THE EFFECT OF TRANSCUTANEOUS AURICULAR VAGUS NERVE STIMULATION

ON READING COMPREHENSION

By

Zoe Ann Richardson

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Project Approved:

Supervising Professor: Tracy Centanni, Ph.D.

Department of Psychology

Uma Tauber, Ph.D.

Department of Psychology

Danielle Brimo, Ph.D.

Davies School of Communication Sciences & Disorders

Abstract

In academic environments, the ability to comprehend written text is critical for successful learning. In spite of the importance of this skill, few programs exist for improving comprehension, especially for typically developing readers. Previous research demonstrated that cervical vagus nerve stimulation (cVNS) is a safe and effective method for driving neural plasticity. However, an invasive and expensive procedure is not practical for a reading intervention. Recent research has demonstrated that the auricular branch of the vagus nerve can be accessed non-invasively through transcutaneous auricular vagus nerve stimulation (taVNS) at the outer ear (Frangos, Ellrich, & Komisaruk, 2015). Recent work in our lab provides evidence that taVNS paired with training can improve novel letter-sound learning (Thakkar et al., under review). Thus, we hypothesized that pairing taVNS with reading would aid reading comprehension in typically developing young adults. We recruited typically developing young adult readers and verified reading ability using standard assessments. Eligible participants were randomly assigned to receive either active or sham stimulation to the posterior tragus of the left ear while reading passages and subsequently answering standard comprehension questions from the GORT-5 (Wiederholt & Bryant, 2012). Participants were scored on time spent reading, errors in reading, and reading comprehension. Data collection suggests a benefit of active stimulation on reading comprehension, as compared to those receiving sham stimulation. Implications of this work may suggest using taVNS as a novel intervention for reading comprehension, but further studies should extend the methods in a sample of struggling readers.

The Effect of Transcutaneous Auricular Vagus Nerve Stimulation on Reading Comprehension

Reading comprehension is an important skill in the modern world. Individuals use this skill every day to respond to emails, read books, navigate roads, and interact with each other. Thus, deficits in this skill negatively impact a person's quality of life, especially in school and work environments (Pedersen, Fusaroli, Lauridsen, & Parrila, 2016). According to Spencer and colleagues (2014) 15% or 285 million children have poor reading comprehension skills and will experience this negative quality of life (Spencer, Quinn, & Wagner, 2014). Due to the prevalence of those who are affected by deficits in reading comprehension, it is imperative that research be conducted on interventions to improve reading comprehension.

Current Interventions

Currently, few interventions to improve reading comprehension exist. Clarke and colleagues (2010) investigated the effectiveness of three different interventions (text-comprehension, oral-language, and the two combined) on improving reading comprehension (Clarke, Snowling, Truelove, & Hulme, 2010). This trial revealed that all three types of interventions could increase reading comprehension in children. Based on these results, Let's Know! was created as a language focused intervention and is specifically geared towards improving reading comprehension in young children (Jiang & Logan, 2019). Jiang and colleagues (2019) investigated the effectiveness of Let's Know! on improving language skills and reading comprehension in first, second, and third grade children (Jiang & Logan, 2019). The researchers reported that when this program was implemented to the whole classroom by a teacher that it resulted in an increase in reading comprehension, but this improvement was not statistically significant. However, the program did significantly impact reading comprehension

indirectly through improving vocabulary. The mixed results from this study show that while it may be a good intervention, it is only indirectly improving reading comprehension. Thus, due to the lack of successful intervention programs and the mixed effectiveness of existing programs, we propose a novel method to improve reading comprehension: vagus nerve stimulation.

Mechanisms of Cervical Vagus Nerve Stimulation (cVNS)

Vagus nerve stimulation is a technique that is effective at enhancing plasticity in the brain. This is accomplished through the release of multiple neurotransmitters, mainly acetylcholine and norepinephrine, that act on the cerebral cortex and other brain regions (Engineer et al., 2011). Cervical vagus nerve stimulation (cVNS) involves the implantation of a programmable pulse generator into the midcervical portion of the left vagus nerve (DeGiorgia et al., 2000). This device can then be used to deliver electrical current to an individual. Many studies have looked at the safety and efficacy of using this method.

A study conducted by Engineer and colleagues (2011) investigated the use of pairing tones with cVNS to reverse noise-induced tinnitus in rats (Engineer et al., 2011). The researchers found that cVNS paired with pure tones reversed the physiological and behavioral symptoms of tinnitus and the effects persisted for weeks after the rats underwent therapy. This paper also supported the idea that vagus nerve stimulation influences brain plasticity, an idea that was suggested by previous studies and is the foundation for why research using vagus nerve stimulation is ongoing. Another study conducted by DeGiorgia and colleagues (2000) provided support for the idea that cVNS was a safe and effective treatment for treating those with refractory epilepsy over a long-term period (DeGiorgia et al., 2000). Although cVNS had previously been approved as a treatment for epilepsy in 1997, this study provided support for expanding the use of this treatment into different populations such as children and the elderly

(Johnson & Wilson, 2018). A further study conducted by Sackeim and colleagues (2001) found that cVNS improved neurocognitive performance of those with treatment-resistant depression and that participants did not display any adverse side effects from using cVNS (Sackeim et al., 2001). This study along with many others led to the approval of cVNS as a treatment for depression by the FDA in 2005 (Johnson & Wilson, 2018). An additional study conducted by Sjogrem and colleagues (2001) involved a pilot study that concluded that cVNS increased cognitive function in Alzheimer's patients and resulted in little to no side effects (Sjogrem et al., 2001). Additional studies have been conducted by Merrill and colleagues (2006) that support the work by Sjogrem and colleagues (2001) as well as support long-term use of cVNS for Alzheimer's patients (Merrill et al., 2006), though this indication is not yet approved by the FDA.

