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PROCEEDINGS

Long-Term Application of Computer-Based Pleoptics in Home Therapy: Selected Results of a Prospective Multicenter Study

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ABSTRACT *Introduction*: The paper presents selected results of a prospective multicenter study. The reported study was aimed at the evaluation of a software-based stimulation method of computer training applied *in addition to occlusion* as a complementary treatment for therapy-resistant cases of amblyopia. The stimulus was a drifting sinusoidal grating of a spatial frequency of 0.3 cyc/deg and a temporal frequency of 1 cyc/sec, reciprocally coordinated with each other to a drift of 0.33 deg/sec. This pattern was implemented as a background stimulus into simple computer games to bind attention by sensory-motor coordination tasks. According to an earlier proposed hypothesis, the stimulation aims at the provocation of stimulus-induced phase-coupling in order to contribute to the refreshment of synchronization and coordination processes in the visual transmission channels. *Materials and Methods*: To assess the outcome of the therapy, we studied the development of the visual acuity during a period of 6 months. Our cooperating partners of this prospective multicenter study were strabologic departments in ophthalmic clinics and private practices as well. For the issue of therapy control, a partial sample of 55 patients from an overall sample of 198 patients was selected, according to the criterion of strong therapy resistance. *Results*: The visual acuity was increased about two logarithmic steps by an occlusion combined with computer training in addition to the earlier obtained gain of the same amount by occlusion alone. Recalculated relatively to the duration of the therapy periods, the computer training combined with occlusion was found to be about twice as effective as the preceding occlusion alone. *Discussion*: The results of combined computer training and occlusion show an additional increase of the same amount as the preceding occlusion alone, which yielded at its end no further advantage to the development of visual acuity in the selected sample of our 55 therapy-resistant patients. In a concluding theoretical note, a preliminary hypothesis about the neuronal mechanisms of the stimulus-induced treatment effect is discussed.

KEYWORDS Amblyopia; stimulation of visual channels; pleoptics; computer training; multi center study

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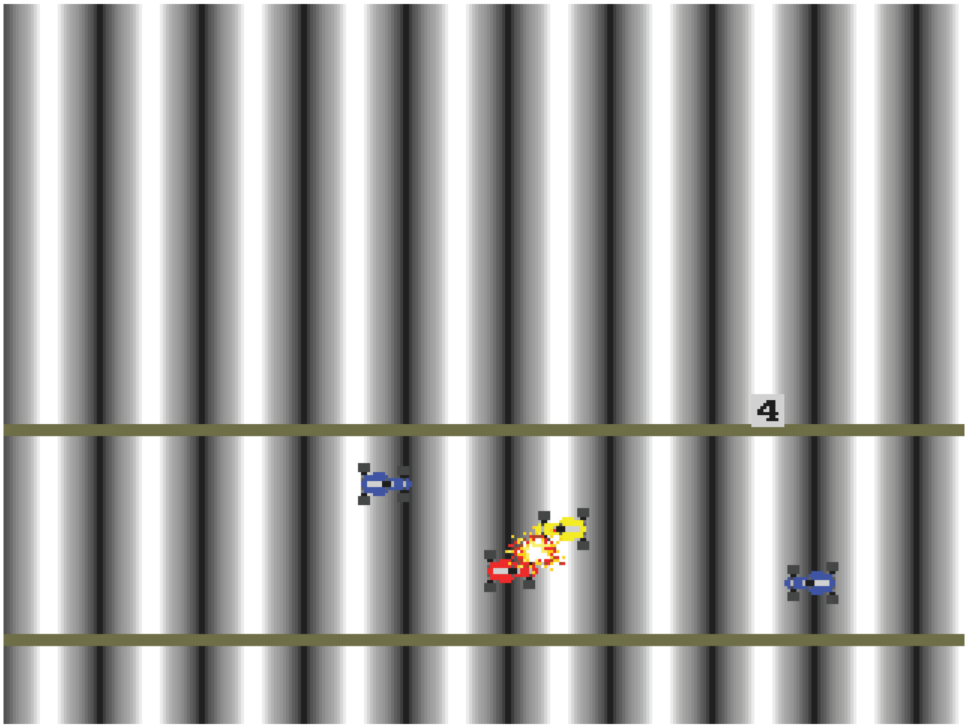

FIGURE 1 Example of a typical screenshot of the training software. In the foreground, as an example, a car game is performed by the patient, while his or her amblyopic eye is stimulated by the sinusoidal drifting grating pattern in the background of the computer screen.

INTRODUCTION

Since Sattler (1927) re-introduced into the practice of applied strabology the occlusion of the lazy eye, this method was indisputably accepted as the gold standard of amblyopia therapy. Complementary, a system of visual exercises and stimulation methods in support of the standard occlusion treatment had been developed (Bangerter, 1953; Campbell et al., 1978; Cüppers, 1960; Otto & Rabethge, 1980; Otto & Stangler, 1969). The presented report is aimed at the question of whether a computer-based modification of such visual training might be of value as a supportive method for the treatment of therapy-resistant cases, for example, of late amblyopia.

Meanwhile, computers have got available at home in our children's disposition at home. Accordingly, the visual training can be carried out in the private area of the patients. In view of this, an interdisciplinary team, including partners of the Dresden University's ophthalmologic clinics, the department of psychology, and the faculty of informatics, developed a software-based visual stimulation system for the complementary treatment of amblyopia (Kämpf et al., 1996, 1997; Kämpf et al., 1998; Kurze et al., 1996; Muchamedjarow et al., 1997).

