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The Relationship Between Attention, Dyslexia, and Convergence Insufficiency

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Peer Review
This work has undergone a double-blind review by a minimum of two faculty members from institutions of higher learning from around the world. The faculty reviewers have expertise in disciplines closely related to those represented by this work. If possible, the work was also reviewed by undergraduates in collaboration with the faculty reviewers.

Abstract
Dyslexia and attention deficit hyperactivity disorder are two distinct conditions belonging to the same class of frequently and comorbidly diagnosed childhood and adolescent developmental disorders. Further complicating treatment and diagnoses is convergence insufficiency, a visual disorder, with symptoms that can appear similar to dyslexia's diagnostic criteria. ADHD and dyslexia have a worldwide prevalence of 5-12% each among the school-age population and 4-10% of young adults. As many as 1 million U.S. ADHD diagnoses are situational with undocumented, pre-existing conditions (e.g., convergence insufficiency, dyslexia). Convergence insufficiency, characterized by an inability to converge the eyes smoothly as a focal object moves from distance to near, affects 2-8% of the worldwide population. Given the number of people worldwide who may be diagnosed, misdiagnosed, or undiagnosed by these three disorders, it is of value to explore the intersectionality of these conditions among college-aged students. This project investigated the relationship between self-reported scores on a standard ADHD measure, as well as ADHD diagnoses, dyslexia, and convergence insufficiency using optometric and neuropsychological assessments. We found ADHD diagnosis and its self-reported symptoms were significantly correlated with total scores on the Adult Reading History Questionnaire, dyslexia diagnoses, and the Convergence Insufficiency Symptom Survey. All three self-report assessments and near visual acuity significantly correlated; indicating that as visual acuity improves, total assessment scores decrease. These combined results highlight a distinct and important relationship between vision, attention, and reading and support a more holistic assessment in the identification, diagnosis, intervention, and treatment of cognitive problems pertaining to reading and learning.

Keywords
attention-deficit hyperactivity disorder, dyslexia, convergence insufficiency, attention, vision, reading

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Attention, the cognitive and affective encoding of new information into consolidated memory (Posner & Peterson, 1990) is the first step in learning new information. Therefore inattention, inhibits learning and consequently, memory. Attentional problems occur along a continuum, from situational (e.g., fleeting inattention) to persistent and problematic inattentiveness that affects quality of life. In the most extreme cases, persistent inattention may require intervention or treatment. Treatment for problematic attention may require a diagnosis of attention deficit hyperactivity disorder (ADHD) based on specific criteria outlined in the Diagnostic and Statistical Manual of Mental Illness (DSM-V; American Psychiatric Association, 2013).

ADHD, a neurodevelopmental disorder affects roughly 4–12% of the worldwide, school-age population (Schelke, Shapiro, Hackett, Chen, Simchon-Steinhof, Ganzer, Isaacson, Tamboer, Van Vliet, Assuras, Chang, & Seifan, 2017) and among four to eight percent of young adults (Barbaresi, Katusic, Colligan, Weaver, Pankratz, Mrazek, & Jacobsen, 2004; Faigel, 1995). According to The ADHD Molecular Genetics Network (2002), ADHD is the most common childhood neurodevelopmental disorder, with medication prescribed to 80% of the ADHD diagnosed population (NIMH 2016; 2017). According to some experts (e.g., Elder, 2010; Evans, Morrill, & Parente, 2010), as many as one million U.S. ADHD diagnoses are developmental or situational, the result of inherent childhood brain changes and/or environmental disruption. Some undocumented, pre-existing conditions (e.g., convergence insufficiency, dyslexia, absence seizures) have symptoms in common with ADHD and therefore may be misdiagnosed.