In addition to treating diseases, researchers have looked at cVNS as a method for improving cognition. A study conducted by Clark and colleagues (1999) found that cVNS improved retention of specific words (verbal memory) when applied after participants read a passage (Clark, Naritoku, Smith, Browning, & Jensen, 1999). Another study conducted by Sun and colleagues (2017) reported that cVNS was capable of improving working memory in those with epilepsy (Sun et al., 2017). These previous findings collectively suggest that cVNS may be beneficial for other cognitive skills and in multiple populations.

While cVNS is a safe and effective treatment, it is invasive and expensive (Yu, Zhao, Guo, & Rong, 2016). Due to these limitations, cVNS is not practical for a reading intervention. Thus, we propose to utilize a novel non-invasive approach to stimulating the vagus nerve: transcutaneous auricular vagus nerve stimulation (taVNS).

Mechanisms of Transcutaneous Auricular Vagus Nerve Stimulation (taVNS)

Recent research by Frangos and colleagues (2015) and Yakunina and colleagues (2016) using fMRI has demonstrated that the auricular branch of the vagus nerve can be accessed in a non-invasive way through the outer ear (taVNS) and activate similar deep brain structures as cVNS (Frangos, Ellrich, & Komisaruk, 2015; Yakunina, Kim, & Nam, 2016). While a relatively new method, a growing body of evidence suggests comparable efficacy of taVNS.

A study conducted by Rong and colleagues (2016) found that taVNS is effective as a long-term treatment for major depressive disorder (Rong et al., 2016). Another study conducted by Redgrave and colleagues (2018) concluded that taVNS was a safe and feasible method to improve upper arm movement in post-stroke patients when paired with a therapy program (Redgrave et al., 2018). A further study conducted by Liu and colleagues (2020) demonstrated that taVNS inhibits central and peripheral inflammation and indirectly decreases the severity experienced by individuals with depression (Liu et al., 2020).

In addition to treating disorders, some studies have been conducted to investigate taVNS as a method for improving cognition. A study conducted by Jacobs and colleagues (2015) demonstrated that taVNS was effective in improving associative memory in older individuals with few side effects (Jacobs, Riphagen, Razat, Weise, & Sack, 2015). An additional study conducted by Hakon and colleagues (2020) concluded that taVNS was a feasible and safe method for improving cognitive function following traumatic brain injury (Hakon, Moghiseh, Poulsen, Oland, Hansen, & Sabers, 2020). Another recent study conducted by our lab provides evidence that taVNS paired with training can improve novel letter-sound learning (Thakkar et al., under review). This previous research on taVNS aided in the development of the current study.

The Current Study

The aim of the current study was to investigate the effect of taVNS on reading comprehension, time spent reading, and errors in reading. Based on previous research, we hypothesized that there would be a benefit of taVNS on reading comprehension, time spent reading, and errors in reading, as compared to sham stimulation. Specifically, we predicted that taVNS would increase comprehension scores, decrease total time spent reading, and decrease total errors in reading.

Method

Participants

Participants were recruited through an online participant pool. To be eligible, participants had to achieve a standard score of 85 or above on the Matrices subtest of the Kaufman Brief Intelligence Test II (KBIT-2) as well as a standard score of 90 or above on the Sight Word Efficiency (SDE), Phonemic Word Efficiency (PDE), Word Identification, and Word Attack subtests. Additionally, participants were native English speakers that did not have any history of diagnoses, medications, disorders, or medical implants such as pacemakers. A total of 53 participants were screened for eligibility. Of these, 31 participants were ineligible and were eliminated from the study (Figure 1). These individuals were ineligible due to safety issues, medications or diagnoses, age, low IQ score, low reading score, or voluntary withdrawal from the study. Thus, a total of 22 participants were eligible (19.85 ± 2.03, 16) and completed the remaining sections, described in a subsequent section. All individuals regardless of eligibility received class credit as compensation for their time spent participating in the study. The study was approved by Texas Christian University's Institutionalized Review Board.

Measures

Participants completed a series of measures during the first session of the study that assessed IQ, reading, memory, and attention. These measures are described below.

KBIT-2. The Kaufman Brief Intelligence Test II (KBIT-2; Kaufman & Kaufman, 2004) was administered to individuals during the first session of the study. Nonverbal IQ was assessed using the Matrices subtest and assessed an individual's ability to solve new problems and complete visual analogies. Participants viewed incomplete pictures or patterns and chose the item that best completes the picture from five possible choices. Raw score was calculated using the scoring guidelines provided by the measure and converted to standard score based on age. Eligible participants had to achieve a standard score of 85 or above.

TOWRE-2. The Test of Word Reading Efficiency, Second Edition (TOWRE-2; Torgersen, Wagner, & Rashotte, 2012) was administered to individuals during the first session of the study. Individuals completed both the Sight Word Efficiency (SWE) and Phonemic Decoding Efficiency (PDE) subtests. The SWE subtest assesses an individual's ability to pronounce printed words accurately and fluently within 45 seconds. The PDE subtest assesses an individual's ability to pronounce phonemically regular nonwords accurately and fluently within 45 seconds. Raw scores were calculated using the scoring guidelines provided by the measure and converted to standard scores based on age. Eligible participants had to achieve a standard score of 90 or above on each subtest.

