Relationship between convergence insufficiency and Stroop test

Marian Ahmed Sheikh Nur

SAERA. School of Advanced Education Research and Accreditation

ABSTRACT

Convergence insufficiency (CI) is a common dysfunction of binocular vision characterized by exophoria more prominent at near than at distance. It also has a receded near point of convergence and reduced positive fusional vergence at near and low accommodative convergence ratios. The Stroop color and word test assesses cognitive processing and provides valuable diagnostic information on brain dysfunction and cognition. These five-minute tests in which the individual reads aloud a succession of words designated by color (red, green, orange, yellow) written in the same way (for example, red printed in red) or in a different way (red printed in blue). This mismatch leads to the Stroop effect. This focuses on the concept of the interference effect when the brain is given a task involving conflicting signals. This study sought to determine the relationship between CI and ST. A total of fifty subjects with aided visual acuity better than 6/12 (20/40) in Al-Ihsan Specialist Hospital, Mogadishu, Somalia were recruited for this experimental study, of which 26 of them were diagnosed with convergence insufficiency while the remaining 24 had no vergence dysfunction, with a mean age of 25.62(+4.19) and 23.17(+3.96) years respectively. Their visual acuity, near point of convergence, accommodation amplitude, and color vision were assessed, and a Stroop card was given to all. The interference effect of those with CI and those without CI was determined with an unpaired T-test. The mean difference between the two groups i.e. 7.6 secs was significant (p=0.00) at a 95% confidence level and even at 99% confidence. There was a very strong correlation between the near point of convergence and IE in the group with CI (r = 0.92, p = 0.00). In conclusion, CI affected the individuals' performance on the ST as those with CI had a significantly higher interference effect than the normal subjects.

Keywords: *Convergence insufficiency; Near point of convergence; Amplitude of accommodation; Interference effect; Stroop test.*

INTRODUCTION

The term convergence insufficiency (CI) is a type of vergence dysfunction and is clinically characterized by higher near exophoria than at distance that is corroborated by a high near point of convergence finding, low positive fusional vergence (PFV) at near and a low accommodative convergence accommodation (AC/A) ratio (Scheiman et al., 2005). Many researchers estimated that CI prevalence is 4.2–6% in schools and clinical settings (Scheiman et al., 2005).

When a binocular or accommodative disorder occurs, specific symptoms such as double vision, blurred vision, headache, asthenopia, or loss of concentration are reported. Ocular symptoms such as double vision, blurred vision, headache, asthenopia, or loss of concentration are associated with CI. They can affect close work tasks such as reading or academic achievement and usually lead to frustration. Borsting et al., (2005) showed that school children diagnosed with CI or accommodative dysfunctions sometimes have attention deficit issues and attention deficit hyperactivity disorder (ADHD) symptoms. Focusing attention is imperative to performing specific cognitive executive functions. These cognitive processes are called high-level cognitive skills, including reasoning, working memory, and task flexibility.

The Stroop test (ST), named after John Ridley Stroop, demonstrates reaction time. It often illustrates the nature of automatic processing versus conscious visual control. It was first published in 1935; these tests showed that most people tend to say the word color for each word test before they say the color of each word test. This difficulty occurs due to semantic interference. When individuals look at the words in the test, we process the color of each word as well as the meaning of each word. If both stimuli i.e. color and word are congruent or compatible, we respond with the correct answer very quickly, which accounts for most individuals having the fastest reaction time to a word. If there is a direct conflict between word and color meanings, the stimuli are incongruent or incompatible. In such cases, we will have to pay more attention to one stimulus than to the other. The capacity to focus attention is imperative to performing specific cognitive executive functions. Recent studies have linked reading comprehension with cognitive executive functions like inhibition. Protopapas et al. (2007) used the ST (whereby the subject must inhibit a reading response in favor of a less obvious response [color denomination]) on poor readers without dyslexia and showed that they took longer to perform this task than normal readers. Cain (2006) also finds difficulty inhibiting a task in favor of another in children with problems with memory and reading comprehension. In fact, reading and Stroop interference tests share common processes relative to executive functions, such as inhibition and attention.

These experiments emphasized the importance of words' meaning rather than their written color. Reading is automatic for most people. Therefore, interference occurs when a person is instructed to do the opposite by paying more attention to the word's color.

This study attempted to measure the cognitive ability of patients with CI using the ST.

1.1.1 Background information

CI or convergence disorder is a sensory and neuromuscular anomaly of the binocular vision system. It is characterized by the reduced ability of the eyes to turn towards each other or sustain convergence.

CI disorder affects a person's ability to see, read, learn, and do other near work. In the past, CI disorder was undetected because vergence dysfunction testing is not routine during eye exams. A person can have a 20/20 vision and still have CI (Cooper and Cooper, 2001-2005).