Dyslexia, the developmental language-based disorder, is associated with the mismatching of words or specific letters in reading materials (International Dyslexia Association, 2017). Reading, writing, and language difficulties despite academic intelligence and learning motivation characterize the disorder (Bjornsdottir, Halldorsson, Steinberg, Hansdottir, Kristjansson, Stefansson, & Stefansson, 2014). Dyslexia has a frequency of 5–10% and is primarily found in school-aged children in first-world cultures (Bjornsdottir et al., 2014). Problems with phonological awareness, processing speed, and slowed reading and writing enduring into adulthood define this disorder (Fink, 1998). According to Sartorius (1999), dyslexia is heritable; people with diagnosed dyslexia may evidence concurrent language, visual, and auditory processing problems as well as inattention (specifically the impulsive and hyperactive type). In fact, in a neurological study using magnetoencephalography and psychoacoustics, Serrallach et al. (2016) found that, among their school-aged sample diagnosed with dyslexia or attention deficit hyperactivity disorder, relative to their controls, both groups evidenced more volume in an area of the auditory cortex called the planum temporal.

Further complicating the issue, dyslexia and attentional problems may comorbidly occur with a common ocular disorder called convergence insufficiency (CI). CI refers to the inability or difficulty with pointing eyes together at the correct area in space in order to form normal and adequate binocular vision, especially for near-centered tasks. Borsting, Mitchell, Arnold, Scheiman, Chase, Kulp, and Cotter (2016) found that 5% of school-aged children have CI. Those with CI experience headaches, blurring of words, loss of concentration, double vision, eye pain, and reading recall difficulties (Porcar and Martinez-Palomera, 1997; Borsting, Rouse, Deland, Hovett, Kimura, Park, and Stephens, 2003; Borsting et al., 2003). For a diagnosis of CI, a person must

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exhibit exophoria at near-point of four prism diopters or greater than at distance, an inability to satisfy Sheard's vergence benchmarks, and a reduced near point of convergence (NPC) measure (Borsting, Rouse, and Chu, 2005; Lee, Moon, and Cho, 2014). In a study of CI among college-aged students, Porcar and Martinez-Palomera (1997) reported that 4% of their university participants had diagnoses of CI. CI manifestation often results in ADHD-like behaviors with some symptoms identical to the inattentive presentation (DSM-5, 2013). This is consistent with a review by Pauc (2008), who found children diagnosed with ADHD also exhibit ocular problems consistent with a CI diagnosis.

Finally, according to Granet, Gomi, Ventura, and Miller-Scholte (2005), as many as 10% of ADHD patients exhibit symptoms more consistent with CI than ADHD. CI frequently emerges later, as reading demands increase in conjunction with more advanced schooling. These latent symptoms may therefore appear consistent with ADHD, but are more typical of the ocular condition. Only vision specialists can diagnose this disorder, however, and are rarely consulted prior to making an ADHD diagnosis (Lee, Moon, & Cho, 2014). Given the potential of misdiagnosing and thereby prescribing unnecessary ADHD stimulant drugs, a number of professions advocate for visual exams prior to an ADHD diagnosis (Borsting, Rouse, and Chu, 2005; Lee, Moon, and Cho, 2014; Rouse et al., 2009). In a study of convergence failure among a psychiatric population with diagnosed ADHD, Tourette's, and obsessive-compulsive disorder (OCD), all conditions associated with basal-ganglia thalamocortical pathways (Shepphard, Bradshaw, Purcell, & Pantelis, 1999), 57% demonstrated convergence failure. Finally, among those with an ADHD diagnosis, comorbidity with dyslexia existed, while 60.87% of the dyslexia diagnoses were comorbid with CI (Pauc, 2008).

Based on the existing literature about attentional problems associated with processing (e.g., dyslexia) and ocular convergence failure, we believed it was worth exploring the intersectionality of these factors among college-aged students. Thus, this project investigated the relationship between self-reported scores on a standard ADHD measure, as well as ADHD diagnoses, dyslexia, and CI using optometric and neuropsychological assessments. We predicted that as reported and tested visual symptoms and problems increased, attentional and dyslexia-related symptoms would also increase. The specific empirical questions of this research included:

1. What is the relationship between attention and convergence insufficiency?
2. How do characteristics of dyslexia relate to attentional symptoms?
3. Are visual problems associated with scores on the dyslexia measure and/or diagnoses?
4. Is there an intersection of symptoms between ADHD, dyslexia, and convergence insufficiency?
5. How does convergence failure and scores on the dyslexia and attentional measures vary across the demographic variables (e.g., gender, age, etc.)?