WRMT-3 (Word Identification Subtest & Word Attack Subtest). The Woodcock Reading Mastery Tests, Third Edition (WRMT-3; Woodcock, 2011) was administered to individuals during the first session of the study. Individuals completed the word identification subtest and the word attack subtest. The word identification subtest requires the participant to read a series of real words with no time pressure. This subtest evaluates an individual's ability to

pronounce printed words accurately. The word attack subtest requires the individual to accurately read nonsense words of increasing difficulty, using the alphabetic and syllabication rules of the English language. This subtest evaluates an individual's ability to pronounce nonwords accurately. Raw scores were calculated using the scoring guidelines provided by the measure and converted to standard scores based on age. Eligible participants had to achieve a standard score of 90 or above on each subtest.

   WRMT-3 (Passage Comprehension Subtest & Oral Reading Fluency Subtest). The Woodcock Reading Mastery Tests, Third Edition (WRMT-3; Woodcock, 2011) was administered to individuals during the first session of the study. Individuals completed the passage comprehension subtest and the oral reading fluency subtest. The passage comprehension subtest requires the participant to read a passage and provide the missing word. This subtest evaluates an individual's comprehension and vocabulary skills. The oral reading fluency subtest requires individuals to read two passages out loud. Participants are scored on accuracy and speed. This subtest evaluates an individual's ability to fluently integrate learned reading abilities such as decoding, expression, and phrasing. Raw scores were calculated using the scoring guidelines provided by the measure and converted to standard scores based on age.

   WRAML-2. The Wide Range Assessment of Memory and Learning, Second Edition (WRAML-2; Sheslow & Adams, 2009) was administered to individuals during the first session of the study. Individuals completed the verbal learning core subtest, the number letter subtest, and verbal learning recall subtest. The verbal learning core subtest requires the participant to repeat a dictated list of single words across four trials. This subtest evaluates verbal working memory skills. The number letter subtest requires the individual to repeat dictated sequences of numbers and letters. This subtest evaluates verbal working memory skills. The verbal learning

recall subtest requires the participant to remember the list of dictated words used in the verbal learning core after a period of no exposure and distraction. This subtest evaluates longer term verbal memory skills. We administered this subtest after the individual had completed the WRMT-3 measure to allow for an adequate time gap from the verbal learning core subtest. Raw scores were calculated using the scoring guidelines provided by the measure and converted to standard scores based on age.

CTOPP-2. The Comprehensive Test of Phonological Processing, Second Edition (CTOPP-2; Wagner, Torgesen, & Rashotte, 2013) was administered to individuals during the first session of the study. Individuals completed the rapid digit naming subtest and the rapid letter naming subtest. The rapid digit naming subtest requires the participant to read a list of digits as quickly and accurately as they can. The rapid letter naming subtest requires the individual to read a list of letters as quickly and accurately as they can. These subtests measure how well an individual's brain can integrate visual and verbal processes. They also help approximate naming speed and fluency. Raw scores were calculated using the scoring guidelines provided by the measure and converted to standard scores based on age.

For each measure, two researchers scored the assessment through standardized practice and reached a consensus to settle discrepancies.

taVNS Device and Thresholding Procedure

If eligible, participants returned to the lab for a second session in which they were fitted with the taVNS earpiece, which was placed on the posterior tragus of the left ear. Participants then underwent thresholding in which four measurements were recorded. The device was turned on and intensity was increased until the participant reported a sensation in their left ear. After this number was recorded, intensity was slowly increased until the sensation began to feel

uncomfortable, but not painful for the participant. This number was recorded as the second measurement. Intensity was then decreased until the participant could no longer feel a sensation and this number was recorded. For the final measurement, intensity was again increased until the sensation began to feel uncomfortable, but not painful for the participant. These four measurements were then averaged together and rounded down to the nearest whole number to determine a safe stimulation intensity for the individual.

Testing Procedure

After thresholding, all individuals completed a subset of passages from the Gray Oral Reading Test, Fifth Edition (GORT-5; Wiederholt & Bryant, 2012). The GORT-5 is a standardized measure used to measure oral reading fluency and reading comprehension. The measure consists of two equivalent forms, Form A and Form B. Each form consists of 16 passages with five comprehension questions each (Figure 2). For the purposes of the current study, individuals completed 7 passages from Form A and 7 passages from Form B for a total of 14 passages (2 practice and 12 real). The order in which the forms were administered counterbalanced across participants. From each form, passage 6 was used as a practice passage and passages 11-16 were used as test passages. For each passage, individuals were asked to read the passage out loud while the research assistant timed how long it took to complete the passage. Participants in the taVNS group received stimulation while reading each passage. Individuals in the sham group received mock stimulation, in which the researcher ramped up current on a channel that was not connected to the taVNS earpiece. After the participant finished reading the passage, stimulation current was turned off and participants were asked to answer comprehension questions regarding the passage. Participants were scored on time spent reading, errors in reading, and comprehension.

For each form, total time spent reading was determined by adding the time spent reading (in seconds) for passages 11-16 together. Similarly, for each form, total errors in reading was determined by adding the errors in reading for passages 11-16 together. Comprehension scores for each form were calculated by adding the comprehension scores for passages 11-16 together. Two researchers scored the assessment using this method and reached a consensus to settle discrepancies.

