Percentage of Binocularity Through Waking Hours - Re-calculations and Case Studies

All communications to:

Eric S. Hussey, OD, FCOVD

1116 E. Westview Ct., Suite A

Spokane, WA 99218

spacegoggle@icloud.com

Abstract

Background: Intermittent central suppression (ICS) is a treatable intermittent loss of central visual sensation. ICS has been shown to negatively affect reading. The mechanism theorized for that reading consequence is degraded fixation accuracy. As a loss of sensation, it is also a defect and loss of binocularity.

Methods and results: An easy equation for calculating a percentage of binocularity based on vectographic testing at near is presented. That percentage of binocularity through waking hours is presented with the caveat that these calculations are an extrapolation from a short testing vignette to binocularity throughout the day. Two prior studies are recalculated for changes in binocularity with therapy for the ICS and three case studies with real-world changes in abilities are presented.

Conclusions: Increasing percentage of binocularity during waking hours increases the amount of visual information available for decision making through the rest of life. As the only profession positioned to evaluate binocularity over time, optometry needs to measure and improve percentage of binocularity during waking hours.

Key Words: Binocularity, intermittent central suppression, reading, quality of life

Introduction

In very practical ways, binocularity is a hard concept. Does the term binocularity mean rough physical alignment of the eyes, pretty good physical alignment of the eyes, or would binocularity be more accurately characterized as the sensory combination for vision, thanks to both motor coordination and sensory stability of two eyes and visual system?

Since the derivation of the term binocularity stems from “bin,” not “bi,” that is, a combining prefix suggesting, with “ocular,” two eyes combining, it seems that the most accurate definition of binocularity would be sensory. This definition of binocularity has been offered previously: “Both eyes having intact visibility of central images that are combined into one percept without loss of visibility of either central image.”[1] To that primary definition, this paper adds “with that combined intact visibility sustained over time.” The point in this addition is not just to stress that in a condition such as intermittent central suppression, central visual sensation changes over time. But, in addition, it is conceivable that a patient could achieve a form of binocularity by some extraordinary or contrived means. Sustaining sensory binocularity over time with extraordinary effort suggests an effort level that at some point is likely doomed to fail to sustain, given enough time. The usefulness of binocularity would probably decrease in proportion to the effort required to sustain it. The cave dweller who had to put maximal cognitive effort into sustaining binocularity to give maximum visual information to his saber-toothed tiger avoidance plan, would be at a disadvantage compared to a rival cave-dweller who could use reduced cognitive effort for vision, thereby allowing other sensory information to add in to the information set.

Vision science links foveation to long-term memory.[2,3] Moving, for example, printed words from a page into long term memory, therefore, requires foveation during fixation.[4] It might be tempting to take lightly a statement that having both foveas properly aligned with the target of regard should increase the available information during a foveated fixation - just consider it simple addition of inputs and redundancy. However, beyond the simple one-plus-one addition of redundant (to some degree) neurology in a properly aligned bifoveal fixation, if sensory dropout, that is, suppression, is involved at all, that potentially additive neurology not only no longer is additive; it is actually subtractive. The perceptual fill-in that occurs especially during intermittent suppression impairs and probably variably impairs central sensation with changing input to the brain since that cortically-produced fill-in is strong enough to be a rivalrous "image."[4]

A rivalrous image by definition will not be fused with the opposite eye's image. Therefore, any intermittency of sensation would be expected to interfere with bilateral foveation and long-term memory. Conversely, correcting intermittency of sensation would be expected to improve long-term memory and fixation-linked visual tasks such as reading.[5] If that correction of intermittency is sustained, those behaviors that might be called symptoms of vision-and-reading problems would be expected to remain improved over time.[6]

Unfortunately, precise measurement of sensory intermittency - intermittent central suppression - is elusive. The very nature of optometric sensory diagnostic testing is subjective. With the added dimension of sensory stability over time, those subjective responses (remembering that often in these considerations clinicians are testing children) become even more problematic. How can accurate subjective responses be pulled from a child without "leading the witness." The goal is not to have the child agree with our viewpoint, but to facilitate a valid, reliable, repeatable response against which we can compare post-therapy changes to see if treatment actually addressed what was diagnosed, and then evaluate if those changes improved the life of the child. With stable central sensation, resulting in properly sustained bilateral foveation, we trust we are aiding a child's - or an adult's - long term visual memory. With long term visual memory maximized, the future life-options for a child or an adult should be broader, less limited, no longer limited by impaired vision and visual memory.