CI is also characterized by the inability to converge the eyes smoothly as the object of observation moves from distance to near Scheiman et al., (2005). This causes loss of proper binocular alignment and results in either exophoria or intermittent exophoria at near Laurich et al., (2010). Some cases of CI also appear to have an etiological connection to accommodative dysfunction (Harrison et al., 1987). It is also associated with an exophoric binocular posture at near. However, patients with this disorder may demonstrate orthophoric or even mild esophoria on examination.

1.1.2 Signs of CI

People with CI will have a receded near point of convergence. (Wright et al., 2003)

1.1.3 Symptoms of convergence insufficiency

Asthenopia (eye strain) and headache

Von Graefe described these symptoms in 1855. Classically, such symptoms occur after short periods of near work, especially reading. This frequently happens due to the constant effort needed to enhance fusional convergence. Accommodative insufficiency is often correlated with CI as well as symptoms of asthenopia and headache (Micheal, 2015). This occurs as the patient tries to eliminate near vision diplopia by increasing accommodative effort. The increased accommodative effort results in greater convergence, which may be more than required for the near vision task. This may result in esophoria. This also explains the frequent occurrence of blurry vision.

Diplopia

The diplopia that manifests in some patients with convergence insufficiency may subjectively present as two images. This distinction may be difficult for the patient to explain. Many patients describe their symptoms as blurry vision rather than double vision. A proper monocular visual acuity test will be required.

Patients with +5.00D uncorrected hyperopia may exact little or no accommodative effort during near tasks (Micheal, 2015). Patients with early-treated presbyopia often demonstrate CI. Some patients with CI do not have diplopia symptoms despite a manifest exodeviation at near (Micheal, 2015). This probably occurs because of suppression of the non-fixating eye.

Blurred vision

The lack of accommodation results in blurry near images. Efforts to increase convergence by stimulating accommodative convergence to eliminate diplopia can result in blurry vision i.e. simultaneously produced blurred near vision due to over-accommodation.

Moving of print

This occurs because of unstable binocular alignment as to near-vision convergence demand. This often happens when a person tries to engage and sustain adequate fusional convergence to activate and sustain binocular vision.

1.1.4. Causes of convergence insufficiency

Exophoria at near coupled with inadequate fusional convergence appears to be the primary cause. Closed head trauma and lesions in the pretectal area of the brain have been associated with acquired convergence insufficiency. Lesions in the midbrain dorsal to the third cranial nerve nuclei may also cause convergence insufficiency with normal third nerve function (Von Graefe, 1855).

1.1.5. Effects of convergence insufficiency

Loss of concentration when reading

Difficulty remembering what has been read

Loss of line during reading.

Mistakenly re-reading the same line of text

1.1.6. Diagnosis of convergence insufficiency

Near point of convergence (N.P.C)

The near point of convergence (NPC) is measured in free space with a fixation stick and a millimeter ruler. The distance is measured from the outer canthus and the results are in centimeters. The NPC is tested by having the patient focus on a near target while slowly moving it toward their nose. Exotropia occurs when the patient cannot maintain a fusion. This is called the breakpoint i.e. as soon as they report double vision, and moving the target away from the patient's "recovery" as soon as they report single vision again. Scheiman et al., (2003) suggested that a clinical cutoff for adults should be 5 cm for the NPC break and 7 cm for recovery.

Cover test

The cover test is an objective evaluation of ocular misalignment. There are two types: single cover test (Unilateral cover test) and Alternating cover test.

Single cover test (Unilateral cover test)

The single cover test is usually performed first. This can be done with an occluder which is used cover one eye. The occluder is simply held in front of the eye for a few seconds and then removed. If a tropia is present in the non-occluded eye, the examiner will observe the contralateral eye move to pick up fixation when the fixating eye is occluded. Otherwise, the eye remains stationary. The presence of any movement on a single cover test indicates a tropia. In the case of phoria, or latent deviation, the examiner observes the eye underneath the occluder. In phoria the uncovered eye does not move; however, the eye under the cover will deviate when occluded and return to a straight position when the occluder is removed. The unilateral cover test can differentiate whether the misalignment is a phoria or tropia.

Alternate cover test

The alternate cover test is done after the single cover test. The examiner occludes one eye and then the other. He switches the occluder back and forth to occlude the eyes without allowing the patient to fuse in between occlusions. The alternate cover test is a kind of cover test done to break fusion and it measures a total deviation, including the tropic plus phoric/latent component. When performing the alternate cover test it is imperative to hold the occluder over each eye to allow the non-occluded eye enough time to pick up fixation. In general, the faster the eyes recover when the occluder is switched, the better the control of deviation.

Amplitude of accommodation

The amplitude of accommodation is the maximum potential increase in optical power that an eye can achieve in adjusting its focus. It refers to a certain range of object distances at which the retinal image is sharply focused.