Data Analysis Plan

Data were imported and analyzed through SPSS. Participant assessment scores were analyzed using two-tailed independent-samples t-tests of stimulation group on each measure.

A two-way mixed-design analysis of variance (ANOVA) was used to investigate the effect of stimulation group (sham vs. active, between-groups) and reading assessment (GORT Form A and GORT Form B, within-participants) on reading comprehension scores. Post-hoc t-tests were used to further understand main effects and interactions. Other dependent variables of interest included time spent reading and errors in reading, which were analyzed in a similar manner.

Results

SPSS was used to import and analyze data. Two-tailed independent-samples t-tests of stimulation group on each English assessment were used to analyze participant assessment scores. There were no significant differences in assessment scores between sham and active stimulation groups with the exception of the number letter subtest $(t(20) = 3.40, p \leq 0.001$; Table 1).

A two-way mixed-design analysis of variance (ANOVA) was used to investigate the effect of stimulation group (between-groups: sham vs. active) and reading assessment (within-

participants: GORT Form A and GORT Form B) on reading comprehension scores. The results revealed a trend in the main effect of stimulation ($F(1,17) = 3.44$, $p = 0.08$; Table 2 & Figure 3). There was no main effect of form ($F(1,17) = 0.31$, $p = 0.58$).

A two-way mixed-design analysis of variance (ANOVA) was used to investigate the effect of stimulation group (between-groups: sham vs. active) and reading assessment (within-participants: GORT Form A and GORT Form B) on time spent reading. The results show a significant main effect of form ($F(1,17) = 70.64$, $p \leq 0.001$), but there was no main effect of stimulation ($F(1,17) = 0.31$, $p = 0.59$; Table 3 & Figure 4). The interaction between stimulation group and form was nonsignificant ($F(1,17) = 1.26$, $p = 0.28$).

A two-way mixed-design analysis of variance (ANOVA) was used to investigate the effect of stimulation group (between-groups: sham vs. active) and reading assessment (within-participants: GORT Form A and GORT Form B) on errors in reading. The results show no main effect of form ($F(1,17) = 0.09$, $p = 0.77$; Figure 5). There was also no main effect of stimulation ($F(1,17) = 1.02$, $p = 0.33$; Table 4 & Figure 5).

Discussion

The goal of the present study was to investigate the effect of taVNS on reading comprehension, time spent reading, and reading errors in young adult typical readers (or individuals without dyslexia). Based on previous research, we hypothesized that there would be a benefit of taVNS on reading comprehension, time spent reading, and errors in reading, as compared to sham stimulation. Specifically, we predicted that taVNS would increase comprehension scores, decrease total time spent reading, and decrease total errors in reading.

With regards to reading comprehension, there was a trend in the main effect of stimulation. While this effect was nonsignificant, it suggests that taVNS could have a benefit on

reading comprehension. This finding might become significant if the study is replicated with a larger sample size. These results are consistent with literature that has shown cVNS and taVNS have a benefit on cognitive tasks. One study by Clark and colleagues (1999) found that cVNS improved recognition and verbal memory (Clark, Naritoku, Smith, Browning, & Jensen, 1999). Another study conducted by Sun and colleagues (2017) concluded that cVNS improved working memory in patients with epilepsy (Sun et al., 2017). A recent study with taVNS by our lab provided evidence that taVNS paired with training can improve novel letter-sound learning (Thakkar et al., under review). Our finding of a trend in the benefit of taVNS for reading comprehension supports prior studies suggesting a use for taVNS in improving cognitive skills. Further, the current study is the first to our knowledge to investigate any form of vagus nerve stimulation for improvement of reading comprehension.

While we observed a trend in the effect of stimulation on reading comprehension, there was no effect of taVNS on total time spent reading or total errors in reading. Form type had no effect on increasing comprehension scores or decreasing total errors in reading. These results suggest that both forms contain passages and comprehension questions that are the same level of difficulty. This is important because it indicates that the trend in the main effect of stimulation is not attributed to differences in form type or the order that the participants completed the forms in. Surprisingly, there was a significant effect of form type on total time spent reading. Participants took more time to read form A than form B regardless of whether they received taVNS or sham stimulation. While there are no differences in length between the two forms, the difference in time spent reading may be due to form A containing more difficult words than form B. It is unlikely that the difference in time spent reading is due to the order the forms were completed in. The results seen cannot be attributed to differences in age, IQ, or reading as there

were no significant differences between active and sham stimulation groups with the exception of the number letter subtest.

While the results do not support our hypotheses regarding the effect of taVNS on total time spent reading and total errors in reading, there is moderate support for our hypothesis about the effect of taVNS on reading comprehension. As mentioned, more data need to be collected to confirm a significant effect. Our lab is currently in the process of continuing this study and collecting more data. With more participants, we expect to see this trend become a significant effect.

