

ORIGINAL ARTICLE

# Nearpoint Phorias After Nearwork Predict ADHD Symptoms in College Students

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## ABSTRACT

**Purpose.** Phorometric findings have been observed to change with stress. We test the hypothesis that postnearwork phorias predict symptoms that have been theorized to result from nearwork-induced visual stress.

**Methods.** We measured nearpoint and farpoint dissociated phorias in 37 unselected college students with an alternate cover test both before and after a challenging reading comprehension test. We also assessed a broad range of putative attention deficit hyperactivity disorder (ADHD)-related symptoms with the Nadeau College-level ADHD Questionnaire.

**Results.** For phorias measured at nearpoint after nearwork, greater deviation from the median phoria (three exophoria) predicted higher symptoms ( $\rho(35) = 0.52, p < 0.001$ ), whether that deviation was in a convergent or a divergent direction (both  $\rho$ 's (18) =  $>0.48, p$ 's  $< 0.04$ ). An analogous result was obtained for "distance-near" stimulus accommodative convergence to accommodation (AC/A) ratios calculated from phorias, where greater deviation from median postnearwork AC/A ratio predicted higher symptoms ( $\rho(35) = 0.52, p < 0.0001$ ). Symptoms did not correlate with prenearwork phorias, prenearwork AC/A ratios, or postnearwork farpoint phorias ( $p$ 's  $> 0.05$ ).

**Conclusions.** Phorias postnearwork, but not prenearwork, predicted self-reported ADHD-related symptoms in college students. These results link binocular imbalance immediately after sustained nearwork to symptoms theorized to result from nearwork-induced visual stress.

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Key Words: heterophoria, attention deficit hyperactivity disorder, nearwork, non-strabismic binocular dysfunction, convergence insufficiency, convergence excess, binocular, phoria

Non-strabismic binocular disorders are classically defined by comparing phorias, or latent deviations of the visual axes, at near and far distances.<sup>1,2</sup> A phoria largest at far is a divergence insufficiency or excess, whereas a phoria largest at near is a convergence insufficiency (CI) or convergence excess (CE). The relatively high prevalence of CI and CE indicate the importance of reliable and clinically valid near phoria measurement.<sup>3-10</sup>

There is ample evidence that phoria can be measured reliably,<sup>11</sup> however, the evidence linking phoria to symptoms is mostly indirect. In only one study to our knowledge has phoria been shown to directly predict symptoms.<sup>12</sup> More typically, phoria predicts symptoms when considered in relation to other binocular measures, such as fusional amplitudes or phoria at another distance.<sup>12-15</sup> Symptoms have also been linked to fixation disparity,<sup>12,13,16-20</sup> which is related to phoria

both theoretically and statistically.<sup>21,22</sup> In still other studies phoria has failed to predict symptoms at all,<sup>16,17</sup> though these studies tested the limited hypothesis that relatively convergent phorias correspond to lower symptoms; the alternative that typical, middling phorias (e.g., those near the median) correspond to lower symptoms was not tested. Given limited evidence for a direct connection between phoria and visual symptoms, a phoria alone is rarely taken as cause for intervention, though the presence of additional binocular anomalies or symptoms may lead to both intervention and a label of "decompensated phoria."<sup>23</sup>

In clinical settings, activities preceding phoria measurements—e.g., a patient's previous engagement, duration in the waiting room, choice of activity in the waiting room—may vary widely in their fusional demand. Varied fusional demands may in turn influence phoria for a time as short as minutes or as long as weeks, by adapting the slow vergence mechanism.<sup>24-28</sup> It is commonly argued that measuring phoria free of such vergence adaptation is optimal, on the grounds that the phoria measurement will be purer and more physiologically basic.<sup>27</sup> A period of monocular occlusion, devoid of fusional demands, can be used clinically to reduce the influence of slow vergence on phoria.<sup>27</sup>