This paper represents a starting point - not necessarily an end-point - for calculating binocularity and then looking at changes in binocularity with therapy. It is limited not only by the requirement of getting subjective responses with some level of accuracy from children, but also by the subjective nature of current binocularity testing itself.

Sensory testing

Sensory testing for intermittent central suppression has been described previously.[5,7] The on-off cyclical nature of intermittent central suppression has also been described as on average a roughly two- to three-second on-off or suppressed/non-suppressed cycle.[8,9] Timing the on-off cycle has most often been done at near using the modified Borish near card.[a] That is, a vectographic near test card with a target two degrees (14 mm at 40cm) in width, cut in half with the right half covered by a polarizer aligned with the phoropter polarization for the right eye, and the left half covered by a polarizer aligned with the phoropter polarization for the left eye (Figure 1). With that target in place at near, and with polarizers in the phoropter, during routine examination, a patient can describe or signal with a hand when one side of the diamond blacks out to the point that the underlying letters cannot be seen.

The goal of therapy, in terms of sensory testing, is to increase the non-suppressed “on” periods and decrease, hopefully to extinction, the suppressed “off” periods.[10] But, following closely after that idea is the question of how do we document any changes in a format that allows some form of analysis? Analysis of sensation over time is good, but it is even better if the data are comprehensible to non-optometrists.

Further complicating the questions of analysis and comprehensibility, is the spectrum of responses of especially young patients to the variety of subtests used to elicit an appropriate ICS response. As described above, the near diamond target with polarized overlays has been effective for timing ICS responses. However, occasionally a patient doesn’t respond to the diamond target stimulus, but will respond on a variety of projected vectographic targets at distance.[a] Timing on distance targets can certainly be done with some forethought.[8] However, the data can get computationally confusing trying to assess changes across multiple targets. Therefore, this analysis will deal with determining the percentage of waking hours patients spend with binocular vision as described by patient responses on the near diamond target.

An easy calculation for percentage of binocularity

The previously discussed caveats have to be applied to this binocularity calculation. Further, it is important to understand that we are projecting patient responses given in a vignette of visual behavior at near to waking hours throughout the day. But, given that an ICS timing sequence has been documented on the diamond target at near, or perhaps with another consistently-timed target that allows bilateral observation, this is the data we have. Other ways to check visual behavior throughout the day are speculative at the moment.

So far, the patient reporting method that works to some degree across the broadest group of people is to have the patient raise a hand on the side that, for example, blacks out on the diamond. And, that is black enough that the letters under the polarizers cannot be seen. Timing that sequence over thirty to sixty seconds should give a range for both off/suppressed and on/non-suppressed periods. Those are easily averaged. Then a percentage of binocular/bilateral vision time can be calculated: [(average non-suppressed seconds) / (average suppressed seconds + average non-suppressed seconds)] x 100. Within the caveats presented, that percentage represents the amount of time during waking hours that a patient is seeing with both eyes simultaneously. That percentage does not address fixation behavior, precise alignment, or the amount of time with precise alignment versus amount of time spent in correction of fixation errors. We don't know those timings. But, a percentage of "binocularity" may still be instructive.

Post-therapy, for calculation of the binocularity percentage, a maximum binocularity timing may need to be picked, assuming therapy has been successful at reducing suppression and increasing binocularity. As an illustration, if a two-second suppression occurred, then no suppression periods were noted during the rest of a typical clinical timing period, twenty seconds has been the timing we've used clinically for calculation purposes for the length of the "on/non-suppressed" period.