One limitation of the current study is the small sample size. Due to time constraints and eligibility criteria, we were only able to recruit 22 participants with 11 participants in each stimulation group. Future studies should include a larger sample size. We expect that with a larger sample size, stimulation will have a significant effect on reading comprehension. Another limitation is that we did not include additional control groups. A previous study conducted in our lab included two control groups that were not included in the present study: an earlobe stimulation group and a computer group (Thakkar et al., under review). The earlobe control group received stimulation to a different region of the ear, the earlobe, instead of the posterior tragus of the left ear. The earlobe, unlike the posterior tragus, is not innervated by the vagus nerve. The inclusion of this control group establishes that the location where stimulation is applied matters. To be effective, stimulation must be applied to a region of the ear that is innervated by the vagus nerve. The computer control group underwent the training program for this other study, learning Hebrew, but was not connected to the stimulation device. This control group was included because current programs to help with learning language, such as Rosetta

Stone, are computer based. The inclusion of both of these groups in future extensions of this study would help strengthen the results by acting as additional control groups.

Another limitation is that the comprehension questions in the GORT-5 are targeting different skills. While there are no differences in difficulty of questions, there are more memory style questions than inferential style questions. The difference in the type of comprehension questions asked may be having an effect on the results seen in the data. In the future, an in-house measure based off of the GORT-5 should be created that includes an equal number of memory and inferential style comprehension questions. A final limitation of the current study is that we were not able to include a dyslexia subgroup due to time constraints. We had initially intended to include this subgroup in order to compare the effects of stimulation on typically developing readers to those with dyslexia. Research has shown that individuals with dyslexia tend to display worse reading comprehension skills than typically developing readers due to difficulties with decoding written languages. These deficits in decoding can impair more complex cognitive problems such as inferencing (Wong et al., 2017). Based on this research, we hypothesized that taVNS would increase reading comprehension in these individuals and remove the existing deficit between readers with dyslexia and typically developing individuals. If taVNS does increase reading comprehension in those with dyslexia, this could have a profound impact on improving quality of life for these individuals. Future studies should be conducted with dyslexia and typically developing subgroups for both adults and children.

Our study contributes to the literature in that it examined another potential application of taVNS in relation to cognitive tasks, specifically reading. Data about the effect of taVNS on reading comprehension will be relevant for ongoing research regarding the use of taVNS as a safe, effective, and practical method for reading intervention in typical and struggling readers.

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Appendix

Table 1

Mean and standard deviation of standard scores for English assessments

Assessment	Sham	Active	T-Statistic
Sample (# Females)	11 (8)	11 (8)	
Age	20.59 ± 2.58	19.11 ± 0.90	1.80
Kaufman Brief Intelligence Test II: Matrices	99.82 ± 9.46	102.91 ± 10.30	0.73
Sight Word Efficiency	106.55 ± 12.72	104.64 ± 13.50	0.34
Phonemic Word Efficiency	108.55 ± 7.06	112.27 ± 7.23	1.22
Word Identification	104.27 ± 6.51	109.27 ± 9.84	1.41
Word Attack	96.55 ± 29.48	102.55 ± 6.76	0.66
Verbal Learning Core	9.91 ± 2.34	11.00 ± 2.19	1.13
Number Letter	9.73 ± 2.20	13.00 ± 2.32	3.40*
Passage Comprehension	99.55 ± 9.73	103.18 ± 11.94	0.78
Oral Reading Fluency	109.64 ± 9.04	111.45 ± 8.45	0.49
Verbal Learning Recall	9.10 ± 3.38	10.27 ± 2.24	0.95
Rapid Digit Naming	11.18 ± 1.47	11.00 ± 1.10	0.33
Rapid Letter Naming	10.64 ± 1.03	10.55 ± 1.21	0.19

* = $p < 0.05$

Table 2

Mean and standard error of reading comprehension scores by stimulation group and form of assessment for which a higher score represents more correct answers

	Sham	Active	
Form A	11.25 ± 1.22	14.18 ± 1.04	12.72 ± 0.80
Form B	11.25 ± 1.13	13.36 ± 1.00	12.31 ± 0.74
	11.25 ± 1.04	13.77 ± 0.88	