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Purity of measurement, however, is only important clinically if what is being purely measured relates clearly and unambiguously to symptoms or other signs of pathology, and as discussed above, such convincing evidence is largely lacking for phoria. Indeed, given that symptomatic patients show abnormally sluggish vergence adaptation (aka slow vergence),<sup>27,29–34</sup> a period of monocular occlusion that succeeds in removing the influence of slow vergence may cause symptomatic patients' phorias to appear misleadingly normal. By the same reasoning, a period of high fusional demand (e.g., sustained nearwork) immediately before the phoria measurement should produce particularly abnormal phorias in symptomatic patients.<sup>35</sup> We, therefore, hypothesized that those whose phorias are abnormal after a period of sustained nearwork should have the highest symptoms, but that abnormal phorias before sustained nearwork would be less predictive of symptoms.

Specifically, we asked if phorias after a challenging reading task would predict self-reported symptoms in an unselected college student population. We recruited college students because they are subject to rather uniformly high nearwork demands, and it seemed plausible that individuals with lower nearwork demands might fail to manifest binocular abnormality associated symptoms. We assessed a range symptoms related to adult attention deficit hyperactivity disorder (ADHD) because symptoms commonly attributed to binocular disorders, such as CI, overlap significantly with the diagnostic criteria for adult ADHD.<sup>15,36–39</sup>

## METHODS

### Participants and Procedure

Thirty-seven college students 18 to 21 years of age, 28 females and 9 males, participated in this research for course credit. Participants gave written informed consent for this study, which followed the tenets of the Helsinki Declaration and received approval from the Williams College Institutional Review Board. During a 30-min testing session, each participant gave informed consent, had their phoria measured, completed a reading comprehension test, had their phoria measured again, and finally completed a questionnaire designed to assess a broad range of ADHD-related symptoms. One extreme outlying subject was dropped from the study because of an unmeasurably high (>45 prism diopters) nearpoint esophoria and both nearpoint and farpoint esophorias more than eight standard deviations from the median. For purposes of power analysis, absent prior relevant data, we assumed an effect size of  $\rho = 0.40$ , classically considered medium-to-large in the behavioral sciences.<sup>40</sup> Given a critical p-value of 0.05 and a true effect-size of  $\rho = 0.40$ , and allowing for unusable data from up to two subjects, an initial sample size of 38 is expected to produce a statistically significant effect in 80% of studies.

### Phoria

Horizontal phoria was measured first at nearpoint (40 cm), then at farpoint (4.5 m) using a subjective alternate cover test with a prism bar.<sup>2</sup> Our procedure closely matches one shown to have high inter-examiner reliability for nearpoint phoria measurements ( $r = 0.91$ ).<sup>11</sup> For both near and far tests, subjects fixated a high-contrast (black on white) target (letter "R") in full room illumination, with

the experimenter standing out of the subject's central field of vision. Subjects wore their habitual refractive correction(s) for near or far distance. The small (15 arc min) target for the nearpoint measure, printed on a bead at the end of a stick, was held 35° below horizontal to simulate a typical reading posture. The larger (1°) target for the farpoint measure was mounted on a wall directly ahead. Participants were repeatedly reminded to keep the targets in focus. Participants were initially told to close their eyes for 5 s while a cover was placed in front of one eye. The cover was moved from one eye to the other at 2-s intervals, and the participant reported whether the target apparently moved in the same or opposite direction as the cover, or not at all. The magnitude and direction of prism required to null apparent target movement was taken as the phoria value. Specifically, a prism bar was used to incrementally add prism power until the subject reported a reversal of movement direction (prism bar values were 1, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 25, 30, 35, 40, and 45 prism diopters). Prism power was then reduced until the subject reported a second reversal. The phoria was taken as the mean of the prism values that produced reversals.

### Stimulus Accommodative Convergence to Accommodation Ratio

We calculated stimulus accommodative convergence to accommodation (AC/A) ratio via the phoria method, using the following formula and assuming an inter-pupillary distance of 60 mm.<sup>41</sup>

Stimulus AC/A = [(near phoria – far phoria) + 15]/accommodative stimulus.