Accommodation amplitude is measured during a routine eye examination. The closest a normal eye can focus is typically about 10 cm for a child or young adult. The accommodation decreases gradually with age, resulting in a reduction after age fifty (Anderson et al., 2008).

The average amplitude of accommodation, in diopters, for a patient of a given age was estimated by Hoffstetter in 1950 to be 18.5 – (0.30 × patient age in years) with the minimum amplitude of accommodation as 15 – (0.25 × age in years), and the maximum as 25 – (0.40 × age in years).

1.1.7. Treatment of CI

Active treatment

The National Eye Institute has revealed via a funded multi-center randomized clinical trial that the best treatment for CI is a supervised office-based vision therapy with home augmentation i.e. 15 minutes of prescribed vision exercises done in the home five days per week. It has been validated that children responded quickly to this treatment protocol. In seventy-five percent of the cases, full vision correction or saw marked improvements within 8-12 weeks is achieved (Archives of Ophthalmology, 2008)

Passive treatment

Prescribing eyeglasses with prisms can relieve some symptoms but not a “cure” and the patient typically remains dependent on prism lenses (Cooper and Cooper, 2001-2005). More so, adaptation issues can result in higher prescriptions in the future.

Pencil Push-ups

The 2002 survey of ophthalmologists and optometrists showed that home-based pencil-pushup therapy is the most common treatment, but scientific research does not support this method. According to their studies, pencil pushup therapy is ineffective in eradicating symptoms. (Scheiman et al., 2005; Gallaway et al., 2002; Archives of Ophthalmology, 2008).

Surgical Care

The decision to do eye muscle surgery should only be considered when other options have been exhausted. Bilateral medial rectus resection is the preferred surgery invention (Cooper and Cooper, 2001-2005). However, the patient should be counseled and educated about the possibility of uncrossed diplopia after surgery with distance fixation which typically resolves within 1-3 months postoperatively.

1.1.8. Stroop Test

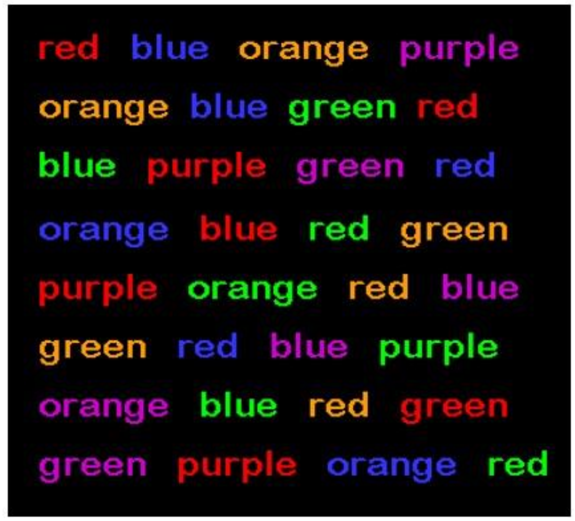
The Stroop color-word test differentiates between non-brain-damaged and brain-damaged individuals. This five-minute test is applicable to those between the ages of 18 and 90. It remains a standard measure in evaluating cognitive processing (Golden and

Shawana, 2004). The version used is made up of two different tasks: reading and naming (denomination) tasks. In the “reading” task, the subject has to read aloud a succession of words designating colors (red, green, blue, or yellow) written in the same color i.e. red printed in red; in the “denomination” phase, which is also the “interference” phase, the subject has to name the color of the print of the word, printed in an incongruent color (red, green, blue, or yellow), for example, the word “blue” printed in green. Each trial contains 35 randomly selected items, and subjects are instructed to finish as quickly as possible without mistakes or omissions. For this analysis, similar methods to those used by Kapoula et al. (2016) were used. Time-corrected errors (when the subject made a mistake but corrected it immediately after), and uncorrected errors are measured for each task and subject. The speed of reading or coloring was calculated by dividing the number of words/items by the time spent (words or items per minute).

1.1.9. Stroop effect

The Stroop effect is one of the best-known phenomena in cognitive psychology (Stroop, 1935). The Stroop effect occurs when people do the Stroop task, which is explained and demonstrated in detail above. The Stroop effect is related to selective attention which is the ability to respond to certain environmental stimuli while ignoring others. Stimuli in the Stroop paradigm can be divided into 3 groups: neutral, congruent, and incongruent. Neutral stimuli are those stimuli where only text (similarly to stimuli 1 of Stroop’s experiment), or color (similarly to stimuli 3 of Stroop’s experiment) are displayed. Congruent stimuli are those in which the ink color and the word refer to the same color (for example the word “pink” is written in pink). Incongruent stimuli are those where ink color and word differ.