As a clinical aside, the concept of percentage of waking hours in binocularity has to date been accepted as comprehensible by parents and adult patients with ICS. Even with fairly thorough explanation of the limitations on the calculation, having a single number that expresses how little of the day an ICS sufferer spends in what might be called "normal" seeing has both diagnostic “shock-value” and post-therapy expression-of-therapeutic-achievement value. That is, patients and parents seem to pay attention.

Re-calculation from prior studies

Data from two prior published studies were used to calculate before- and after-therapy binocularity percentages. Again, the thrust of that percentage is it gives us an admittedly limited idea of how little or how much of waking hours are spent in full sensory binocularity. That number must come with the accompanying understanding that this represents an extrapolated, estimated total timing as not-suppressed and not a timing of actual binocularity according to the above definition. We currently don’t have a binocularity meter for objective readout over time, and we certainly don’t have a wearable version of a binocularity meter. So, we rely on extrapolation from what we can learn in subjective testing. As stated above, for calculations, 20 seconds is the maximum “on/non-suppressed” period; similarly one hundred percent is the maximum amount of binocularity during waking hours. Some level of inaccuracy in the calculations must be accepted due to inherent subjective-response and clinical-examination limitations. Further, as purely clinical studies, neither had a true control group.

The Job Corps study

The first study re-calculated for a percentage of binocularity is the Job Corps ICS study published in 2012.[5] In that study, 26 young adults at a Job Corps facility in north central Washington state who were trying to finish their high school diploma or GED (general equivalency diploma), were referred by their teachers for evaluation and treatment. The teachers’ concern was reading problems, and that those reading problems might be related to vision problems, specifically to ICS. In that group, using electronic rapid alternate occlusion (rapid alternation), the alternation therapy decreased suppression periods and increased binocularity periods and as a result of the increased binocularity (and corresponding decreased suppression), quality of life scores improved, reading-related quality of life scores improved, and in a subset (18 students) Test of Adult Basic Education® (TABE®; CTB/McGraw-Hill) reading scores improved. The therapy was accomplished away from the clinic, without other therapeutic interventions, on post-developmental young adults, using rapid alternation, a visual-sensation-targeted therapy that has no known broader vision-therapeutic effects. To a great degree, therapy was an isolated vision-only ICS therapy without direct, daily doctor influence.

Recalculating for a percentage of waking hours in binocularity using group-timing-averages, prior to rapid alternation therapy, this group of young adults (mean age 19.7±1.6 years) spent about 53% of waking hours in binocularity; post-therapy that changed to better than 90%. Looking at individual-binocularity-percentages, a paired t-test shows the pre-therapy versus post-therapy binocularity percentages to be significantly different (p<<0.0001). Ninety-nine percent confidence intervals for averaged individual binocularity percentages pre- and post-therapy show no overlap in confidence intervals, suggesting post-therapy this is a very different population than prior to therapy (pre-therapy 99% confidence interval maximum binocularity 60.6 % of waking hours; post-therapy 99% confidence interval minimum binocularity 71.9% of waking hours). That increase in binocularity during waking hours co-occurred with the improved quality of life scores. Doing the same calculations for the subset of 18 students for which pre- and post-therapy reading scores were available shows precisely the same results: Two significantly different groups, pre- and post-therapy in their waking hours percentage of binocularity (p<<0.0001; 99% confidence intervals show no overlap, pre-therapy maximum binocularity 65.3% and minimum post-therapy binocularity 80.2%) with concurrent improved reading scores post-therapy.

The long-term study

The second study recalculated was the long-term ICS treatment study, submitted 2019.[6] In this study, a group of 18 patients who had completed therapy for ICS using rapid alternation were sent a list of 13 quality of life questions derived from the questions that changed at the highest level of significance in the Job Corps study (above).[5] Those 18 patients had completed therapy an average 2 1/4 years prior to the questionnaires being sent. Scoring on the questions could range from 2, this symptom changed a lot, to -2, this symptom changed, but reverted. Pre- and post-therapy examination data provided suppression timing for evaluation. This group of 18 patients showed those 13 quality of life symptoms improved and stayed improved over the 2+ years post-therapy. Increasing binocularity improved their symptoms and the improvements stayed; they did not revert.

