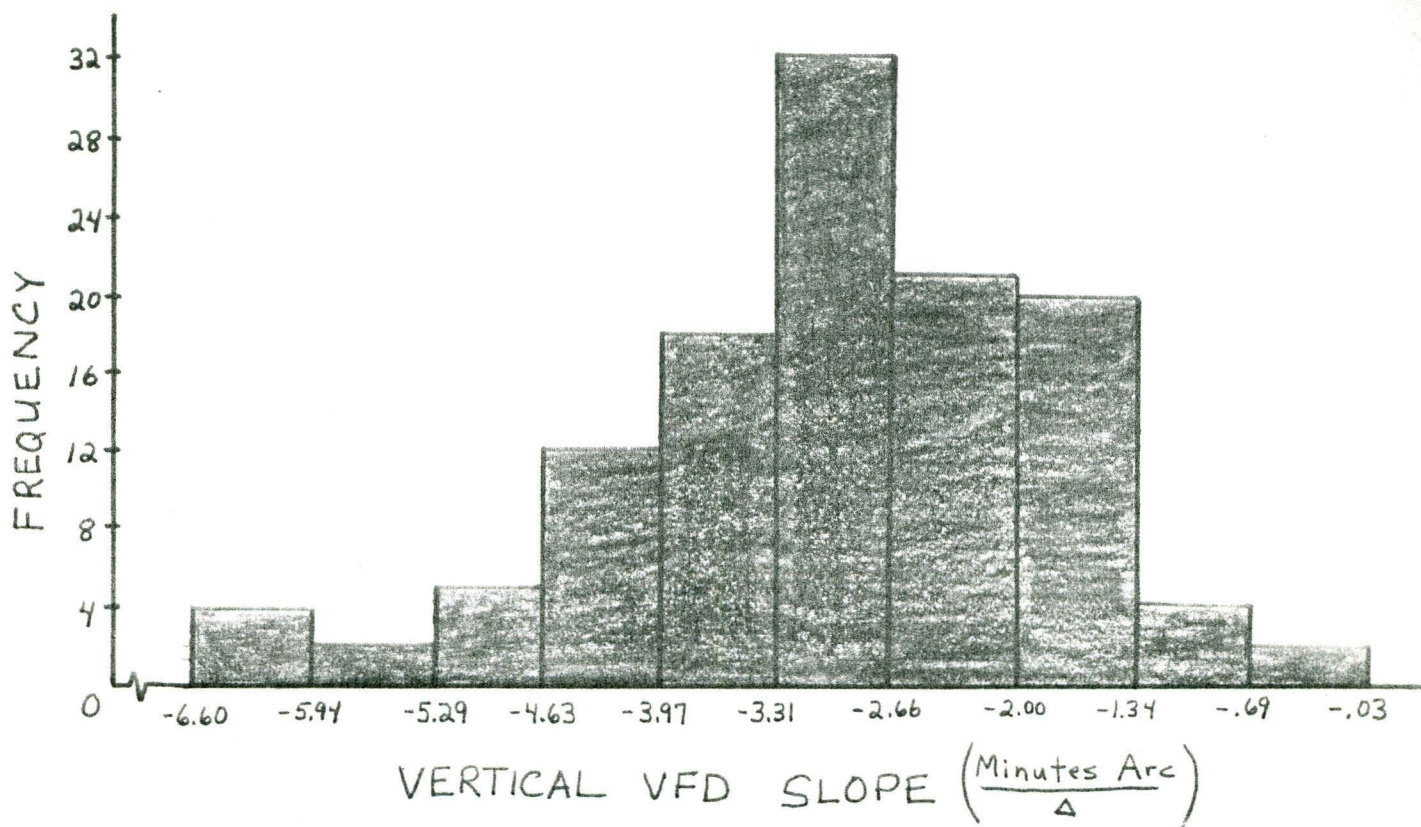


Figure 2. Distribution of vertical fixation disparity curve slopes for twenty patients.