Figure 1. Stroop Effect Chart (Thompson-Schill et al., 2009)



Findings regarding Stroop experiments were recurrently obtained in three experiments. The first finding is a semantic interference, which emphasized that ink color naming for neutral stimuli (e.g. when the ink color and word do not interfere with each other) is swifter than in incongruent conditions (Van Maanen et al., 2009). This is referred to as semantic interference because it is often accepted that the association regarding the concept between ink color and word is at the base of the interference. The second finding is called semantic facilitation which explains that naming the ink of congruent stimuli is quicker (e.g. when the ink color and the word match) than when neutral stimuli are available (e.g. stimulus 3; when only a colored square is shown). The third finding is that both semantic interference and facilitation disappear when the task consists of reading the word instead of naming the ink (Van Maanen et al., 2009). It is seldom called Stroop asynchrony and has been explained by a reduced automatization when naming colors compared to reading words (Van Maanen et al., 2009).

In interference theory, the most commonly used procedure is similar to Stroop's second experiment, in which subjects were tested on naming colors of incompatible words and control patches (MacLeod 1991).

1.1.10. Theories employed to articulate the Stroop effect (Johnson, 2004)

Processing speed

This theory established that there is a lag in the brain's prowess to identity the color of the word because the brain reads words quicker than it perceive colors (McMahon, 2013). This is based on the concept that word processing is significantly faster than color processing. In a condition where there is a discrepancy regarding words and colors (e.g. Stroop test), if color is to be reported, the word detail gets to the decision-making stage prior to details about the color information which presents processing confusion. On the contrary, a decision can be made ahead of the conflicting information if the word is to be reported, because color details lags after word information (Lamers et al., 2010).

Selective attention

Selective Attention Theory states that more attention is needed during color identification i.e. the brain requires more concentration to identify a color than a word encoding, so it takes more time (McMahon, 2013). The responses are as a result of the interference observed in the Stroop task. This may be partly due to the allocated attention to responses or an enhanced inhibition of distractors that are not expected responses.

Automaticity

This theory referred to as the most common explanation for the Stroop effect (McMahon, 2013). It suggests that since identifying colors is not an "automatic process", there is hesitancy to respond; whereas the brain automatically understands words through habitual reading. This concept is based on the premise that automatic reading does not require controlled attention but still utilizes adequate attentional resources to reduce the amount of attention accessible for color information processing (Monahan, 2001). Stirling (1979) came up with the concept of response automaticity. He demonstrated that altering the responses from colored words to letters except that no part of the colored words increased reaction time while reducing Stroop interference.

Parallel distributed processing

This theory suggests that when information is processed by the brain, multiple but specific pathways are developed for variety of tasks (Cohen1990). Some pathways, such as reading, are more potent than others; hence, it is the prowess of the pathway and not the speed of the pathway that is important (McMahon, 2013). More so, automaticity is a function of the prowess of each pathway. Hence, when dual pathways are activated at the same time in the Stroop effect, interference occurs between the stronger (word reading) path and the weaker (color naming) path, more specifically when the pathway that leads to the response is the weaker pathway (Cohen etal., 1990).

1.1.11 Uses of the Stroop Test

The Stroop effect has been broadly utilized in psychology. Among the most important uses is the creation of validated psychological tests based on the Stroop effect that can measure a person's selective attention capacity and skills, as well as their processing speed ability (Lamers, 2010). It is also used with other neuropsychological assessments to examine executive processing abilities. It can help with the diagnosis and characterization of different psychiatric and neurological disorders (McMahon, 2013).

Researchers also use the Stroop effect during brain imaging studies to investigate regions of the brain involved in planning, decision-making, and managing real-world interference (e.g., texting and driving) (Root-Bernstein, 2007).

There are different test variants commonly used in clinical settings. These variants differ in the number of subtasks, type, and number of stimuli, times for the task, or scoring procedures. All versions have at least two sub tasks. In the first trial, the written color name differs from the color ink it is printed in, and the participant must say the written word. In the second trial, the participant must name the ink color instead. However, there can be up to four different subtasks, including in some cases stimuli consisting of groups of letters “X” or dots printed in a given color with the participant having to say the color of the ink; or names of colors printed in black ink that have to be read.

The number of stimuli varies from fewer than twenty items to more than 150, closely related to the scoring system used. While in some test variants, the score is the number of items from a subtask read in a given time, in others it is the time it takes to complete each trial. The number of errors and different derived marks are also considered in some versions.

This test measures selective attention, cognitive flexibility, and processing speed and is used to evaluate executive functions (Howieson et al., 2004). An increased interference effect is found in disorders such as brain damage, dementia, and other neurodegenerative diseases, attention-deficit hyperactivity disorder, or a variety of mental disorders such as schizophrenia, addictions, and depression (Lansbergen et al., 2007).