Figure 1 shows a screen shot of the training software displaying a computer game in the foreground of the monitor that demands motor coordination and/or sensory fixation performance from the children. This gaming activity serves for attention binding, which had been previously proven to be a decisive factor for the success of visual training exercise. At the same time, background stimulation is provided by a sinusoidally contrast-modulated drifting grating pattern of constant spatial and temporal frequency. Due to such periodicity, the drifting stimulus grating is assumed to induce resonance within and between certain band-pass filter systems of visual transmission channels (see Appendix).

After a successful placebo-controlled clinical pilot exploration of the proposed computer training (Kämpf et al., 2000, 2006; Kämpf & Muchamedjarow, 1996; Kämpf, Muchamedjarow, & Seiler, 2001a, 2001b; Kämpf, Muchamedjarow, Brockmann, & Sadowicz, 1999; Kämpf, Muchamedjarow, Brockmann, Henke, & Sadowicz, 1999), the present paper was written as a preliminary report about selected results of a prospective multicenter study. The selection criterion for the reported results is motivated by the issue of therapy control. Applying PC-based training, the aim of our study was in no way to generally challenge occlusion therapy as a standard method for amblyopia treatment; rather it was aimed at the question for the value of *complementary to occlusion* computer training for therapy-resistant cases, especially for such of late amblyopia. In accordance with this objective, our preferred condition for the therapy control was not the usual placebo versus treatment group design, as had been applied in earlier clinical pilot studies (Kämpf et al., 2000, 2006; Kämpf & Muchamedjarow, 1996; Kämpf, Muchamedjarow, & Seiler, 2001a, 2001b; Kämpf, Muchamedjarow, Brockmann, & Sadowicz, 1999; Kämpf, Muchamedjarow, Brockmann, Henke, & Sadowicz, 1999). Departing from that we chose a post-hoc design for the purpose of therapy control in which a sample of patients was selected according to the criterion of strong therapy resistance, that is, achieving no further progress at the end of a more or less long-lasting period of occlusion therapy. Therefore, these patients served as their own "matched pairs" for the comparison of standard occlusion versus additional computer training.

MATERIALS AND METHODS

The reported results were selected from a prospective multicenter study. A total of 198 patients participated in the study, which was supported by a number of cooperating ophthalmologic centers. The patients had to fulfill an initial start-up treatment of 1 week under supervision of an orthoptist in the ophthalmology departments. Subsequently, they continued the training during 6 months at home, being monitored for evaluative purposes by our collaborators from the study centers.

The patients trained at a distance of 60 cm from a computer monitor. In the background of the screen a drifting grating was presented while a computer game was played in the foreground. The set of the games included, for example, driving a racing car against oncoming traffic, or maneuvering a rocket under meteor bombardment. The stimulation was performed by a drifting sinusoidal grating, which was contrast-modulated in gray nuances from black to white. Its dynamic modulation according to the drift rate followed a time frequency of 1 cyc/sec and a spatial frequency of 0.3 cyc/deg, reciprocally coordinated with each other to an angular drift rate of 3.33 deg/sec. According to the prospective design of our study, the variation of the stimulus parameters explored was limited to the listed parametric conditions that proved effective by the pilot research (Kämpf et al., 2000; Kämpf et al., 2006; Kämpf & Muchamedjarow, 1996; Kämpf, Muchamedjarow, & Seiler, 2001a, 2001b; Kämpf, Muchamedjarow, Brockmann, & Sadowicz, 1999; Kämpf, Muchamedjarow, Brockmann, Henke, & Sadowicz, 1999; Kämpf et al., 1998; Kämpf et al., 1996, 1997; Kurze et al., 1996; Muchamedjarow et al., 1997). The patients were to daily perform two training sessions. Each session consisted of 20 minutes of training. Additionally, the patients were occluded.

For the assessment of the so-called crowding phenomenon, the test of near vision was performed by means of the C-test (Haase & Hohmann, 1982; Hohmann & Haase, 1981) using Landolt rings being arranged as rows of optical characters that were laterally and very narrowly stringed together (2,6′). For comparison a measurement of singular optical characters was carried out. The strict adherence to a distance of 40 cm was checked up by means of a measuring tape. The test of the far vision at 4 m distance was performed by means of Landolt rings that were presented as singular optical characters. If the technical conditions were appropriate, the far-vision acuity was tested for comparison by means of row optical characters as well.

For the comparison of pure occlusion treatment and additional effects of computer training in therapy-resistant patients, a partial sample of 55 patients were selected from the 198 participants of our whole study according to both of the following criteria:

1. Therapy resistance at the end of conventional treatment, that is, no further treatment advances were finally obtained under occlusion alone.
2. The visual acuity data achieved at the end of occlusion treatment, thus, corresponding to the values at the beginning of computer training, were the highest values they ever achieved by occlusion standard treatment.

The computer-training results of the selected patients were compared with their previous visual acuity data, collected during the preceding occlusion treatment of different duration. Therefore, we gained retrospective data about occlusion-therapy success preceding the PC-training study with regard to these 55 children. To the selected group of patients belonged 32 boys and 23 girls born from 1988 to 1997 and hence representing lately detected amblyopia. In their case, no sufficient visual acuity enhancement could be attained through previous conventional treatment methods, and in their actual situation no further progress of visual acuity was recorded before starting PC training.