Table 2. Vertical intercepts compared between group wearing base-up prism and group wearing base-down prism.

	Before	Insert	10 Min	20 Min	40 Min	80 Min
BU Mean	-0.624	3.317	1.236	0.106	0.223	0.629
BD Mean	0.504	3.468	2.775	2.465	1.706	1.371
Alpha	0.053	0.906	0.189	0.090	0.160	0.340

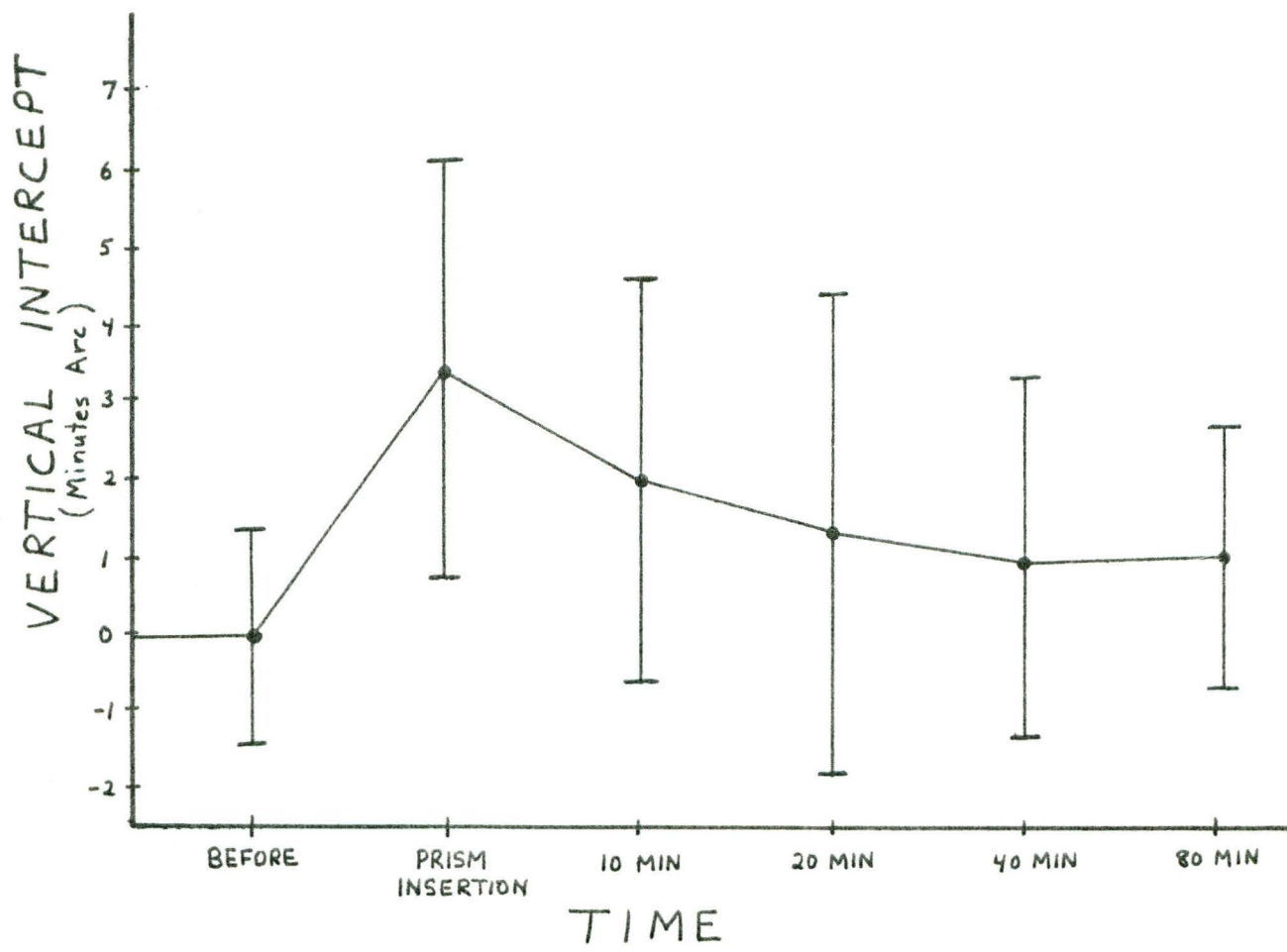


Figure 3. Average vertical intercept of twenty patients over time.