### Reading Comprehension Test

This test consisted of two reading comprehension passages. Each passage consisted of approximately 250 words and was followed by four multiple-choice questions, taken from a Graduate Record Examination (GRE) preparation book.<sup>42</sup> This test length was chosen based on prior experience with individuals whose phorias change with nearwork. The reading test took approximately 11 min (mean 11.3, std = 2.8) and was immediately preceded and followed by phoria measurements. Neither time taken nor percent correct on the reading comprehension task correlated significantly with any of our phoria-related variables.

### ADHD Symptom Questionnaire

We used the Nadeau College-level ADHD Questionnaire,<sup>43</sup> which consists of 137 items rated on a scale of 0 ("I do not feel this statement describes me at all") to 4 ("I feel this statement describes me to a very large degree"). All items are worded such that higher numbers correspond to greater ADHD-related symptoms. Nadeau suggests grouping items into 21 categories (Table 1). We calculated category scores by adding up all items in a category and calculated total score by adding up all items on the questionnaire. Such adding of items is simple and relatively a-theoretical, though it assumes equal weighting of items relative to the construct being measured.<sup>44</sup> We found high internal consistency among our participants both for the questionnaire as a whole (Cronbach alpha = 0.97) and for many of the individual categories (Table 1, last item

**TABLE 1.**  
Correlations between nearpoint phoria and self-ratings for individual ADHD-related categories

| Category                | (No. items, mean rating, internal consistency) | Correlation w/deviation from median phoria (post-nearwork) |              | Correlation w/deviation from median phoria (pre-nearwork) |             |
|-------------------------|--|--|--------------|---|-------------|
|                         |  | $\rho$   | $p$          | $\rho$  | $p$         |
| Memory lapses           | (8, 1.0, 0.90)                                 | <b>0.33</b>  | <b>0.05</b>  | 0.01  | 0.96        |
| Oppositional tendencies | (6, 1.2, 0.87)                                 | <b>0.45</b>  | <b>0.005</b> | 0.20  | 0.24        |
| Self-discipline         | (8, 1.4, 0.85)                                 | <b>0.43</b>  | <b>0.007</b> | 0.04  | 0.82        |
| Impulsivity             | (7, 1.4, 0.85)                                 | <b>0.34</b>  | <b>0.04</b>  | 0.00  | 0.99        |
| Organization/structure  | (11, 1.1, 0.85)                                | <b>0.38</b>  | <b>0.02</b>  | -0.06   | 0.73        |
| Frustration tolerance   | (5, 1.7, 0.85)                                 | <b>0.38</b>  | <b>0.02</b>  | 0.10  | 0.54        |
| Distractibility         | (7, 1.8, 0.84)                                 | <b>0.35</b>  | <b>0.03</b>  | 0.07  | 0.69        |
| Self-esteem/confidence  | (6, 1.6, 0.83)                                 | <b>0.35</b>  | <b>0.03</b>  | -0.08   | 0.64        |
| Emotional lability      | (7, 1.4, 0.82)                                 | 0.30   | 0.07         | -0.11   | -0.51       |
| Anger                   | (6, 1.1, 0.82)                                 | <b>0.45</b>  | <b>0.006</b> | 0.08  | 0.64        |
| Inattention             | (6, 1.4, 0.81)                                 | <b>0.43</b>  | <b>0.007</b> | 0.17  | 0.32        |
| Social/interpersonal    | (7, 1.3, 0.79)                                 | <b>0.39</b>  | <b>0.02</b>  | 0.05  | 0.77        |
| Academics               | (10, 0.5, 0.78)                                | <b>0.37</b>  | <b>0.02</b>  | 0.14  | 0.41        |
| Anxiety/depression      | (10, 0.8, 0.75)                                | <b>0.36</b>  | <b>0.03</b>  | 0.02  | 0.91        |
| Time management         | (6, 1.5, 0.74)                                 | 0.24   | 0.15         | <b>-0.34</b>  | <b>0.04</b> |
| Hyperactivity           | (7, 1.7, 0.70)                                 | <b>0.40</b>  | <b>0.01</b>  | 0.09  | 0.60        |
| Substance abuse         | (5, 0.3, 0.68)                                 | -0.07  | 0.67         | -0.10   | 0.54        |
| Family history          | (4, 0.6, 0.66)                                 | -0.03  | 0.86         | <b>-0.32</b>  | <b>0.05</b> |
| Sleep/arousal problems  | (5, 1.2, 0.66)                                 | <b>0.39</b>  | <b>0.02</b>  | -0.10   | 0.55        |
| Hyperfocusing           | (2, 1.8, 0.58)                                 | 0.15   | 0.39         | 0.04  | 0.80        |
| Stimulants              | (3, 0.2, 0.19)                                 | 0.16   | 0.36         | 0.17  | 0.32        |
| Mean score              | (137, 1.2, 0.97)                               | <b>0.52</b>  | <b>0.001</b> | 0.00  | 0.99        |