RESULTS

According to the variables of a factor design to be described below, the geometric means of the visual acuity data of all patients were calculated. From the viewpoint of mathematics it is of equal value to use the logarithmic steps of the visual-acuity data, to calculate the arithmetic mean over the logarithmic steps and to subsequently de-logarithm these arithmetic means (Bach & Kommerell, 1980). The arithmetically additive/subtractive behavior of the logarithms allows for the use of linear statistics; consequently the logarithmically transformed data were evaluated by a 2 × 2 × 2 analysis of variance (ANOVA) of three bipolar factors including the following variables:

1. amblyopic versus normal eyes (AMBNORM)
2. visual-acuity test results before versus after the treatment (PREPOST)
3. by occlusion alone versus together with PC training (OCCPCS)

Figure 2 presents the mean value of the near-vision acuity before and after occlusion alone versus before and after subsequent computer training plus occlusion measured by rows of optical characters for the amblyopic eyes. the preceding occlusion therapy alone (left two columns) versus combined with an additional to occlusion computer training (right two columns).

Figure 3 shows the mean value of the far-vision acuity before and after occlusion alone versus before and after subsequent computer training plus occlusion measured by single optical characters for the amblyopic eyes. Figure 4 presents the analogous data of the eyes with normal vision for far visual acuity measured with single optical characters. Because of an insufficient number of near-vision data, the analysis of variance was carried out only for far visual acuity of the normal versus amblyopic eyes. Table 1 shows the results of this analysis.

Complementary to the absolute visual-acuity gain, the comparison between the effects of occlusion alone and the additional PC training was reanalyzed on a relativistic base. Although the PC training lasted for a defined time period of 6 months, in contrast, the preceding occlusion treatment differed over a considerable range of individually different duration values. The cumulated occlusion duration values for each pa-

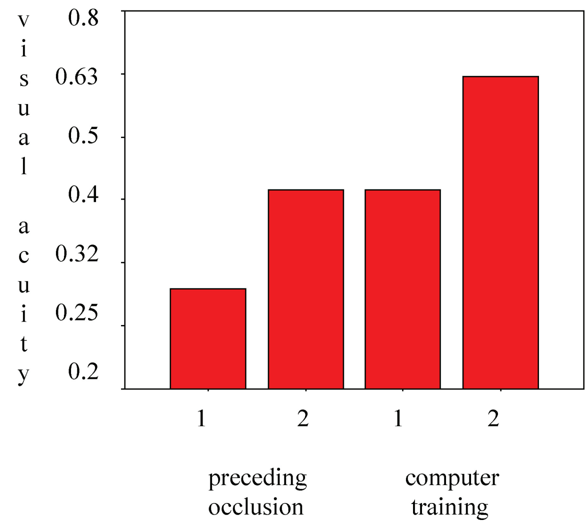

FIGURE 2 Geometric means of near visual acuity of the amblyopic eyes measured by rows of optical characters before (1) versus after (2) the preceding occlusion therapy alone (left two columns) versus combined with an additional to occlusion computer training (right two columns).

tient ranged from 1 month (minimum) up to 120 months (maximum) while the mean value for all patients amounted to 23.23 months with a standard deviation of 28.80 months. To provide an approximate comparison we tried to normalize the results gained through occlusion by rather different individual amounts to the relativistic basis of a standardized span of 6 months, that is, to the duration of our additional to occlusion computer training. The increment gained by occlusion (i.e., the difference between the acuity before versus after the occlusion treatment) was multiplied for each patient by the normative time period of the PC training of 6 months and divided afterwards by the cumulative number of occlusion months. (This is, of course, only a rough estimate since we did not take into account the pauses made between occlusion treatments for individual patients, which lead to a decrease in the cumulative duration of the therapy). For these recalculations, we possessed sufficient data only for the far, but not for near visual acuity. Composing the new factor RELDIF, the normalized prepost differences of preceding occlusion alone, recalculated from its own absolute scale to relative values with regard to the time scale of PC training, were incorporated into the variable FOEDFREL and the absolute pre-post differences of the combined PC training

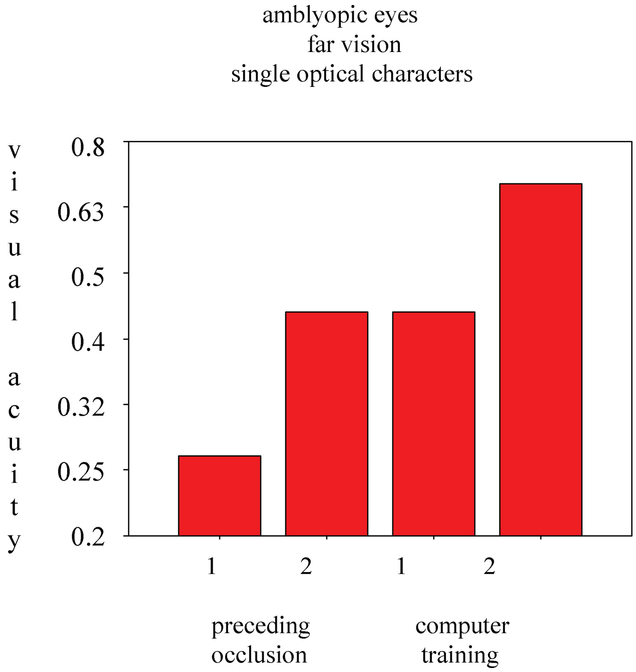

FIGURE 3 **Geometric means of far visual acuity of the amblyopic eyes measured by single optical characters before (1) versus after (2) the preceding occlusion therapy alone (left two columns) versus combined with an additional to occlusion computer training (right two columns).**

plus occlusion were incorporated into the variable FVEDIFF. Their values were compared with the visual acuity difference of each patient before and after the 6-month training on PC. the preceding occlusion therapy alone (left two columns) versus combined with an additional to occlusion computer training (right two columns).

Figure 5 shows the outcome of this comparison procedure as a relative pre-post difference of visual acuity in logarithmic steps for the preceding occlusion therapy alone (left two columns) versus combined with an additional to occlusion computer training (right two columns).