1.2 Statement of the problem

CI has often been undiagnosed; therefore, it has been undetected in our practice today. Patients with this dysfunction, in which their ability to maintain optimal cognitive function is compromised, have been disadvantaged. As a matter of fact, vergence and accommodation are very critical functions for near work. This study measures the cognitive ability of subjects with CI using the ST.

1.3 Aim of the study

This study measures the cognitive ability of a patient with CI using the ST.

1.3.1. Objectives

- To find out the effect of the ST on subjects with CI.
- To find out the effect of the ST on subjects without CI.
- To compare the effect of the ST on subjects with and without CI.

1.4 Hypothesis (Ho):

Null Hypothesis Ho1: There is no relationship between CI and ST.

The alternate hypothesis (HA):

HA1: There is a relationship between CI and ST.

1.5 Significance of the study

This study will help optometrists understand the correlation between CI and the Stroop interference effect. It suggests that the CI score could be a reliable indicator of cognitive executive function since symptoms are negatively correlated to Stroop interference performance. This has clinical interest especially for young students, revealing that every vision disorder that leads to symptoms in near vision should be managed. Inhibition measured with the ST is linked to attention, memory, and comprehension in reading.

MATERIAS AND METHODS

IEthical approval to undertake this study was obtained from the Ethics Committee of the Al-Ihsan Specialist Hospital, Mogadishu, Somalia. A total of 50 voluntary subjects with aided VA > 6/12 aged between 18 and 35 years were selected for a duration of three months for the experimental study. Measurement of monocular and binocular vision at 6m using the Snellen visual acuity chart. The 6/6 endpoint was used, and N5 for the near-distance chart was standard.

NPC was measured in free space using the tip of a pencil as a target and a meter rule to determine the distance. It was measured from the outer canthus and the results are in centimeters. An endpoint (NPC 7.5 for break and recovery is 10.5 cm by Rouse et al., 1999), which was considered normal, while 7.5/10.5 was considered abnormal by Scheiman et al., (2003).

The cover test is an objective determination of ocular deviation. There are two types: single cover test (Unilateral cover test) and Alternating cover test. The single-cover test is usually performed first. This is done by using an opaque or translucent (fogged) occluder to occlude one eye. The occluder is just held in front of the eye for a few seconds and then removed. If a tropia is present in the non-occluded eye, the examiner will observe the contralateral eye move to pick up fixation when the fixating eye is occluded, otherwise the eye remains stationary. The presence of movement on a single cover test indicates tropia. In the case of phoria, or latent deviation, the examiner observes the eye underneath the occluder. In phoria the uncovered eye does not move; however, the eye under the cover will deviate when occluded and return to a straight position when the occluder is removed. The unilateral cover test can differentiate whether the misalignment is a phoria or tropia. The alternate cover test is performed after the single cover test. For this test, the examiner occludes one eye and then the other. He switches the occluder back and forth to occlude the eyes without allowing the patient to fuse in between occlusions. The alternate cover test is regarded as dissociative cover test and measures a total deviation, including the tropic as well as phoric/latent component. When performing the alternate cover test it is imperative to hold the occluder over each eye to allow the non-occluded eye enough time to pick up fixation. In general, the faster the eyes recover when the occluder is switched, the better the deviation control.

Accommodation amplitude is the maximum potential increase in optical power that an eye can achieve in adjusting its focus. It refers to a certain range of object distances at which the retinal image is sharply focused. The amplitude of accommodation (AOA) is measured during a routine eye examination. The closest a normal eye can focus is typically about 10 cm for a child or young adult. Accommodation decreases gradually with age, effectively reducing just after age fifty (Anderson et al., 2008). The average amplitude of accommodation, in diopters, for a patient of a given age was estimated by Hoffstetter (1950) to be 18.5 – (0.30 × patient age in years) with the minimum amplitude of accommodation as 15 – (0.25 × age in years), and the maximum as 25 – (0.40 × age in years).

2.1. The Stroop Test

The version used was made up of two different tasks: in the 'reading' task, which is congruent, the subject has to read aloud a succession of words designating colors (red, green, blue, or yellow), the subject has to name a succession of names of colors written (red, green, blue, or yellow); in the 'interference' phase (incongruent), the subject has to name the color of the print of the word, printed in an incongruent color (red, green, blue, or yellow). For example, the word 'blue' is printed in green. Randomly placed subjects were instructed to finish as quickly as possible without mistakes or omissions. For this analysis, we used similar methods to Kapoula et al. (2010). The reading speed was calculated by subtracting the time spent on the incongruent from the congruent.

2.2. Procedure

A total of 50 voluntary subjects aged between 18 and 35 were selected. Monocular and binocular visual acuity tests were conducted on each subject to establish how well they can see at a distance and near. Near point of convergence was done on these subjects to determine how well they converge at near. This was done with a range of 5-7 for a break and 7-10 for recovery. The amplitude of accommodation was also calculated using the average ([18.5-(0.3 x age)) (Hoffstetter, 1950) used to calculate these subjects' accommodation status. Ophthalmoscopy was performed to rule out some obvious pathological conditions which might exclude the subject from the study such as Retinitis Pigmentosa.