Table 3. Vertical intercepts of twenty patients over time.

	Before	Insert	10 Min	20 Min	40 Min	80 Min
Mean	-0.06	3.39	2.01	1.29	0.96	1.00
S.D.	1.32	2.74	2.58	3.11	2.33	1.69

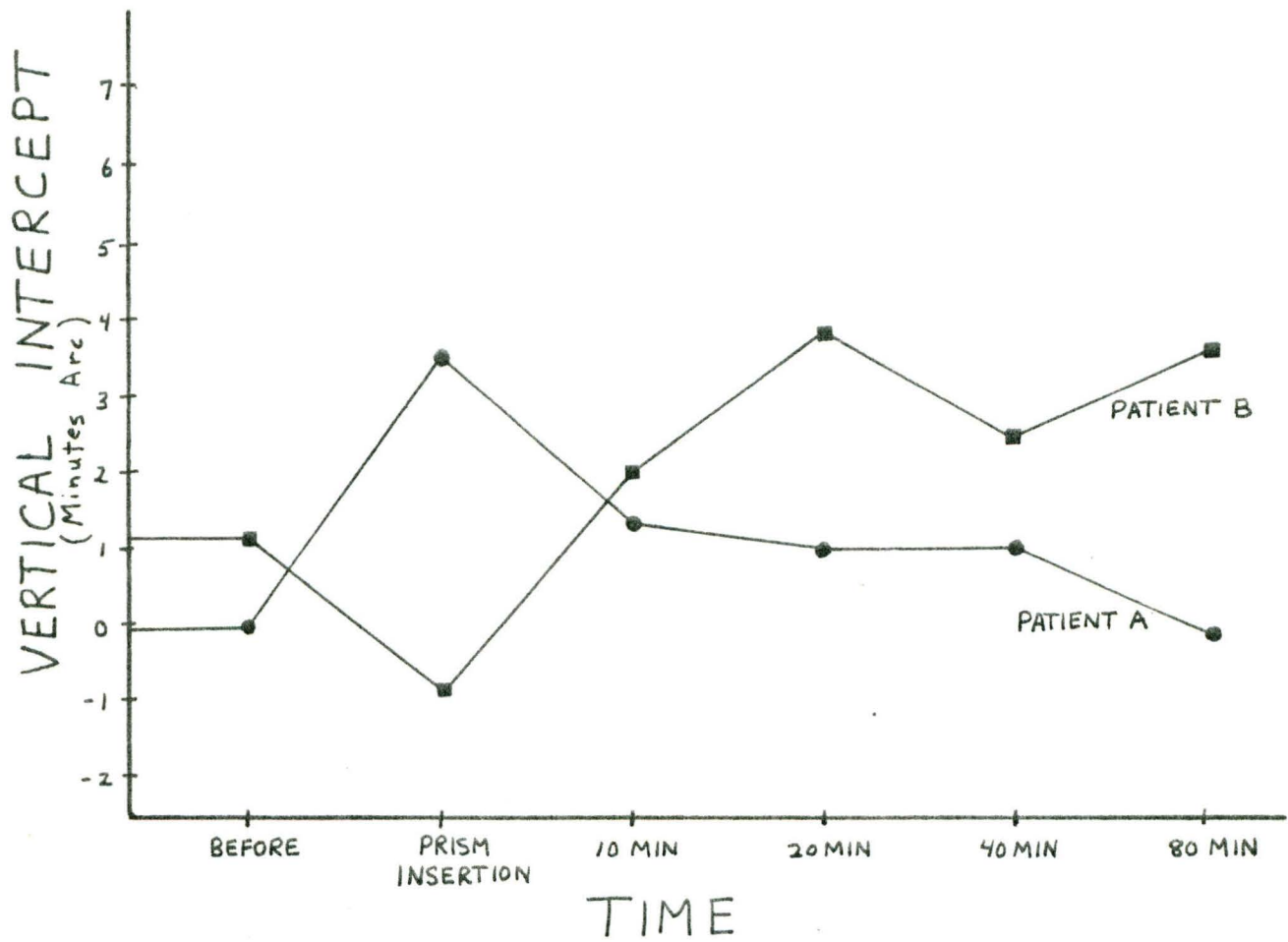


Figure 4. Examples of vertical intercept over time for two different patients. Patient