Table 2 shows the test of contrasts for this difference.

Table 3 shows the geometric mean and standard deviation of the normalized relative differences between the results of preceding occlusion therapy alone versus combined with computer training.

DISCUSSION

The most important of the reported results was the increase of about two logarithmic visual-acuity steps in the pre-/post-comparison for the amblyopic eyes, which was approximately of the same amount for the 6 months of PC training combined with occlusion as for the whole occlusion-alone treatment before. In order to correctly estimate this result, one should keep in mind that the preceding occlusion alone produced at its end, that is, at the beginning of the PC training, no further progress to the development of visual acuity in the selected sample of our 55 therapy-resistant patients.

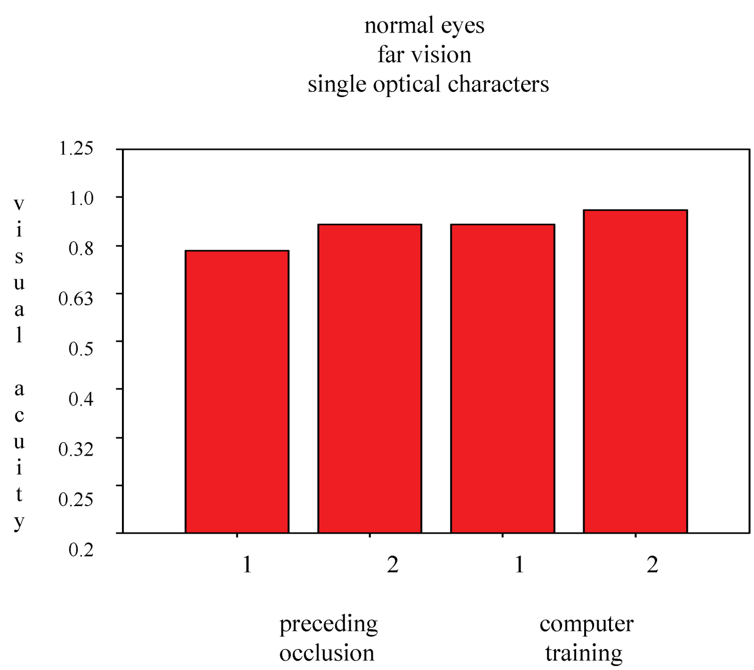

FIGURE 4 **Geometric means of far visual acuity of the normal eyes measured by single optical characters before (1) versus after (2) the preceding occlusion therapy alone (left two columns) versus combined with an additional to occlusion computer training (right two columns).**

TABLE 1 **Analysis of variance for the far-vision of the amblyopic versus normal eye (AMBNORM) measured by single optical characters before and after (PREPOST) occlusion therapy alone vs. combined with subsequent computer training (OCCPCS).**

Effect	Value	*F*	*df* hypothesis	*df* error	Significance
OCCPCS	.642	69.930	1	39	.000 +
AMBNORM	.678	82.177	1	39	.000 +
PREPOST	.642	69.930	1	39	.000 +
OCCPCS by AMBNORM	.519	42.084	1	39	.000 +
OCCPCS by PREPOST	.014	00.543	1	39	.466 −
AMBNORM by PREPOST	.519	42.084	1	39	.000 +
OCCPCS by AMBNORM by PREPOST	.000	00.001	1	39	.976 −

Table 1 presents the analysis of variance, which relates to the data obtained by single optical characters for far visual acuity in comparison of the amblyopic and normal eyes. The analysis of variance came out in a significant main effect for the factor OCCPCS, originating from the fact that occlusion and PC training started up from considerably different base values. Moreover, the approximately equal difference of visual acuity achieved from these rather different base levels with both methods accounts for the significant main effect in the factor PREPOST showing no significant interaction with the factor OCCPCS. Thus, we have to underline that the half-year PC-training support of continued occlusion after stagnant visual acuity development yielded an increase of approximately the same amount as the occlusion alone applied for many years before. Complementary, we observed a significant interaction between the factors AMBNORM and PREPOST, which we attribute to the fact of a selective visual acuity augmentation caused by the therapy, namely on the amblyopic and not the normal vision eye. In case of normal eyes it is evident that their visual acuity alternations before and after the treatment, as assessed by the different measurement methods, are of a rather minor dimension if compared with amblyopic eyes. Therefore the visual acuity of normally functioning eyes shows no changes during the training, since the pre/post differences are limited to less than half of one logarithmic visual-acuity step. Moreover, we found a significant interaction between the factors OCCPCS and AMBNORM resulting from the different growth of the acuity levels of the amblyopic and not of the normal eyes during the courses of occlusion alone versus additional computer training. The graphic analysis of the data for normal eyes during the therapy indicates that neither occlusion alone nor the additional PC training do affect the visual acuity of the normal eye in any negative way. Small increases in the course of the therapy are marginal and can be ignored in the present context.