MATERIALS AND METHODS

Participants. Convenience sampling occurred on the Pacific University (Oregon) campus among both undergraduate and graduate populations, using email solicitation, list-serves, and word-of-mouth. The average age of the sample was 23 years (M_{total} = *23.10*; SD_{total} = *6.40*). The

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exclusionary criteria were limited only to those under 18 years of age. IRB approval was obtained prior to testing. A one-tailed correlation power analysis using G*Power® software for a sample size of 118 participants (92 females, 26 males), yielded a power coefficient of 0.85, a low probability of making a type I error.

Materials. This study included seven measures including a demographics questionnaire. The following were used in the course of this research.

The Adult ADHD Self-Report Scale (ASRS-v1.1, Adler et al., 2012) is an eighteen-item survey using a five-item, Likert-like frequency scale to assess self-reported experience with attention and hyperactivity. Each listed ADHD experience is weighted from zero to four, with zero reported as "never" and four reported as "very often." Four or more selections (totaling > 9) on the first six questions indicate consistency with ADHD. The sample's Cronbach alpha score for reliability for the ASRS-v1.1 was α = .90.

The Adult Reading History Questionnaire (ARHQ, Lefly and Pennington, 2000) was used to assess dyslexia symptoms. Specifically, it assesses levels of difficulty in certain areas of reading, using a twenty-three-item questionnaire on a five-item, Likert-like quality scale. Each listed dyslexia symptom was weighted from zero to four, with zero reported as "below average" and four reported as "above average." Scores of 36 or more are consistent with dyslexia. The ARHQ Cronbach alpha for the sample was α = .84.

CI was assessed using the Convergence Insufficiency Symptom Survey (CISS, Scheiman et al., 2005), a fifteen-item self-report measure using a five-item, Likert-like frequency scale targeting presence and frequency of CI symptoms. Each listed CI symptom was weighted from zero to four, with zero reported as "never" and four reported as "always." The sample's Cronbach alpha score for the CISS was α = .87. Scores of 16 or more are consistent with CI. A twenty-one-item demographic questionnaire was used to assess multiple variables relative to participant sex, diagnoses of ocular disorders, ocular prescriptions, medication history, prescription or recreational drug use, history of traumatic or acquired brain injury, and technology use.

Ocular assessment was conducted with three tests. For the Near Point Convergence measurement, we used a standard Brock String (Scheiman and Wick, 2014) to determine the participant's convergence amplitude. The bead was placed 40 centimeters from the face and slowly moved in toward the participant's nose as the person was asked to report when the bead became, or broke into, two or doubled. The breakpoint, when the bead appears to break into two, indicates the limits of the two eyes to converge together at varied near distances (Lee et al., 2014).

Cortical suppression was controlled for by asking the participant to report if they were able to recognize physiological diplopia (the image of two strings in front of or behind the bead). If the participant was completely unable to recognize the physiological diplopia, their results for NPC were considered unreliable and not used in analysis. This test uses the standard normative results for NPC testing.

Near Visual Acuity (NVA) was assessed using a standard Sloan letter near vision card (Sloan & Brown, 1963). The Sloan card consists of descending rows of letters in diminishing sizes (the smaller the row, the greater the acuity demand). Testing occurred under both monocular and binocular conditions with the card held slightly below eye level at a distance of 40 centimeters. The participant read the line of letters closest to

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the bottom that was clear and continued on until no less than three letters could be read. The threshold of NVA was recorded according to the normative values on the card.