Long-term recalculation using averaged timing

In the original study, the examining doctor's clinical estimation of improvement in intermittent central suppression was used as an estimator for retention of long-term therapy gains to evaluate alongside retained quality of life symptoms. This broader, but more doctor-subjective scoring, showed binocularity gains over the 2 1/4 years of post-therapy time that did not deteriorate.

Recalculating for a percentage of waking hours in binocularity using group-timing-averages, shows prior to rapid alternation therapy, this group (mean age 10.5 ± 6 years) was binocular about 43% of waking hours; post-therapy that changed to better than 96%. Looking at individually calculated percentages, a paired t-test shows the pre-therapy/post-therapy binocularity percentages to be significantly different ($p<<0.0001$). Ninety-nine percent confidence intervals for averaged individual-binocularity-percentages pre- and post-therapy show no overlap, suggesting post-therapy this is a very different population than prior to therapy (pre-therapy 99% confidence interval maximum binocularity 68.3 % of waking hours; post-therapy 99% confidence interval minimum binocularity 91.3% of waking hours). That increase in binocularity during waking hours co-occurred with the improved and retained quality of life scores.

From the conclusions of the long-term study, it is suggested that "since the ICS was treated largely in isolation, and since the QOL changed for the better with this single-factor targeted therapy, we can say without hesitation that increased time through the waking hours with true binocularity is beneficial. Further, if ICS is treated to increase binocularity, positive changes tend to stay over time. Loss of improvements is minimal."

The doctor-estimate of changes in suppression through therapy backed the assertion that improvements in suppression remained long term. To assess that long-term retention with percentage of binocularity during waking hours, on-off period timing was averaged retrospectively both immediately as rapid alternation therapy ended, and then at the individual long-term study points. Immediately following therapy, percentage of binocularity was better than 97% versus the longer term 96+% discussed above. Therefore, time took about 1% of binocularity away calculated with group-timing-averages.

Long-term recalculation using individually calculated percentages of binocularity

To check retention of binocularity further, beyond and in support of the more generalized doctor-estimation percentages of improvement in suppression through therapy, individual-binocularity-through-waking-hours-percentages were calculated, again as immediately close to the finish of rapid alternation therapy as possible, and then at the individual long-term visits. Those individual percentages of immediately-finished and later visits (average 2.24 years) were compared.

Calculating first the individual-percentages of binocularity-during-waking-hours, then taking averages of those individual percentages of binocularity, at the finish of rapid alternation therapy, the long-term group average of individual-percentages of binocularity during waking hours was 95.7%. At the later date, averaging, again, 2.24 years after the end of therapy, the same group averaged just over 93.4% binocularity during waking hours. These calculated losses of under 3% of binocularity are very similar to the losses documented in the original study in both the clinical estimation of improvements through therapy for ICS with rapid alternation, and with the loss of QOL over time. Thus, we should expect losses over time in improvements in ICS, improvements in QOL, and percentage of binocularity during waking hours of less than 5%. The closeness of those quantifications of loss over time suggest some level of validity to the clinical estimations of improvement in ICS during, at the end and after therapy that were used in the original long-term study.[4]

Similar to the treatment of pre-/post-therapy percentages of binocularity above, a paired t-test and 95% confidence intervals were then calculated for percentage of binocularity during waking hours as calculated for examinations immediately at the end of therapy and then at the long-term examination. A paired t-test of individual percentages of binocularity during waking hours shows the immediate end-of-therapy binocularity percentages and the long-term binocularity percentages are not different ($p>0.07$). Calculating 95% confidence intervals for immediately post-therapy and longer term post-therapy binocularity percentages shows either confidence interval overlaps the other group's mean binocularity percentage, again suggesting that immediate end-of-therapy binocularity percentages and the long-term binocularity percentages are not different (long-term mean 93.43±3.62%; immediate mean 95.73±3.21%).