All in all, the results of prior clinical and further pilot investigations were confirmed and the

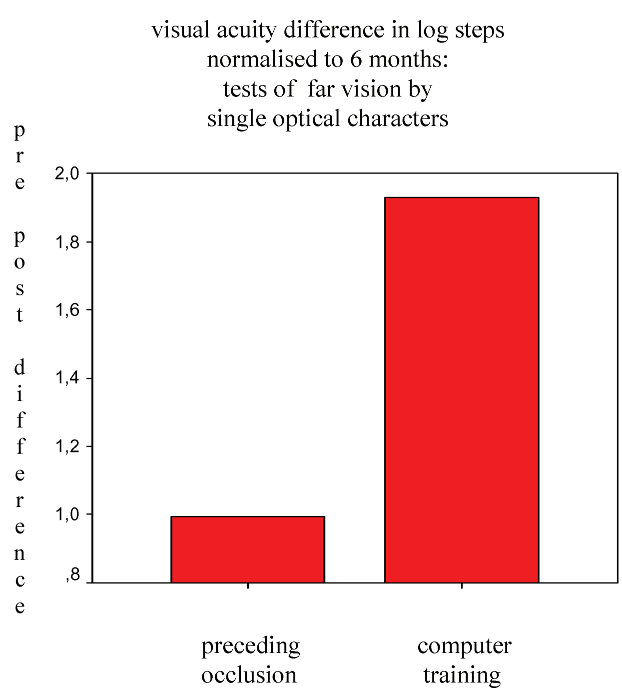

FIGURE 5 **Pre-/post differences in logarithmic steps (dB) of the far visual acuity assessed by single optical characters for the preceding occlusion alone normalized by recalculation in relation to a span of 6 months (left column) versus for the computer training combined with occlusion (right column).**

TABLE 2 **Test of within subjects' contrast for the relative differences of occlusion therapy alone vs. combined with subsequent computer training**

Effect	Sum Square	df	Mean Square	F	Significance
RELDIFF	16.184	1	16.184	3.935	.055
error (RELDIFF)	148.044	36	4.112		

TABLE 3 **Geometric mean and standard deviation of the normalized relative differences for the success of occlusion therapy alone vs. combined with subsequent computer training**

Variable	Geometric Mean	Standard Deviation	Standard Error
1 FVEDIFF	1.9308	1.88493	.30988
2 FOEDFREL	.9955	2.59027	.42584

computer-supported visual training according to the background-stimulation approach under attention-binding by computer games, which was tested in a prospective distributed multicenter study by independent researchers, proved to be successful as a supportive treatment of therapy-resistant amblyopia. The direct comparison of both therapies (before/after the treatment) in the same sample of selected patients yielded no significant interaction since the visual acuity enhanced in both cases about two steps. However, by the computer training combined with occlusion a further visual acuity augmentation was achieved even though the preceding occlusion-alone therapy had given no further progress at its end. Since the data for near visual acuity were not sufficient to carry out an analysis of variance, the near visual acuity measured in rows of optical characters was demonstrated only as a graph. Yet this graph shows essentially analogous relations as seen on the graph for far visual acuity: both the near and the far visual acuity were improved thanks to the PC training by an extra amount of about two steps of visual acuity. In other words, the computer training improved stagnant visual acuity by an additional amount of the same rate of increase as has been accumulated by the previous occlusion therapy. The comparative evaluation of therapy success in the selected sample of patients indicates that the computer-supported training under occlusion added to the result, achieved by occlusion only, an equally considerable augmentation of visual acuity.

However, the visual acuity values before the beginning of occlusion therapy were collected together post hoc from patient files in ophthalmologic practices and therapeutic centers. Since these measurements were collected apart from the scientific context of our study, we had to deal with the situation that the results of many years of conventional therapy (often with breaks) had to be compared with the results of 6 months' PC training. Therefore, we had to recalculate the absolute acuity-gain of rather different occlusion-alone duration into relative differences "normalized" to a span of 6 months of occlusion combined with computer training.

Figure 5 displays the logarithmic pre-post differences achieved by PC training plus occlusion over 6 months in a comparison with the relative success of the preceding occlusion alone. For the assessment the latter had been recalculated from the absolute differences to this normative range of 1/2 year too. From the recompiled data it may be concluded that the rate of visual-acuity increase achieved within the 6-month period of PC training was about twice as high as the "normalized" to a 6-month standard relative acuity-gain of preceding occlusion alone. A single factor analysis of variance was performed using the factor RELDIFF compiled from the variables of the PREPOST-difference found out in the relative time period with regard to occlusion alone versus PREPOST-difference of the occlusion with additional computer training.

Table 2 shows this factor slightly missing the significance level of 5%.

Table 3 shows a probable cause of this failure, namely that the standardized deviation from the normative occlusion differences was considerably higher than the deviation of the PC-training differences. This is likely due to the heterogeneity of the occlusion periods incorporated into the re-calculation of the normative effect.

As seen in the absolute and the relativistic increases as well, a straightforward conclusion can be drawn from the comparison of occlusion and PC training in the light of the therapy control. While the occlusion-alone results stagnated at its end, the 6 months of PC-training supported occlusion yielded an absolute extra amount of visual-acuity gain of two steps, that is, of the same amount as the preceding occlusion treatment (with a mean of 23.23 months and a standard deviation of 28.80 months). Recompiled into a proper relation to the treatment duration of 6 months, the relativistic efficacy of the PC training is suggested to be approximately twice as high as the result of the occlusion without training.

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REFERENCES

Abeles M. Role of cortical neuron: Integrator or coincidence detector? *Isr J Med Sci*. 1982;18:83–92.

Abeles M, Vaadia E, Bergman H, Prut Y, Haalman I, Slovin H. Dynamics of neuronal interactions in the frontal cortex of behaving monkeys. *Concepts in Neuroscience*. 1993;4(2):131–158.

Bach M, Kommerell G. Sehschärfebestimmung nach europäischer Norm: Wissenschaftliche Grundlagen und Möglichkeiten der automatischen Messung. *Klin Mbl Augenheilkd*. 1998;212:190–195.

Bangerter A. *Amblyopiebehandlung*. Basel: Karger, 1953.

Blakemore C, Campbell FW. On the existence of neurons in the human visual system selectively sensitive to the orientation and size of retinal images. *J Physiol*. 1969;203:237–260.