Categories listed in descending order of internal consistency (Cronbach alpha).

We use rank-order correlations (Spearman  $\rho$ ) to demonstrate that correlations are not due to outliers or non-normality of data.

One in 40 correlations (2.5%) are expected to be statistically significant in the predicted direction at the reported  $p = 0.05$  level (two-tailed) because of chance alone; for postnearwork, nearpoint phorias we observe statistically significant correlations for 15 of 21 symptom categories (71%).

in column 2). This high internal consistency may reflect measurement of relatively pure construct(s), though it may also reflect redundancy among questionnaire items.<sup>45</sup>

We chose the Nadeau questionnaire for three reasons. First, it is the only available instrument designed for college students. Second, it is both broader in scope and more detailed than other instruments, covering issues such as attentiveness, cognitive and social performance, affect, and self-discipline (Tables 1 and 2). As this was the first study to our knowledge to probe for psychological correlates of postnearwork phoria, such a combination of depth and breadth was deemed important for (a) detecting an association if present, and (b) characterizing it richly enough to guide future investigation.

Third, in a supplementary study of 27 additional students drawn from our college student population, the Nadeau Questionnaire demonstrated excellent concurrent validity. The details of this supplementary study are as follows. Each student completed both the Conners Adult ADHD Rating Scale (CAARS), arguably the best-validated self-report instrument for adult ADHD symptomatology,<sup>46-48</sup> as well as the Nadeau Questionnaire.<sup>43</sup> The CAARS ADHD Index alone has previously shown 71% sensitivity and 75% specificity for discriminating adult ADHD participants from age- and sex-matched controls.<sup>46</sup> In our supplementary

study, the total score on the Nadeau questionnaire correlated highly with both the ADHD Index and the factor analytically derived Inattention Scale of the CAARS ( $\rho(25) = 0.72$ ,  $p < 0.0001$  and  $\rho(25) = 0.80$ ,  $p < 0.0001$ , respectively). Moreover, the mean ADHD Index score in our sample ( $M(27) = 12.2$ ,  $SD = 5.6$ ) did not differ significantly from that in the CAARS' normative sample ( $M(261) = 11.3$ ,  $SD = 6.0$ ;  $t(286) = 0.70$ ,  $p = 0.48$ ; higher scores indicate greater symptoms), suggesting that our population, though reasonably high-achieving, is not unusually low in ADHD symptomatology. Indeed, three female participants from our sample (11%) had an ADHD Index score above 19, the cutoff recommended for follow-up in ADHD screenings.

Diagnosis of adult ADHD is based on a combination of survey instruments and interviews that consider the patient's history and rule out other diagnoses.<sup>49</sup> In the United States, a diagnosis requires identification of either six or more symptoms of inattention or six or more symptoms of hyperactivity-impulsivity; these symptoms must have been present since childhood and must impair function in at least two domains of life.<sup>50</sup> Because we studied a normal population, and as survey data alone is insufficient for ADHD diagnosis, our study does not support firm conclusions about clinical-level ADHD. Rather, our study