A approximates the average pattern, while patient B is decidedly deviant from the average pattern.

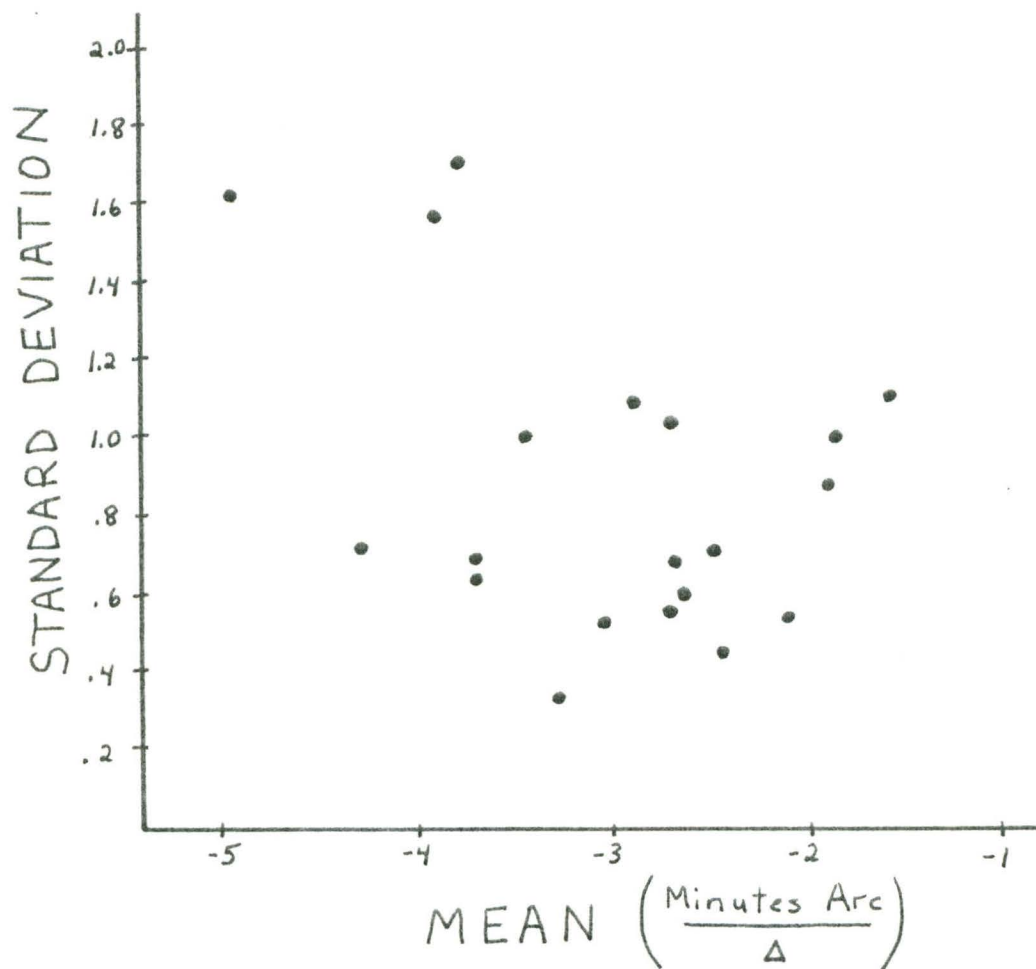


Figure 5. Standard deviation of a patient's slopes plotted as a function of the mean of a patient's slopes. A limited correlation is demonstrated.