Based on the results of the tests above, the subjects were grouped into Control and Experimental groups. The Control group comprises subjects who fall within the normal range of the test above AOA greater than 5.00D for primary eye care. The Experimental group is subjects who fall outside the norm for the test above (NPC greater than 7.5 for a break and 10.5 for recovery, while AOA less than 5.00D).

Each of these groups performed the ST. The ST is also divided into two types; congruent, the color reading form, and incongruent, the color naming form. For the congruent, the subjects were asked to read aloud the written color irrespective of the color coated as fast as they could, i.e. RED printed in RED, and the time taken was recorded. For the incongruent, the subjects were also asked to name the colors coated regardless of what name they were given i.e. GREEN printed in BLUE, and the time was recorded. The interference effect (IE) was determined by subtracting the time taken to read the second card from the first. Interference card time and the data collected from each group were compared.

2.3. Research Material

Materials used include a Snellen chart, Near point card, Ophthalmoscope, Meter rule, Stroop card, Recording sheet and Stopwatch.

2.4. Statistical Analysis

Data collected were analyzed using the statistical package of social science version 25.0 (SPSS) software. The analysis results were presented in tables and graphs. The mean was used to describe the measured parameters. An unpaired T-test was conducted to determine the significance difference in the interference effect between the case and control group. A Pearson's R correlation was also conducted to determine the relationship between near of convergence and interference effect in the case group.

2.5. Limitations of the study

Getting subjects with CI within the time frame of this study was difficult.

RESULTS

3.1. Description of the data

This study involved a total of 50 subjects comprising 26 individuals with CI (case group) and 24 individuals with normal convergence (control). The mean age of all subjects was 24.44 ± 4.22 years. The table below shows the mean age of the groups.

Table 1. The demographics of both groups

Group	Case	Control
Age/years, Gender	25.62 ± 4.19	23.17 ± 3.96
Males	12	11
Females	14	13

The mean age of the case group and control was 25.62 ± 4.19 years and 23.17 ± 3.96 years respectively. Also, the distribution of males and females in the case and control is also depicted in the table below. The case group consisted of 12 males and 14 females while the control consisted of 11 males and 13 females. Furthermore, the parameters measured in the groups are summarized in the table below.

The Interference effect measured during the ST for subjects with CI (20.77 ± 7.34sec) was markedly higher than that of subjects without CI (13.17 ± 3.14sec). In the same vein, the Near Point of Convergence (NPC) measured for subjects with CI (11.08 ± 3.10cm) was higher than that of subjects without CI (6.25±1.45cm). On the contrary, the Amplitude of Accommodation (AOA) measured for subjects with CI (7.73 ± 2.06D) was lower than that of subjects without CI (11.76 ± 1.89D). The mean values relative to vergence, accommodative functions, and interference effect in case and control are given in the table below:

Table 2. Accommodative functions and Interference Effect during ST for Case and Control.

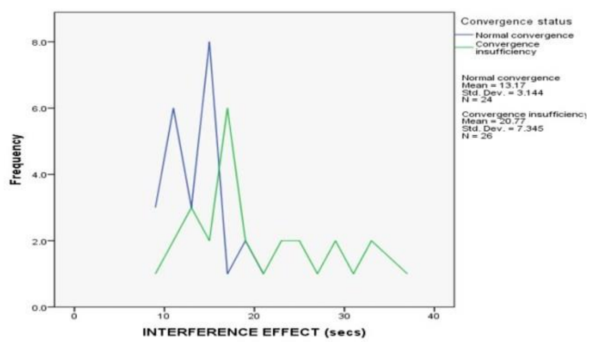
Parameters	Without CI (Mean ± SD)	With CI (Mean ± SD)	P-value
Interference Effect (sec)	13.17 ± 3.14	20.77 ± 7.34	0.00
NPC (cm)	6.25± 1.45	11.08 ± 3.10	0.00
AOA (D)	11.76 ± 1.89	7.73 ± 2.06	0.00

Interference effect = Stroop score time II minus Stroop score time I in seconds.

3.2. Comparing the Interference Effect of Both Groups.

As determined with the unpaired T-test, the mean difference between the two groups i.e. 7.6 secs, was significant (P = 0.000) at the 95% confidence level and even at 99% confidence level. The frequency distribution of the interference effect is shown with the graph below.

Figure 2. Frequency distribution of the interference effect of those with CI (case group) and those with normal convergence (control).