**TABLE 2.**Correlations between deviation from median nearpoint phoria postnearwork and self-ratings for individual ADHD-related items<sup>42</sup>

| $\rho$ | p     | #   | Topic                                      | Category                  |
|--------|-------|-----|--|---------------------------|
| 0.48   | 0.003 | 41  | Laziness                                   | (Self-discipline)         |
| 0.48   | 0.003 | 81  | Childhood fighting                         | (Anger)                   |
| 0.48   | 0.003 | 59  | Difficulty prioritizing                    | (Organization/structure)  |
| 0.47   | 0.004 | 102 | Zoning out during tests                    | (Academics)               |
| 0.46   | 0.004 | 122 | Frequent arguments                         | (Oppositional tendencies) |
| 0.46   | 0.005 | 36  | Difficulty improving self                  | (Self-discipline)         |
| 0.44   | 0.006 | 23  | Tangential conversation                    | (Distractibility)         |
| 0.44   | 0.007 | 118 | Apprehension about mistakes                | (Self-esteem/confidence)  |
| 0.44   | 0.007 | 73  | Forgetting of to-dos                       | (Memory)                  |
| 0.43   | 0.008 | 85  | Anger at criticism                         | (Anger)                   |
| 0.43   | 0.008 | 5   | Wandering of mind during reading           | (Inattention)             |
| 0.43   | 0.008 | 123 | Stubbornness                               | (Oppositional tendencies) |
| 0.43   | 0.008 | 9   | Interruption of others                     | (Impulsivity)             |
| 0.42   | 0.010 | 106 | Apprehension about future                  | (Anxiety/depression)      |
| 0.42   | 0.010 | 20  | Restlessness in class                      | (Hyperactivity)           |
| 0.42   | 0.010 | 19  | Lack of patience                           | (Hyperactivity)           |
| 0.42   | 0.010 | 82  | Short fuse                                 | (Anger)                   |
| 0.41   | 0.010 | 48  | Ease of falling asleep                     | (Sleep/arousal)           |
| 0.41   | 0.010 | 69  | Need of reminders from others              | (Memory)                  |
| 0.40   | 0.010 | 22  | Frequency of tangential thought            | (Distractibility)         |
| 0.40   | 0.020 | 16  | Fidgetiness                                | (Hyperactivity)           |
| 0.39   | 0.020 | 42  | Irresponsibility                           | (Self-discipline)         |
| 0.39   | 0.020 | 130 | Excessive bluntness                        | (Social/interpersonal)    |
| 0.38   | 0.020 | 6   | Confusion during group conversation        | (Inattention)             |
| 0.38   | 0.020 | 10  | Speaking before thinking                   | (Impulsivity)             |
| 0.38   | 0.020 | 86  | Losing own calm in face of others' anger   | (Anger)                   |
| 0.38   | 0.020 | 125 | Arguments with supervisors                 | (Oppositional tendencies) |
| 0.37   | 0.020 | 77  | Frustration proneness                      | (Frustration tolerance)   |
| 0.37   | 0.020 | 1   | Difficulty focusing                        | (Inattention)             |
| 0.36   | 0.030 | 32  | Unrealistic time estimates                 | (Time management)         |
| 0.36   | 0.030 | 49  | Lack of planning                           | (Organization/structure)  |
| 0.34   | 0.040 | 132 | Proneness to conflict                      | (Social/interpersonal)    |
| 0.34   | 0.040 | 120 | Difficult as child                         | (Oppositional tendencies) |
| 0.34   | 0.040 | 103 | Proneness to careless mistakes             | (Academics)               |
| 0.33   | 0.040 | 47  | Sleepiness in class                        | (Sleep/arousal)           |
| 0.33   | 0.040 | 79  | Difficulty waiting                         | (Frustration tolerance)   |
| 0.33   | 0.040 | 52  | Tendency to fall behind in projects        | (Organization/structure)  |
| 0.33   | 0.050 | 121 | Averseness to others' instructions         | (Oppositional tendencies) |
| 0.33   | 0.050 | 24  | Tendency to lose focus with projects       | (Distractibility)         |
| 0.33   | 0.050 | 111 | History of therapy                         | (Anxiety/depression)      |
| 0.33   | 0.050 | 127 | Tendency to not get along with others      | (Social/interpersonal)    |
| 0.32   | 0.050 | 21  | Proneness to being sidetracked             | (Distractibility)         |
| 0.32   | 0.050 | 37  | Lateness due to focus on other activity    | (Self-discipline)         |
| 0.30   | 0.070 | 115 | Avoidance of competition                   | (Self-esteem/confidence)  |
| 0.30   | 0.070 | 25  | Tendency to lose track of time             | (Distractibility)         |
| 0.29   | 0.080 | 87  | Moodiness                                  | (Emotional lability)      |
| 0.29   | 0.080 | 99  | Lack of academic motivation                | (Academics)               |
| 0.29   | 0.080 | 131 | Inconsiderateness                          | (Social/Interpersonal)    |
| 0.28   | 0.090 | 4   | Difficulties with sustained studying       | (Inattention)             |
| 0.28   | 0.090 | 110 | History of drugs for anxiety or depression | (Anxiety/depression)      |
| 0.28   | 0.100 | 74  | Tendency to forget unless take notes       | (Memory)                  |
| 0.28   | 0.100 | 8   | Tendency to act before think               | (Impulsivity)             |