Breitmeyer BG, Ganz L. Implications of sustained and transient channels for theories of visual pattern masking, saccadic suppression and information processing. *Psychol Rev*. 1976;83:1–36.

Campbell FW, Hess RF, Watson PG, Banks R. Preliminary results of a physiologically based treatment of amblyopia. *Br J Ophthalmol*. 1978;62:748–755.

Campbell FW, Robson JG. Applications of Fourier analysis to the visibility of gratings. *J Physiol.* 1968;197:551–566.

Cüppers C. Grenzen und Möglichkeiten der pleoptischen Therapie. Travemünde: Tagung der Nord-West-Deutschen Augenärzte. In: *Schielbehandlung: Einführungs- und Fortbildungsvorträge*. Wiesbaden, 1960;S.39–97.

Fries P, Roelfsema PR, Engel AK, König P, Singer W. Synchronized gamma frequency oscillations correlate with perception during binocular rivalry in awake squinting cats. *Soc Neurosci Abstr*. 1996;22: 282.

Haase W. Wert und Unwert der Occlusionstherapie im Rahmen der Schielbehandlung. *Münch Med Wochenschr*. 1978;120: 99–102.

Haase W, Hohmann A. Ein neuer Test (C-Test) zur quantitativen Prüfung von Trennschwierigkeiten („crowding") - Ergebnisse bei Amblyopie und Ametropie. *Klin Mbl Augenheilkd*. 1982;180:210–215.

Hess RF, Bradley A. Contrast perception above threshold is only minimally impaired in human amblyopia. *Nature*. 1980;287:463–478.

Hess RF, Burr DC, Campbell FW. A preliminary investigation of neural function and dysfunction in amblyopia: Cooperative activity of the amblyopic channels. *Vis Res*. 1980;7:757–782.

Hess RF, Howell ER. The threshold contrast sensitivity function in strabismic amblyopia: Evidence for a two type classification. *Vis Res*. 1977;17:1049–1055.

Hohmann A, Haase W. Entwicklung der Sehschärfe beim Menschen– ein neuer Test mit standartisierten Einzel- und Reihenoptotypen. In: Freigang M, ed. *Arbeitskreis Schielen*, Nürnberg, 1981;13:131–136.

Kämpf U, Brockmann F, Henke R, Muchamedjarow F, Mascolus W. Variierte vs. konstante Frequenzen in der Schielbehandlung mit Sinusoidalgittern. *TWK 2000: 3. Tübinger Wahrnehmungskonferenz*. Tübingen, 2000.

Kämpf U, Mascolus W, Muchamedjarow F, Shamshinowa A, Kaschenko T. Coherence induction via phase conjugate adaptive resonance coupling: Computer-generated sinusoidal grating patterns as a background stimulus in amblyopia treatment. *J Psychophysiology*. 2006;20(2):149.

Kämpf U, Muchamedjarow F. Amblyopiebehandlung durch schmalbandselektive Visusstimulation bei spielerischer Aufmerksamkeitsbindung. In: Schorr A, ed. *Experimentelle Psychologie. Beiträge zur 38. Tagung experimentell arbeitender Psychologen*. Lengerich: Pabst Science Publishers, 1996;148.

Kämpf U, Muchamedjarow F, Brockmann F, Henke R, Sadowicz K. Unterstützende Behandlung der schielbedingten Schwachsichtigkeit (Amblyopie) durch oszillierende Sinusoidalgitter: Eine placebokontrollierte Studie. In: Wachsmuth I, Jung B, eds. *KogWis99: Proceedings der 4. Fachtagung der Gesellschaft für Kognitionswissenschaft,* Bielefeld, 28. September - 1. Oktober. Sankt Augustin: Infix, 1999;171–176.

Kämpf U, Muchamedjarow F, Brockmann F, Sadowicz K. Spielen statt Schielen: Behandlung der unilateralen Schwachsichtigkeit (Amblyopie) durch oszillierende Sinusoidalgitter. *TeaP '99: 41. Tagung experimentell arbeitender Psychologen*, Leipzig, 28.März - 01.April 1999.

Kämpf U, Muchamedjarow F, Gräfe J, Rimbach J, Mascolus W. Visusstimulation und Aufmerksamkeitsbindung: Software und Hardware zur unterstützenden Behandlung von Amblyopien (Computerdemonstration). *41. Kongreß der Deutschen Gesellschaft für Psychologie, Dresden*, 27. September–1.Oktober, 1998.

Kämpf U, Muchamedjarow F, Mascolus W, Kurze U, Ludwig D. Enhancing the visual ability of the amblyopic child's eyes: A new computer supported approach of visus stimulation by sinusoidally oscillating gratings. *International Workshop on Short-term Storage and Processing in Human Cognition: Dynamic Characteristics and Neural Mechanisms*. Leipzig: Universität Leipzig, November 21–24, 1996.

Kämpf U, Muchamedjarow F, Mascolus W, Kurze U, Ludwig D. Visusstimulation mit sinusoidal moduliert oszillierenden Gittern: Eine neue computergestützte Methode zur Behandlung von Amblyopie. In: van der Meer E., et al., eds. *Experimentelle Psychologie. Abstracts der 39. Tagung experimentell arbeitender Psychologen*. Lengerich: Pabst Science Publishers, 1997;486.

Kämpf U, Muchamedjarow F, Seiler T. Amblyopia treatment by means of computer games with background stimulation by sinusoidal drifting gratings. In: *Myopia and other disorders of refraction, accomodation and the oculomotor system. Proceedings of an International Symposium*, Moscow (Russia), Dec. 18–20, 2001a;189–190.