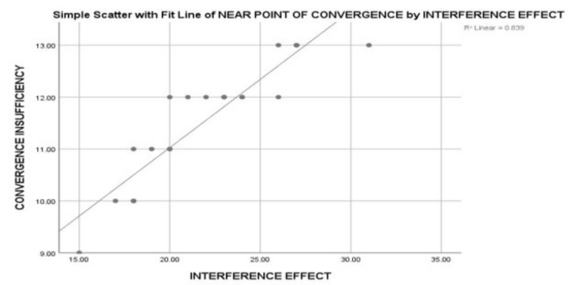


There is a positive correlation between the interference effect and near point of convergence in subjects with CI (r = 0.916, p = 0.00). The higher the near point of convergence, the higher the interference effect. This is seen in the plot below.

3.3. Determining the relationship between Interference Effect and Near Point of Convergence in the case group

There is a positive correlation between the interference effect and near point of convergence in subjects with CI (r = 0.916, p = 0.00). The higher the near point of convergence, the higher the interference effect. This is seen in the plot below.

Figure 3. Graph showing the relationship between interference effect and near point of convergence in the case group.



DISCUSSION

This study sought to determine the measurement of the cognitive ability of subjects with CI using the ST (an indicator of cognitive processing). Its limitation may be the sample size as it affects the generalization of the results of the study while its strength was in the appropriateness of the techniques used which included standard eye examination of each subject. This study involved a total of 50 subjects comprising 26 individuals with CI (case group) and 24 individuals with normal convergence (control). The mean age of all subjects was 24.44 ± 4.22 years. The case group consisted of 12 males and 14 females while the control consisted of 11 males and 13 females.

To determine the effect of CI on cognition as estimated by the ST, the time lag or difference (or interference effect) in seconds between the time taken to respond to the congruent stimuli (the ink color and the word refer to the same color) which we denoted as Stroop score time 1 (secs) and the incongruent stimuli (which ink color and word differ) denoted as Stroop score time 2 was recorded (Table 1) and compared in both the case i.e. the case and control group. The case group had a higher interference effect than the control (20.77 ± 7.35 secs vs. 13.17 ± 3.14 secs), detail is in Table 2.

In the ST, a lower interference effect is the desired outcome. Furthermore, the time difference or mean time difference between the two groups i.e. 7.6 secs, was significant (p = 0.000) at both 95% and 99% confidence levels. This indicated that the subjects with CI in this study had lower cognitive responses to the stimuli or tasks in relation to their normal counterparts. This may result especially from the impedance of concentration fueled by other visual problems (e.g. headache and asthenopia) related to CI (Borsting et al., 2005). Studies linking CI and poor cognitive performance were reviewed. In agreement with our study, Daniel et al. (2016) reported a connection between optometric results, learning disabilities, and reading problems. They examined the associations between optometric tests of binocular vision; vergence and accommodation, reading speed, and cognitive executive functions as estimated by the ST in participants aged 20.43 ± 1.25 years which was close to the mean age of the subjects in this study. An association between positive fusional vergences (PFVs) at near and the interference effect (IE) in the ST was established: the higher the PFV findings were, the less the interference effect. Consequently, in this study, the case group of 26 subjects presenting a higher near point of convergence (low PFV) findings had a significantly strong association with higher IE during the ST with a correlation of 91.6%, p = 0.00. This finding explains the relationship between convergence capacity and the interference score in the ST i.e. increased IE observed may be a result of the fact that vergence control and cognitive functions mobilize the same cortical areas, for example, parietofrontal areas.

More so, saccadic movements or involuntary programming of eye movements by linguistic cues has been shown to occur (Timothy et al., 2009). Deficits in these movements are usually found in those with CI, they investigated the effect of the linguistic cue on eye movement using a modified version of the Stroop task in which a saccade was made to match the location of a peripheral color patch that matched the ink color of centrally presented word cue, their results showed that oculomotor programming was influenced by word identity, even though the written word provided no task-relevant information. They concluded that deficits in these movements are usually found in those with CI, hence the higher interference effect or lower cognitive response found in these individuals. This is buttressed by Alvarez et al. (2013) who did work on the analysis of saccades and peak velocity to symmetrical convergence stimuli while comparing binocularly normal controls with CI patients. They assessed the potential velocity asymmetry between the left–eye and right-eye movement responses stimulated by symmetrical vergence steps in those with normal binocular vision and those with CI before and after vergence training, their study also evaluated whether vergence training influenced convergence peak velocity and the prevalence of saccade within the first second of the response. The normal subjects had saccades significantly more symmetrical (left-eye peak velocity was approximately equal to right-eye peak velocity) compared to CI subjects, p < 0.001.