# is the sequential number of the item within the questionnaire. Because actual items could not be reproduced because of copyright restrictions, "topic" lists the gist of each item in the investigators' own words; for actual items, refer to original questionnaire.<sup>41</sup> Also listed for each item is correlation ( $\rho$ ), statistical significance (p), and category (in parentheses).

Items listed in descending order of correlation. We use rank-order correlations (Spearman's  $\rho$ ) to demonstrate that these correlations are not because of outliers or non-normality of data.

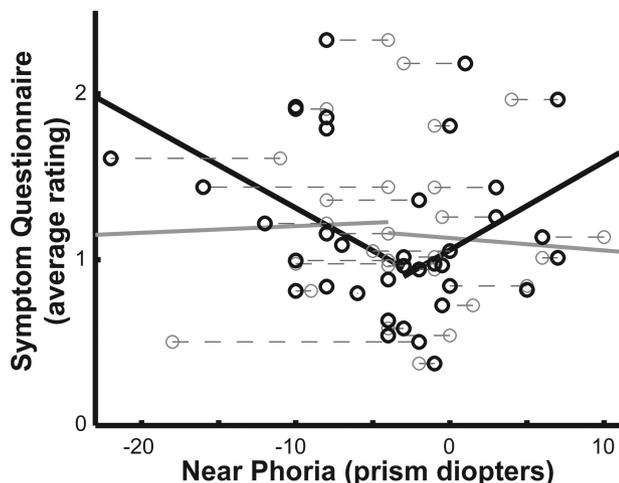
One in 40 correlations (2.5%) are expected to be statistically significant in the predicted direction at the reported  $p = 0.05$  level (two-tailed) because of chance alone; for post-nearwork, nearpoint phorias we observe statistically significant correlations for 43 of 137 items (31%).

was designed to link phoria to subclinical ADHD symptoms in the population at large.

## RESULTS

### Nearpoint Phorias Predict Symptoms PostNearwork but Not PreNearwork

Fig. 1 shows the relationship between mean ADHD symptom self-ratings (hereafter “symptoms”) and nearpoint phorias. Convergent (eso-) phorias are indicated by positive values and divergent (exo-) phorias by negative values. Postnearwork (black circles), participants with phoria measurements further from the median (three exophoria), irrespective of direction, reported higher symptoms. This relationship holds for phorias both more convergent (>) and less convergent (<) than the median. Indeed, phorias either  $\geq$  or  $\leq$  the median show similar correlations with symptoms ( $\rho(17) = 0.48$ ,  $p = 0.03$  and  $\rho(17) = -0.58$ ,  $p = 0.008$ , respectively) and nearly identical slopes (absolute least-squares slopes, 0.053 and 0.052, respectively). Because differing in either direction from median nearpoint postnearwork phoria predicted similar increases in symptoms, we