Table 3

Mean and standard error of time spent reading by stimulation group and form of assessment for which a lower score represents less time spent reading
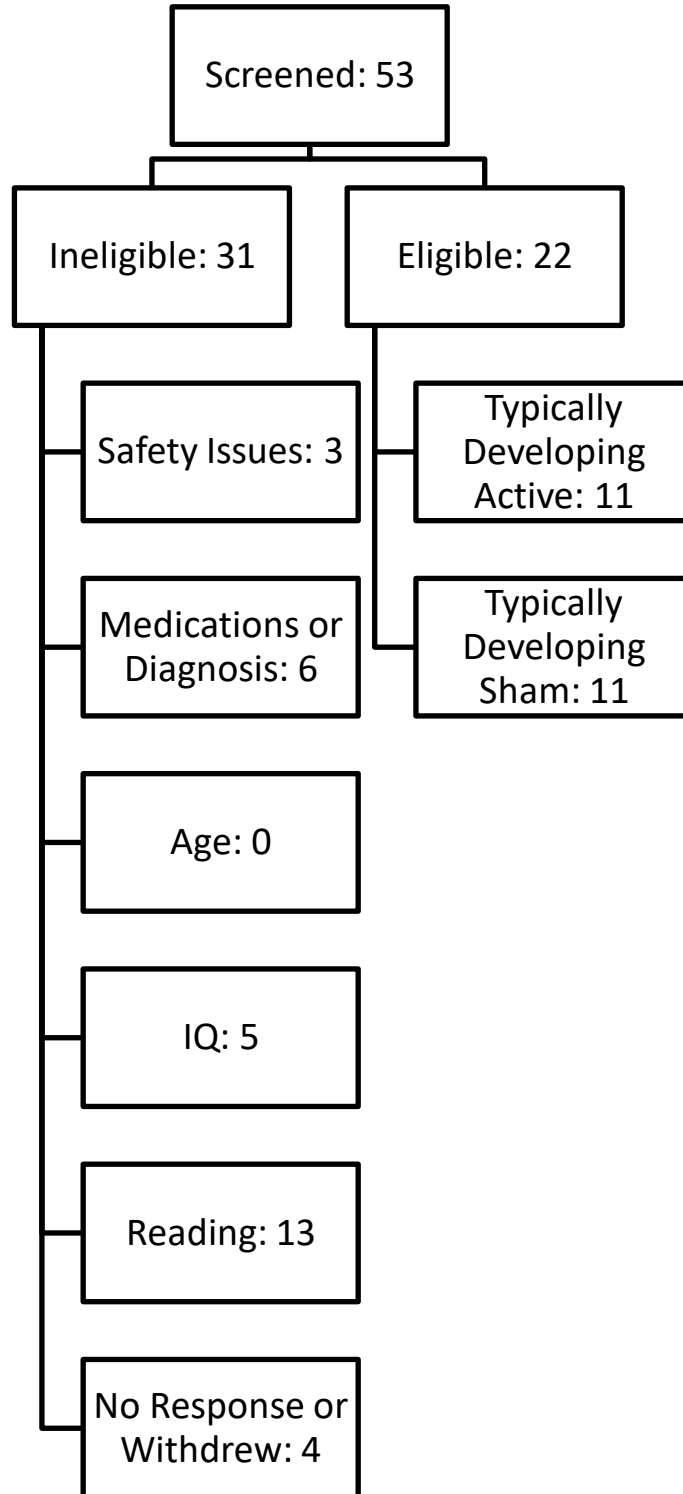
	Sham	Active	
Form A	480.50 ± 26.20	458.00 ± 22.35	469.25 ± 17.22
Form B	441.13 ± 23.16	427.91 ± 19.75	434.52 ± 15.22
	460.81 ± 24.53	442.96 ± 20.92	

Table 4

Mean and standard error of errors in reading by stimulation group and form of assessment for which a lower score represents less errors in reading

	Sham	Active	
Form A	20.75 ± 3.82	14.18 ± 3.26	17.47 ± 2.51
Form B	18.88 ± 4.35	15.09 ± 3.71	16.98 ± 2.86
	19.81 ± 3.91	14.64 ± 3.33	

Figure 1. Participant tracking. Flow chart displays number of participants eligible with randomization and number of participants excluded due to various reasons

A

There are sundry definitions of jazz, all of them vague. Their vagueness seems imperative, however, if they are to accommodate the custom of jazz to appropriate everything in sight. This receptivity to sources derives from a dominant feature of jazz: improvisation. The emphasis on improvising entails an openness to the entire legacy of diverse musical elements. Although formulating the content of jazz is not feasible, there is little difficulty in pinpointing the group that spawns the music. Jazz musicians have always constituted a subculture of music, a cultish but scarcely organized body of instrumentalists who rarely manage to eke out a livelihood from their music. Until recently they have been unschooled in their chosen music, except as they have imitated recordings of other musicians. Never accepted by academics, only partially accepted by the public, jazz musicians comprise a closed community in which innovation and experimentation are more valued than tradition.

B

| #	Score	Question	Correct Response
1		What does the story state as to why jazz is difficult to define?	Tends to absorb other types of music; composed of different elements; jazz appropriates everything in sight
2		Why are jazz musicians probably less organized than other musicians?	Jazz is individualistic; no set rules; music is improvised
3		According to the last sentence of this story, what two elements do jazz musicians value more than tradition?	Innovation and experimentation
4		In the story, what one word described a dominant feature of jazz?	Improvisation
5		According to this story, what group has never accepted jazz?	Academics