These two groups - immediately post-therapy and two-years post-therapy - are not significantly different. This supports the conclusions about suppression from the long-term QOL study that improvements in suppression - stated differently, improvements in binocularity - remain two years post-therapy. Improvements from therapy do not deteriorate significantly over time.

In these two groups of ICS patients, previously reported on for improvements with ICS therapy using rapid alternation, calculating pre- and post-therapy percentages of binocularity during waking hours shows indisputable increases in binocularity, as defined by standardized vectographic testing at near. As those ICS sufferers increased in their waking hours binocularity from roughly 50% to roughly 90% of the day, their symptoms, and probably their lives improved.

Case reports

Group data are very important since that drives many of the narratives in modern healthcare. But, in those data groups, sometimes individuals can be lost. Here we present three individual case studies with changes in calculated waking-hours binocularity and improvements in performance.

Case 1 actually comes from the Job Corps study.[5] JR was a 21 year-old Job Corps student who was enrolled in masonry and brick laying as his trade. He had been told he was dyslexic. JR was in therapy for 5 months, using rapid alternation on site at Job Corps, two and a half hours by car (good weather) from our clinic. JR's starting percentage of binocularity during waking hours was 9%. That is, averaged times of bilateral sight versus suppression period on either side were 5-seconds-long suppressions, spaced by 0.5 second periods of bilateral sight. The 0.5 second timing is a rough average of direct alternation (0 seconds bilateral sight) with short periods (about one second) of bilateral sight. On some of the distance vectographic targets, JR literally could not describe the target alternation over time. His full COVD QOL score was 60 and he was reading at the 2.6 grade level on the TABE test.

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Post-therapy, JR was binocular over 95% of his waking hours. That was accompanied by an increase in his reading score to the 9.2 grade level. Although his full QOL score was still high post-therapy at 38, his 16-reading-questions QOL[5] score dropped from 23 to 6, essentially dropping by three-quarters. Reading had become easier. Teachers "are amazed. I'm their miracle kid. I'm not a very fast reader, but things have really improved…oh man!"

Perhaps a little more interesting to some clinicians would be the "real world" changes: Prior to therapy JR had trouble aligning bricks in his chosen trade. Further, JR said his depth perception would "just go out." His masonry instructor commented on improvement post-therapy, praising JR's newly found ability to align bricks properly. In JR's words, it had made a "huge difference in trade [bricklaying]. Awesome." The "going out" of depth perception was eliminated post-therapy.

Case 2 is the story of the Division 1 scholarship basketball player. KK was referred to our clinic as a redshirt senior out of frustration by family and doctors in 2016 because someone had seen "something wrong with what her eyes were doing" when she played. She had been through some form of therapy for visual skills, and as a Division 1 athlete, was not convinced she had any problems, but was being pushed to get further evaluation by family.

My initial evaluation of 21 year-old KK showed a two-second cycle of suppression and bilateral sight, so a waking hour percentage of binocularity of about 50%. After explaining the effects of ICS on fixation, KK agreed she wanted to work to eliminate her suppression.

In watching KK's basketball games on television, it was painfully obvious that free throws were not her strong suit. She played one of the forward positions, so got fouled often, with the result all too often only being the sound from the metal rim as the ball bounced off to the side. Adding insult to injury, another of our patients, 10 years younger and also a female basketball player, quite by accident, happened once to be in the clinic at the same time as KK. SM had just won a city free throw shooting award. We had changed her percentage of waking hours binocularity from 50% to 89%. KK was quite gracious as SM told us of her award, telling the younger player "I wish I could shoot like that." SM had difficulty speaking with the 6 foot 2 inch college player in the same room, although her eyes spoke loudly and eloquently as they were the size of platters.

We were able to get SM's percentage of waking hours binocularity to 100%, with her mother telling us she would now read on her own. Post-therapy KK's binocularity during waking hours was at 98+%. She would suppress one side's image for a "flash," maybe 1/4 second, every six to twenty (average 13) seconds. KK graduated college, went to a tournament in China and hit 90% of her free throws. Her last question before leaving to play professionally in Europe was, "what do we do if this comes back?" I assured her that we would find a way to treat it long distance.