Kämpf U, Muchamedjarow F, Seiler T. Unterstützende Amblyopiebehandlung durch Computerspiele mit Hintergrundstimulation: Eine placebokontrollierte Studie. *Klin Mbl Augenheilkd*. 2001b;218:243–250.

Kelly DH. Retinal inhomogenity I. Spatiotemporal contrast sensitivity. *J Opt Soc Am*. 1984;A1:107–113.

Kelly DH. Retinal inhomogenity II. Spatial summation. *J Opt Soc Am*. 1984;A1:114–119.

König P, Engel AK, Löwel S, Singer W. Squint affects the synchronzation of oscillatory responses in cat visual cortex. *Eur J Neurosci*. 1993;5:501–508.

Koskela PU. Contrast sensitivity in amblyopia: 1. Changes during CAM-treatment. *Acta Ophthalmol (Copenh)*. 1986a;64:344–351.

Koskela PU. Contrast sensitivity in amblyopia: 2. Changes during pleoptic treatment. *Acta Ophthalmol (Copenh)*. 1986b;64:563–569.

Kulikowski JJ, Tolhurst DJ. Psychophysical evidence for sustained and transient channels in human vision. *J Physiol*. 1973;232:149–163.

Kurze U, Ludwig D, Kämpf U, Muchamedjarow F, Mascolus W. Therapie, Prophylaxe und Nachsorge von Amblyopien: Basissoftware zur Visusstimulation und Videogames zur Aufmerksamkeitsbindung (Computerdemonstration). In Schorr A, ed. *Experimentelle Psychologie: 38. Tagung experimentell arbeitender Psychologen*, Eichstätt: 1. - 4. April. Düsseldorf: Pabst Science Publishers, 1996;180.

Linke B. Erfahrungen der Amblyopiebehandlung mit dem Campbell-Stimulator. In: Freigang M, ed. *Arbeitskreis Schielen, Nürnberg*. 1980;12:67–73.

McCana F, Cuthbert A, Lovegrove W. Contrast and phase processing in amblyopia. *Vis Res*. 1986;26:781–789.

Mehdorn E, Mattheus S, Schuppe A, Klein U, Kommerell G. Amblyopiebehandlung mit dem Cambridge-Stimulator: Eine kontrollierte Studie. In: Freigang M, ed. *Arbeitskreis Schielen*, Nürnberg: 1980;12:61–62.

Muchamedjarow F, Kämpf U, Mascolus W. Visusstimulation mit sinusoidal moduliert oszillierenden Gittern: Eine neue computergestützte Methode zur Nachsorge von Amblyopie. *6. Tagung der Bielschowsky-Gesellschaft für Schielforschung*, Gießen, 29.-31. August. *Klin Mbl Augenheilkd*. 1997;211:5.

Osterloh J. Beeinflussung von Fixation und Fernvisus amblyoper Augen durch optomotorische Reize. *Dissertation Fachbereich Medizin*. Universität Hamburg, 1972.

Otto J, Rabethge G. Über die optomotorische Amblyopiebehandlung. In: Freigang M, ed. *Arbeitskreis Schielen, Nürnberg*. 1980;12:74–80.
Otto J, Stangler E. Wirkung optomotorischer Reize auf Fixationsort und Auflösungsvermögen amblyoper Augen mit exzentrischer Fixation. *Ophthalmologica*. 1969;157:135–141.
Rentschler I, Hilz R, Brettel H. Amblyopic abnormality involves neural mechanisms concerned with movement processing. *Invest Ophthalmol Vis Sci*. 1981;20:695–700.
Roelfsema PR, König P, Engel AK, Sireteanu R, Singer W. Reduced synchronization in the visual cortex of cats with strabismic amblyopia. *Eur J Neurosci*. 1994;6:1645–1655.
Sattler CH. Erfahrungen über die Beseitigung der Amblyopie und die Wiederherstellung des binokularen Sehaktes bei Schielenden. *Z Augenheilk*. 1927;63:19–124.
Stangler E. Ist das Visumeter für die Amblyopiebehandlung geeignet? *Klin Mbl Augenheilkd*. 1974;164:563–566.
von der Malsburg C, Schneider W. A neural coctail-party processor. *Biol Cybernetics*. 1986;54:29–40.

APPENDIX: A THEORETICAL NOTE

At the end of this paper, a preliminary hypothesis about the possible neuronal mechanisms of the stimulus effect will be discussed. The prototype for the proposed computer-based background stimulation was a repetitive-grating modification of the light stripe therapy derived from a training approach that had been originally proposed by Otto and Stangler (Otto & Stangler, 1969). These authors described and confirmed a beneficial effect of so-called optomotor and/or optosensory stimulation on the fixation stability of amblyopic eyes (Otto & Rabethge, 1980; Stangler, 1974). Modifying the original stimulus, replacing it by the wall-projection of a cylindrical arrangement of rods turning around an inner light source, Haase (1978) and Osterloh (1972) found an amplification of this effect. The shadows of the illuminated rotating rods were exposed to the patients as a moving-grating pattern, superimposed to a fixation cross. Thus, the displayed pattern was a slightly blurred repetitive arrangement of bars, appearing as a grating of constant spatial and temporal frequency in continuous motion.

Due to its periodicity, such drifting stimulus grating is assumed, as a hypothesis, to induce–beyond the optomotor stimulation effect–an optosensory resonance within and between certain complementary band-pass filter systems of visual-transmission channels. Constrained to one another in cooperative synergy, the firing patterns of these complementary channels are assumed to correspond–roughly speaking–to the neuronal correlates of visually perceived form (parvo system, sustained channels) versus motion (magno system, transient channels) (Breitmeyer & Ganz, 1972; Kulikowski & Tolhurst, 1973). The filters of each of these channels are selectively tuned to a narrow band of spatial frequencies (Blakemore & Campbell 1969; Campbell & Robson, 1968) associated with an inversely tuned temporal frequency range. Due to the opposite relationship between spatial and temporal frequency ranges for each of those systems (Kelly, 1984a, 1984b), the filters associated with form correlates are reciprocally tuned, as compared with the filters of motion correlates, in their spectral resolution.