The Alpha Omega Pupillary Response Test (Pulaski, 2016), theoretically measures autonomic nervous system stress. Test performance includes a bright light source aimed at and maintained on the pupil of the eye. In a neurologically stressed individual exhibiting the AO reaction, the pupil will constrict but then assume a dilated state again within seven seconds. The amount of dilation to constriction is in proportion to the individual degree of ANS fatigue. (For normative scoring, see Pulaski, 2016).

Procedure. In an effort to control for order effects, each participant was randomly assigned a different presentation order for the self-report assessments and the ocular testing. Participants received informed consent protocols prior to all assessment and administration of self-reports. All testing was completed at the behavioral neuroscience laboratory within the Psychology Department at Pacific University. Participants were provided informed consent documentation, and given verbal as well as written instruction for each assessment. They were evaluated individually, and given as much time as they needed to fully complete all assessments. No participant took longer than 45 minutes in the single appointment to complete the assessments.

For those receiving the ocular testing, we first administered, in order, the Sloan near point acuity test, the NPC test with the Brock String, and the Alpha Omega pupillary test under dimly lit conditions. The group assigned to complete the survey first received randomly shuffled self-report assessments and were asked to entirely complete them. When each group finished their assigned task, the participants switched roles and completed the remaining assessments. After completion of the research protocols, participants were provided a verbal and written debriefing of the study.

RESULTS

All analyses were conducted using IBM® SPSS® software. Descriptives, Pearson's product-moment correlations, and tests of between-subjects effects were completed for all analyses (see Table 1). Regarding the relationship between attention and CI, we found a significant and positive correlation between total scores on the ASRS attention measure and total scores on the CISS, $r(113) = 0.53$, $p < .01$. We also found a positive, significant correlation between the two variables of the total scores on the ASRS and the ARHQ dyslexia measure, $r(115) = .94$, $p < .01$ and self-reported ADHD diagnoses and the total scores on the ARHQ, $r(115) =.30$, $p < .01$; $\sum^2 = .05$ (a small to moderate effect).

The question of a relationship between visual problems and scores on the dyslexia measure, yielded a significant and positive correlation between the NPC threshold and self-reported dyslexia diagnosis, $r(110) = .22$, $p = .02$. A negative and significant correlation exists between the ARHQ and NVA for both eyes together, $r(116) = -.20$, $p = .04$. In addition, this study found a significant positive correlation between the total scores on the CISS and self-reported dyslexia diagnosis, $r(115) = .19$, $p = .04$. Similarly, a significant positive correlation existed between CISS total scores and ARHQ scores, $r(114) = .51$, $p \leq 0.001$. Lastly, a negative, significant correlation was found between NVA, the CISS total scores, and the ASRS total, $r(115) = -.21$, $p = .03$.; $r(115) = -.52$, $p<.01$.

Finally, in addressing the intersectionality of attentional problems, dyslexia, and CI, we ran a Pearson's r multiple correlational analysis result for total scores on the ASRS, the CISS, and the

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ARHQ. These multiple correlational analyses reveal significant positive relationships between scores on the ASRS (adult attentional measure) and the ARHQ (dyslexia measure), and the convergence insufficiency measure with the ARHQ and the ASRS at the .01 level (see Table 1).

Additional exploratory analyses were conducted to address the demographic variables reported with convergence failure, attention, and dyslexia. We found a positive, significant correlation between incidence of previously diagnosed traumatic brain injury (TBI) and total NPC threshold values, $r(110) = .33$, $p < .01$, as well as marijuana use frequency and ADHD diagnoses, $r(117) = 0.42$, $p <.01$. Self-reported caffeine usage on testing day yielded positive correlations between caffeine intake and ADHD diagnoses, $r(117) = .21$, $p = .02$. Further, convergence failure symptoms as measured through scores on the CISS compared with the ARHQ were significantly correlated to the number of hours spent using blue light technology (e.g., iPads, iPhones, and laptops), at the exact same associated value of $r(113)=.23$, $p = .01$ respectively.