It is also worthy of note that an improvement in the symmetry of the saccades was observed after vergence training. Leigh and Zee, (2015) in their study Neurology of Eye Movements, reported that the cortical area associated with cognitive control can be presented in two parts, these were further explained by Milham et al., 2003, and Botvinick et al., 2004 in their work on Practice-related effects that demonstrated complementary roles of anterior cingulate and prefrontal cortices in attentional control in which they reported that the first, top-down frontal cortex structures including the dorsolateral prefrontal cortex is responsible for integrating information from other brain regions and initiating top-down response preference based on task demands and the anterior cingulate cortex, which is responsible for conflict and monitoring; secondly, there are also the response organization areas, including the posterior parietal cortex, modulating attentional orientation to task-relevant information and creating the stimulus-response mapping, and the supplementary motor areas and pre-supplementary motor area, both play a role in the selection and executive responses. Nachev et al. (2008) in their work on the Functional role of the supplementary and pre-supplementary motor areas, reported that some of the areas are therefore highly involved in the cognitive task of inhibition as measured by the ST: the dorsolateral prefrontal cortex, the anterior cingulate cortex, especially the dorsal subdivision and the posterior parietal cortex. Mohanty et al. (2007) reported that the correlation between the vergence capacity and the Stroop performance could be attributed to the fact that these areas are highly involved in both tasks-vergence control and inhibition which both require attention deployment.

Finally, neurological conditions e.g. traumatic brain injury may serve as modifiers of cognitive responses hence reading ability or academic achievement as they are known to cause CI and other vergence and accommodative anomalies (Harrison, 1987). Quaid et al. (2013), on the association between reading speed, refractive error under cycloplegia, and oculomotor function in reading-disabled children versus the control, the connection between reading (specifically objectively determined reading speeds and eye movement data) refractive status and binocular vision-related measurement remains elusive, 100 subjects were used for the study of which 50 control and 50 case study age 6-16 years old in which they found significant associations between reading speed, refractive error, and vergence facility. Also, Ben-David et al. (2011) also investigate Stroop effect in persons with traumatic brain injury; selective attention, speed of processing, or color naming? They rather used the Stroop color and word test, which is the most common tool used to assess selective attention in persons with traumatic brain injury. They found a larger Stroop effect for TBI patients, as compared to controls. However, they posited that the differences may be strongly biased by TBI-related slowdown ($r^2 = 0.81$ in a Brinley analysis). Bush et al. (1999), in their work on anterior cingulate cortex dysfunction in attention-deficit/hyperactivity disorder, which was done by firing and counting Stroop, showed that the anterior cingulate cognitive division plays a central role in attentional processing by modulating stimulus selection i.e. focusing attention and mediating response selection, they also hypothesized that anterior cingulate cognitive division dysfunction might therefore contribute to producing hyperactivity disorder, namely in attention and impulsivity, they concluded that subjects with attention deficit disorder (ADD) have performance deficits on the color ST. Protopapas et al. (2007), in their work on reading ability is negatively related to Stroop interference, carried out this study on 7th-grade pupils, in which Stroop interference is often taken as evidence for reading automaticity even though young and poor readers who presumably lack reading automaticity, present larger Stroop interference, they also carried out their work on dyslexia children in which they reported more errors in an interference task and longer reaction times in this children.

In two separate experiments, positron emission tomography was used to measure changes in regional cerebral blow flow, while the normal subjects performed the Stroop color and word interference test (a test of selective attention). In normal subjects, the performance of the Stroop task has been associated with activation of right orbitofrontal and bilateral parietal structures including the focal activation of the right anterior cingulate and right frontal polar cortex, which occurred during the Stroop task (Bench et al., 1992).

Hence, engagement of a widespread network of anterior brain regions and reciprocal inhibition of posterior brain regions during the performance of the task. The results provided evidence for the involvement of the anterior right hemisphere and medial frontal structures in attentional tasks but also indicate that time effects can confound task-specific activations. Higher interference effects in individuals with reading disorders or any neurological condition may be due to the slow activation of these areas.

Conclusion

CI has often been undiagnosed, and undetected in our routine practice today. Patient with this dysfunction which often deplete their ability to maintain optimal cognitive function have been disadvantaged. CI disorder interferes with a person's ability to see clearly, read, learn and work at near. This experimental study measures selective attention, cognitive flexibility and processing speed especially in young students.

CI had an effect on the performance of the individuals on the ST as those with CI had a significantly higher interference effect than the normal subjects. So this study will help enlighten optometrists on the correlation between CI and ST and has suggested that the CI score could be a good indicator of cognitive executive function.

The finding revealed that CI (vergence disorder) leads to symptoms at near and should be manage properly as these can affect the patient comprehension in reading, attention, memory as measured with the ST. The ST may be a tool that can be used in the evaluation of executive function.

Recommendations

The public (especially parents and teachers) through various means e.g. the media should be educated on CI and its effect on reading, selective attention, and consequently the academic or near task performance of children as well as adults. More so, visual screening of children as well as adults should be conducted routinely as early detection of CI may lead to more successful vergence training.

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