Figure 2a-b. Sample passage and comprehension questions. 2a. A sample passage (Form A passage 11). 2b. Sample associated comprehension questions asked after reading for the passage shown in 2a.
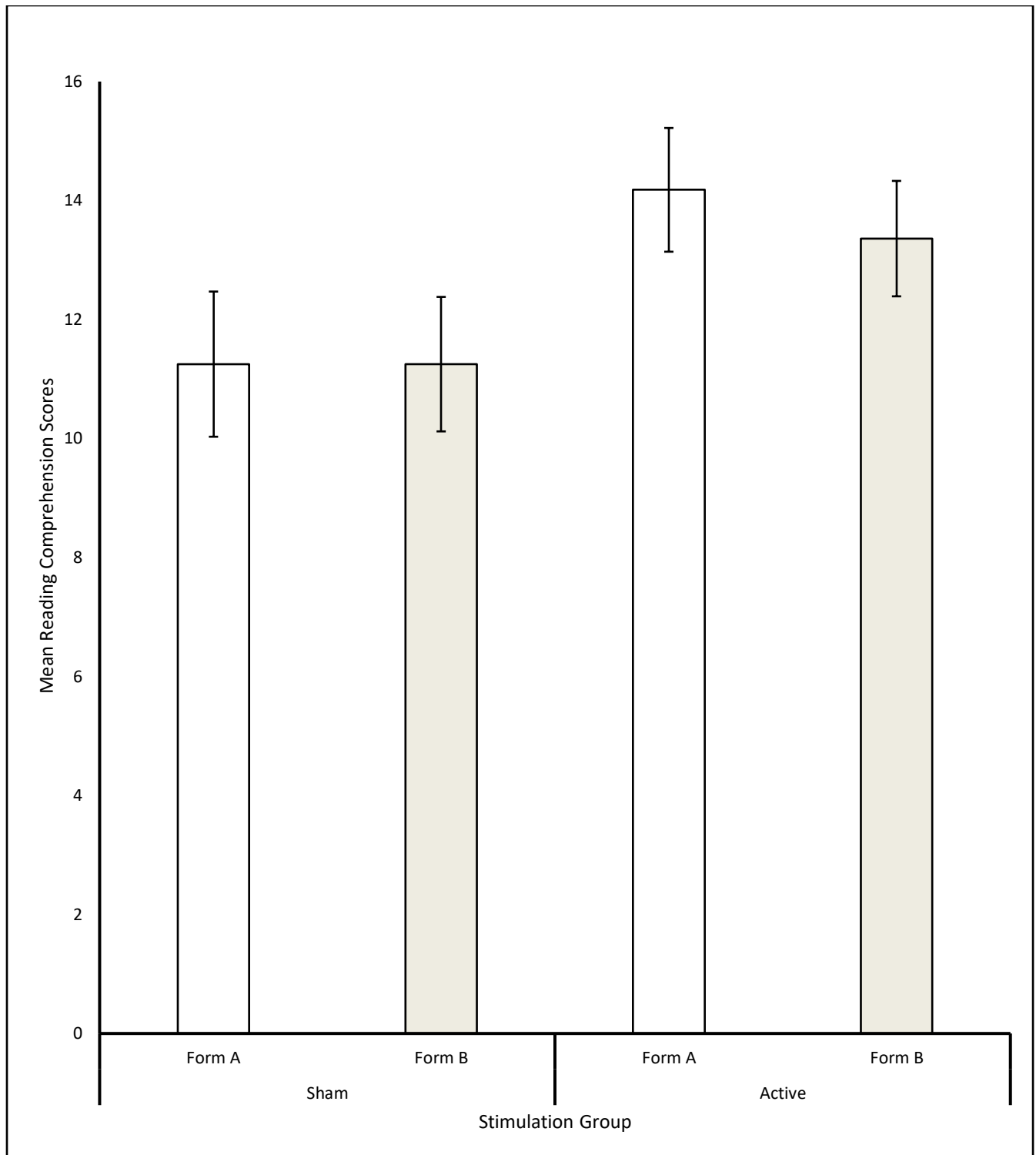
Figure 3. Effect of taVNS on reading comprehension. Results show a trend towards significance such that active stimulation increases scores, compared to sham stimulation. Error bars represent standard error of the mean.