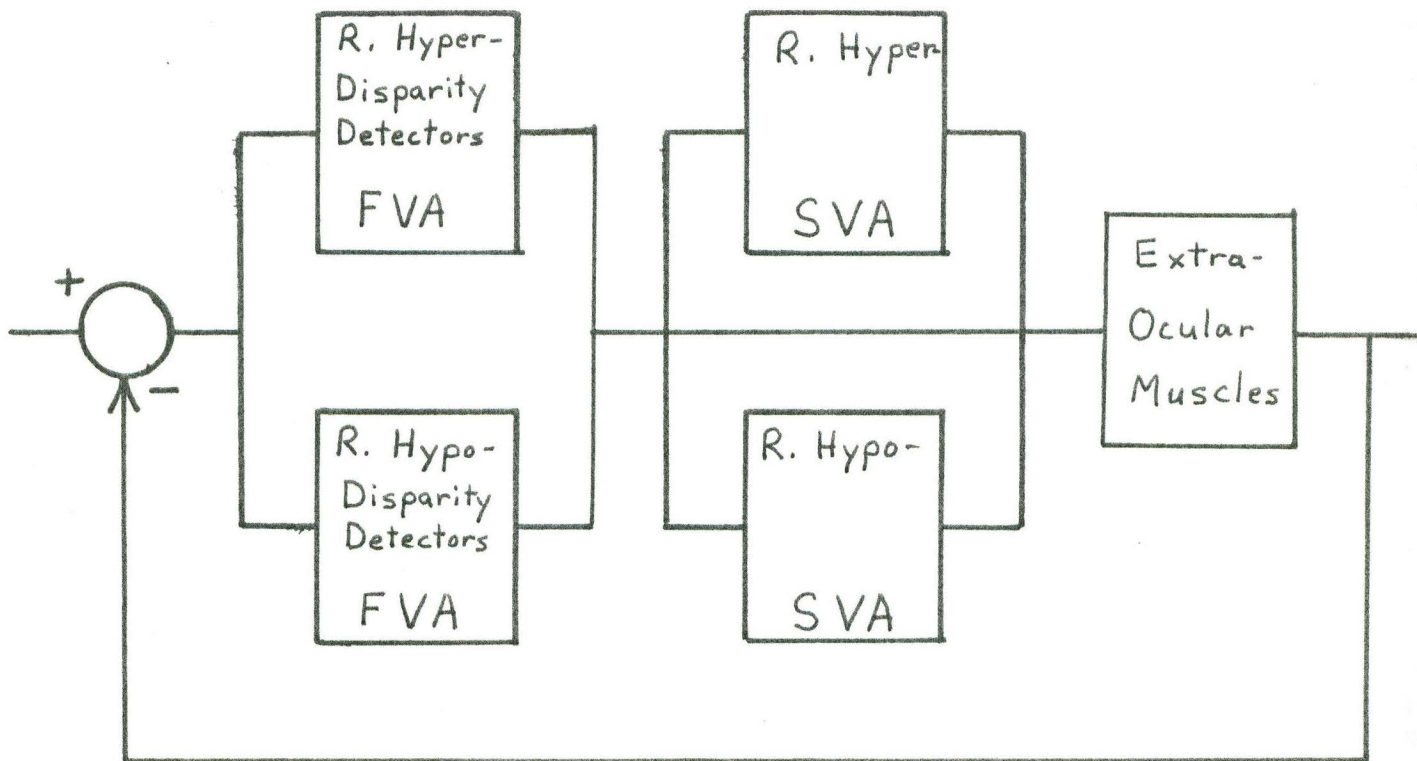


Figure 6. A control systems model of vertical vergence and fixation disparity.

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