Case 3 is another sports story. DW is a 16 year-old high school baseball player. DW's problem was his batting average. Although he "lives for baseball" and is primarily a pitcher, he has to also bat at his level of serious high school tournament play. His batting average was the issue. At the start of therapy, sixty percent of his waking hours were spent in binocularity, or at least bilateral sight. As we came to 94% waking hours binocularity, that is, periods of loss of the image for maybe 1/4 second spaced by an average 4 seconds of binocular vision, his batting average went past 400. This was accomplished with no extra batting instruction or practice as DW had just refused to bat for over a month while on the road in tournaments. During that traveling tournament time he was concurrently treating his ICS across the country from our clinic with rapid alternation. As competition improves, a 400 batting average may not survive forever, but DW changed a poor batting average to an enviable one with six weeks of rapid alternation and the resultant increase in binocularity. DW discontinued therapy a month later with just over 99% binocularity during waking hours. That is, very brief suppressions spaced by 13 seconds, and sometimes over 20 seconds of bilateral sight, i.e., binocularity.

Figure 1 summarizes the changes in waking hour binocularity and concurrent changes in what might be called real-world abilities and symptoms.

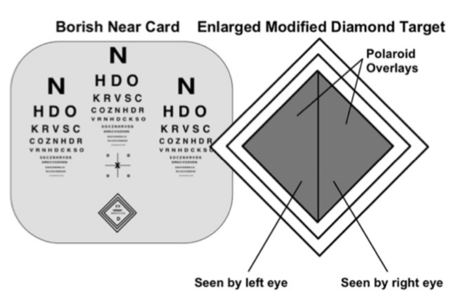
Conclusion

We live in a four-dimensional world; not a two-dimensional world nor even a three-dimensional world, but a four-dimensional world. When we fail to increase the amount of time a student is binocular, we may be limiting the life-options of that student. Said positively, as we change someone from seeing with both eyes simultaneously from 40 or 50 percent to 90 or even 100 percent of waking hours, the amount of information their cortex has for decision making increases, their vision of the world increases, maybe “opens up,” and quite probably their options for the future in life also open up.

In the two study groups, although this is a slightly different treatment of the data, the endpoints are the same. That endpoint is improved binocularity accompanied by improved performance and improved symptoms. The change in data treatment did not lead to new conclusions. Reading improved and symptoms of reading problems decreased as percentage of binocularity during waking hours increased. The three case studies presented show that not only does reading improve, but the kinds of real-world skills that can either give someone skills for employment, or skills for enjoyment of sports, improve.

As the only profession positioned to evaluate binocularity over time, optometry needs to measure and improve percentage of binocularity during waking hours.

a. Available, Bernell, Inc. Mishawauka, IN

The Timing Target, 40 cm,	Group/Patient	Pre- %	Post- %	Real World Results
	Job Corps	53 ✳	92 ✳	RS✳QOL✳RQOL✳
	Long-Term Results Group	43 ✳	96 ✳	QOLRet ✳
	JR	9	97	RS, QOL, RQOL, R, B
	KK (& SM)	50	98 (100)	SP (SP @ 89%, R)
	DW	60	99	SP @ 94%, R

binocularity. RS = Reading scores improved. QOL = Quality of life scores improved. RQOL = Reading quality of life scores improved. QOLRet = Quality of life scores retained over time. R = Reading reported as easier. B = Bricklaying improved. SP = Sports performance improved. ✳ = p<0.0001

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Correspondence regarding this article should be emailed to Eric S. Hussey, OD, FCOVD at spacegoggle@icloud.com or mailed to Eric S. Hussey, OD, FCOVD at 1116 E. Westview Ct. Spokane, WA 99218. All statements are the author's personal opinion and may not reflect the opinions of the representative organizations, Optometry and Visual Performance, the Optometric Extension Program Foundation, or any institution or organization to which the author may be affiliated.