In amblyopia, the transmission coherence of the channel system, which is supposed to preferably filter the frequency-modulated correlates of visual form, appears to be more impaired than that of the complementary system of channels for the transmission of spectrally filtered motion correlates. Accordingly, at surface, the amblyopic vision disorder manifests itself as a dysfunction of the form channels of high spatial versus low temporal frequency resolution (Hess & Howell, 1977). Motion channels of low spatial versus high temporal frequency resolution (Rentschler et al., 1981) seem to be comparatively less disordered.

Probably, the observable effects of this coherence disorder in amblyopia are the so-called "spatial distortions." They primarily affect the band pass of high spatial-frequency filters, as compared with the complementary "crowding phenomenon" within the spatial low-frequency range. From the model of spectrally filtering the visual input by spatial-frequency bands (Blakemore & Campbell 1969; Campbell & Robson, 1968), this might be interpreted as a consequence of coherence losses within the temporally synchronized cooperation of the visual channels, when transmitting the visual input's spatial phase. According to this hypothesis, the amblyopic disorder may be characterized by decoherent interaction between different channels rather than by malfunction of the transmission within singular narrow-band selective channels per se. From such point of view, the spatial-phase losses are assumed to be caused by a distortion of the temporal synchronization of this cooperation process (Hess & Bradley, 1980; Hess et al., 1980; McCana et al., 1986), while the "machinery" of the form versus movement senses is impaired to a various extent (Rentschler et al., 1981).

From the neuronal aspect, this might be due to an incapability of the participating cortical clusters to coordinate their excitatory activity by phase-coupling of the oscillatory discharge patterns in the context of systemic coherent population dynamics. A registration of the neuronal activity from the visual cortex of strabismic cats demonstrated that the channels fed by the amblyopic eye do not "fire" less intensively than those of the healthy eye; however, they work disharmonized and are unable to synchronize their neuronal impulses (König et al., 1993; Roelfsema et al., 1994). Instead of a phase-coherent oscillatory discharge pattern, they produce chaotic discharges, possibly damaging their cooperation in course of the binding of visual features (Fries et al., 1996; Roelfsema et al., 1994; von der Malsburg & Schneider, 1986). Moreover, the coherence loss of the neuronal discharge pattern responding to the amblyopic eye takes place only by stimulation from grating patterns of high spatial frequency and not of low spatial frequency (Roelfsema et al., 1994), so differing from the normal eye's discharge pattern being coherent in both cases of stimulation.

Accordingly, the proposed stimulation (Kämpf et al., 2001a, 2001b; Kämpf & Muchamedjarow, 1996; Kämpf et al., 2006) is designed to affect the spatially high and temporally low frequency-tuned form channels not directly but collaterally using the cooperative interplay with reciprocally, that is, spatially low, and temporally high frequency-tuned motion channels. Complementary to the fixation-stabilizing optomotoric effect of the traditional light-stripe stimulation (Haase, 1978; Osterloh, 1972; Otto & Rabethge, 1980; Otto & Stangler, 1969) we suppose the drifting sinusoidal grating to support the coherence of cooperative visual processing due to an optosensoric resonance effect. In order to induce such an effect, the drifting light stripe stimulation under spatial and temporal periodicity of a limited frequency bandwidth (which is, by the way, characteristic for certain of the traditional pleoptic training too, for example, as for the spiral pattern of the centrophor exercises [Bangerter, 1953; Cüppers et al., 1960]) should be applied to the disturbed system's neuronal dynamics as an external order parameter. It is supposed that the optomotoric and optosensoric effects induced by the repetitively moving grating stimulus do mutually interact, taking part in the self-organized cortical dynamics by non-linear coupling of so-called neuronal synfire-chains (Abeles, 1982; Abeles et al., 1993). These are precisely timed circuits of neurons of up to 500 msec loop duration and a timing coherence of normally less than 1 msec. The drifting-grating stimulus is expected to externally support these processing loops in the visual brain to regain their normally highly ordered, but desynchronized in amblyopia, internal coherence. As a result, the complementary bandwidth-selective filters of form channels are expected to be resynchronized in resonance to the motion channels' system. In view of our preliminary hypothesis, the internal synchronization in the form channels is externally supported via phase coupling to the repetitive signals provided by the motion channels.

Independently of the above-presented hypothesis, the reference to channels of bandwidth-selective visual filters had been already the topic of an earlier proposal of supportive amblyopia treatment by grating stimulation. This approach was developed by the British physiologist Campbell and his team in Cambridge (Campbell et al., 1978). However, their results were controversially discussed in view of placebo-controlled unsuccessful replication attempts (Koskela, 1986a, 1986b; Linke, 1980; Mehdorn et al., 1980). The Cambridge stimulator aimed at a direct stimulation of form channels by gratings of different spatial frequency, thus omitting the possible synergies induced by resonance to motion channels. On the contrary, as has been stated above, the stimulation method we evaluated in the present paper aims to synchronize the demonstrably decoherent (Fries et al., 1986; König et al., 1993; Roelfsema et al., 1994) internal systemic dynamics of the form channels in a roundabout way. Namely, by resonance-driven phase coupling to intact motion channels, that is, to their time frequency as an external order parameter.