Assessment	Males (*n*=26)	Females (*n*=92)	Total (*N*=118)
Near Point Convergence	2.04 (5.62)	3.68 (7.23)	3.29 (6.97)
Self-Reported TBI/ABI	.57 (0.85)	0.56 (0.95)	0.56 (0.92)
Variety of Technology Use	4.69 (1.26)	4.02 (0.85)	4.17 (0.99)
ASRS Total Score	26.19 (9.38)	29.58 (11.46)	28.81 (11.08)
ARHQ Total Score	14.92 (4.66)	15.96 (6.05)	15.72 (5.76)
CISS Total Score	17.24 (7.05)	21.17 (10.40)	20.31 (9.88)

Table 1. Descriptives and total scores by gender

DISCUSSION

The purpose of this study was to explore the relationship and intersectionality between attentional problems as measured through self-reported ADHD (ASRS), dyslexia, visual stress, and convergence insufficiency using both optometric and neuropsychological assessments. We found ADHD diagnosis as well as self-reported symptoms for ADHD were, significantly, positively correlated with total scores on the Adult Reading History Questionnaire, dyslexia diagnoses, and the Convergence Insufficiency Symptom Survey.

All three self-report assessments and near visual acuity (with both eyes) significantly, negatively correlated, indicating that as NVA improves, total scores on all three self-report assessments decrease. The significant, positive correlation between near point convergence and diagnosed dyslexia demonstrate the complexity and potential intersectionality of diagnosed visual problems and attention. These combined results highlight, a distinct and important relationship between vision, attention, and reading.

Although we did not attempt to address questions pertaining to LED and blue-light exposure relative to attention, dyslexia, and visual problems; we did ask participants to report the number of hours spent on blue-light technology devices as well as the variety of blue-light technology sources they use every day. According to Bansal, Prakash, Randhawa, and Kalra (2017), continuous exposure to LED screens results in reduced cortical activity and increased alertness and exposure to blue light screens was correlated with dizziness and decreased memory performance and mood. Our results revealed a significant positive correlation between dyslexia symptoms and hours spent on blue-light technology, but not between attention and convergence insufficiency.

Neuroimaging studies (e.g., Gabrieli, 2009) suggest dyslexia occurs in part, as the result of neurological differences in processing language and writing, relative to those without a diagnosis. Though visual problems almost certainly contribute both to dyslexia as well as problems with attention (ADHD), a disorder frequently comorbid with dyslexia (Laasenon, Salomaa,

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Cousineau, Leppämäki, Tani, Hokkanen, & Dye, 2012). We believe the results of this study highlight the importance of further interdisciplinary investigation and professional collaboration to help identify what is an attentional problem, from what might be a visual convergence problem, or a difference in cognitive processing.

Limitations. Fatigue effects and binocular suppression during the NPC test were addressed by repeating the NPC twice and by use of the Brock string (e.g., probing the participant for responses about the number of strings he or she was aware of in their peripheral visual space). Written request was given prior to the testing day to ensure that participants used prescription glasses during NVA testing. If the participant did not bring their prescription glasses and their NVA responses indicated subnormal results, their data was not included in the final analyses. Despite these precautions, some participants reported feeling cognitively fatigued following the optometric assessments.

CONCLUSION

The results of this study support a need for a more holistic assessment in the identification, diagnosis, intervention, and treatment of cognitive problems pertaining to reading and learning. We assert that the correlational significance and intersectionality between attention, reading, and vision warrant further research. In order to expand and advance diagnosis and intervention, replication of this study in a pediatric setting may identify and support more meaningful and accurate diagnoses and inform clinical intervention. Additionally, investigations involving binocular vision disorders (e.g., strabismus, amblyopia, and convergence excess) within the same scope of testing or with alternative NPC methods would be important. Convergent validity assessments for attentional problems, dyslexia, and convergence insufficiency as well as cross-cultural examination of assessment across these conditions would strengthen the physiological antecedents and interventions for those with ADHD, dyslexia, and CI.

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