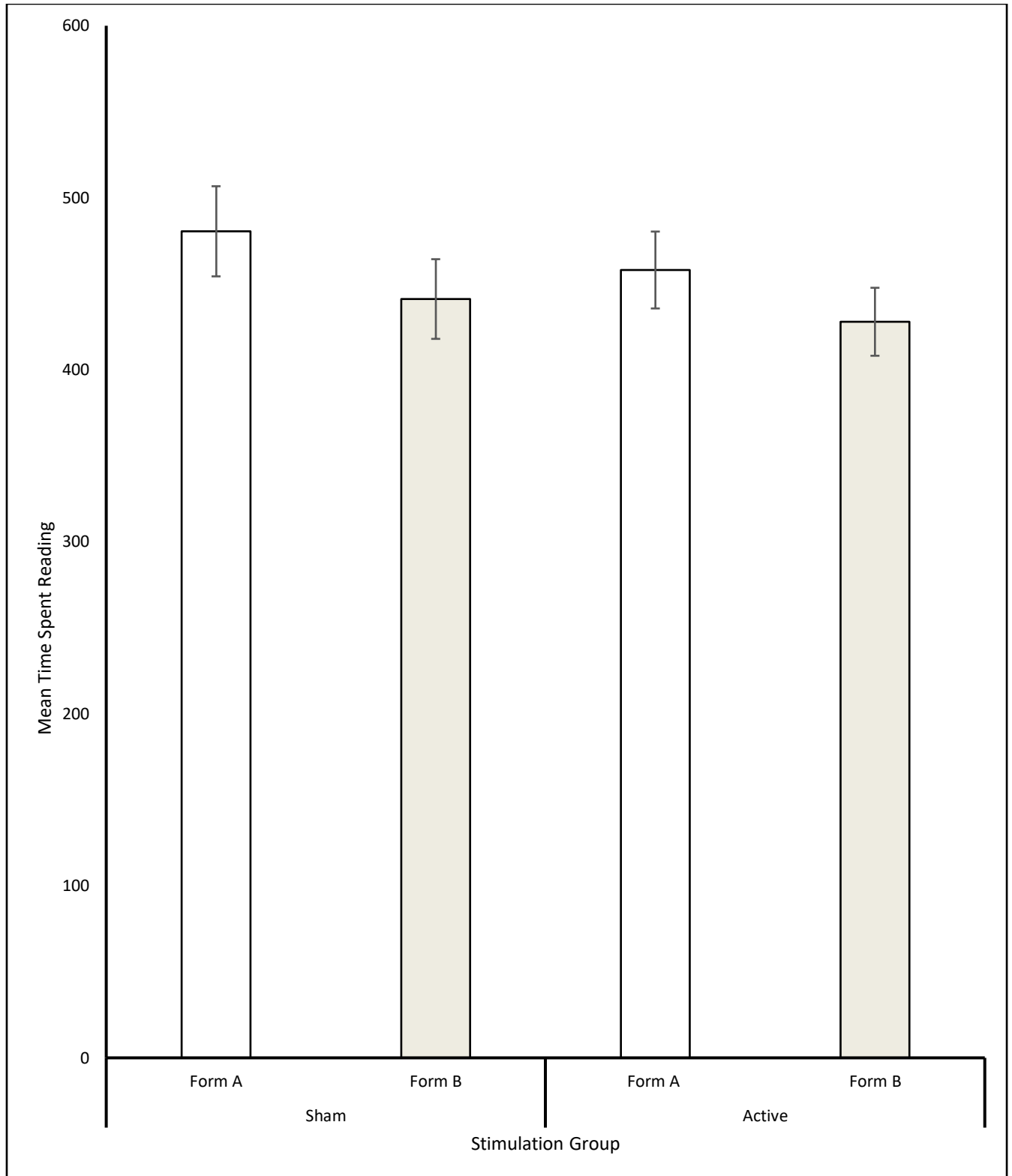
Figure 4. Effect of taVNS on time spent reading. Results show no significant difference between active stimulation and sham stimulation. Error bars represent standard error of the mean.
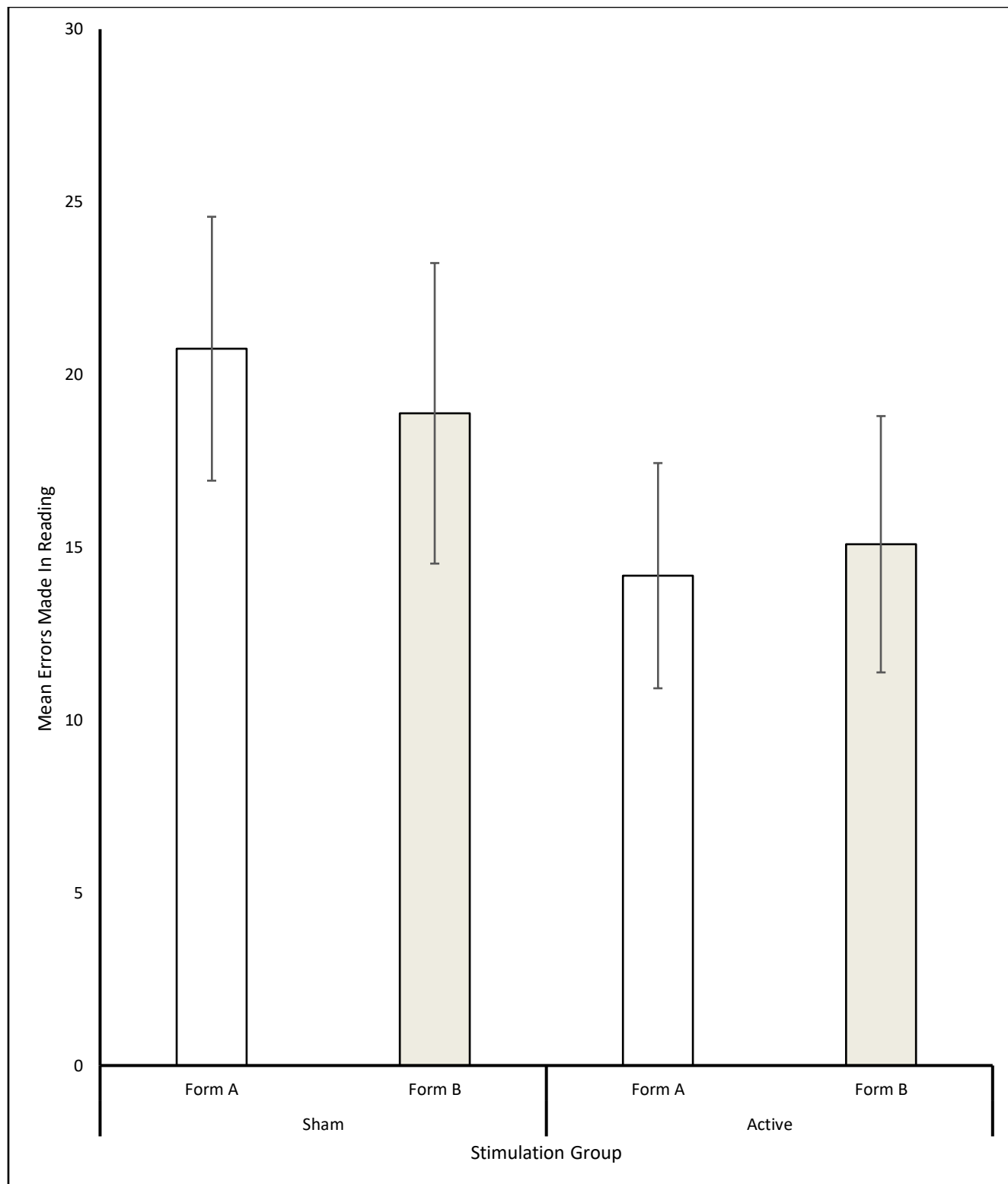
Figure 5. Effect of taVNS on errors in reading. Results show no significant difference between active stimulation and sham stimulation. Error bars represent standard error of the mean.