**FIGURE 1.**

Relationship between phoria and ADHD questionnaire self-ratings. X axis shows phoria measured at nearpoint (40 cm) via alternating cover test with prism bar. Convergent (eso-) phorias are indicated by positive values and divergent (exo-) phorias by negative values. Phorias for each individual are indicated by two icons, a gray circle for phoria before nearwork and a black circle for phoria after nearwork; the two icons are connected by a dotted line to show change in phoria. Y axis shows average self-rating on the Nadeau College-level ADHD Questionnaire.<sup>43</sup> Possible ratings ranged from 0 to 4, with higher ratings indicating greater ADHD symptoms. Best fit (least-squares) lines are shown separately for phorias  $\geq$  and  $\leq$  the median, both pre- (median = -4) and postnearwork (median = -3). The equations for these lines are as follows:

$$S = 0.05 \times (P_{\text{postcon}} - 3) + 0.90$$

$$S = -0.05 \times (P_{\text{postdiv}} - 3) + 0.95$$

$$S = -0.01 \times (P_{\text{precon}} - 4) + 1.16$$

$$S = 0.00 \times (P_{\text{prediv}} - 4) + 1.23$$

where S is symptoms, P is near phoria, subscripts pre and post are pre- and postnearwork, respectively, and subscripts con and div are  $\geq$  and  $\leq$  median phoria, respectively. The r-squared values for these four linear fits are 0.14, 0.22, 0.00, and 0.00, respectively.

collapsed over convergent and divergent data, calculating absolute deviation from median. This deviation measure correlated highly significantly with mean symptom rating ( $\rho(35) = 0.53$ ,  $p = 0.0008$ ).

Fig. 1 shows that while ADHD symptoms are predicted by nearpoint postnearwork phorias (solid black best-fit lines; black circles), the same does not hold for nearpoint prenearwork phorias (solid gray best-fit lines; gray circles connected to postnearwork values via dashed lines). Prenearwork, nearpoint phorias  $\geq$  and  $\leq$  the median (-4), as well as absolute deviation from the median, all failed to significantly predict symptoms ( $\rho(17) = -0.06$ ,  $p = 0.78$ ,  $\rho(17) = -0.13$ ,  $p = 0.55$  and  $\rho(35) = -0.002$ ,  $p = 0.99$ , respectively). Indeed, the latter two measures both failed to significantly predict symptoms even when an outlying participant (gray circle in bottom left of Fig. 1) was dropped ( $\rho(16) = -0.19$ ,  $p = 0.38$  and  $\rho(34) = 0.09$ ,  $p = 0.60$ , respectively).

Despite the clear dissociation whereby nearpoint phorias measured postnearwork, but not prenearwork, predicted symptoms, nearpoint phorias measured post- and prenearwork did substantially predict each other ( $\rho(35) = 0.71$ ,  $p < 0.0001$ ). This high correlation suggests that the dissociation did not result from unreliable prenearwork phoria measurement. Rather, it suggests that there are core mechanisms common to both measures that did not relate to the symptoms we assessed, while the influence of a separate mechanism only postnearwork did relate to symptoms.

Correlations between symptoms and nearpoint postnearwork phoria were robust to substantial jittering of the median value. Absolute deviation from any phoria value between 5.5 exophoria and orthophoria correlated significantly with symptoms ( $p < 0.05$ ). We have used Spearman rank-order correlations for all of our analyses ( $\rho$ ) because they are minimally influenced by extreme datapoints and, thereby, focus on robust trends in the data. All correlations remain highly similar, however, when computed as Pearson correlations ( $r$ ). Change in nearpoint phoria from pre- to postnearwork did not correlate with symptoms ( $r(35) = -0.03$ ,  $p = 0.85$ ).

### Stimulus AC/A Ratios Predict Symptoms PostNearwork but Not PreNearwork

Comparing Fig. 2 to Fig. 1, it can be seen that stimulus AC/A ratios postnearwork (black circles, Fig. 2) and nearpoint phorias postnearwork (black circles, Fig. 1) predicted symptoms similarly. That is, postnearwork AC/A ratios  $\geq$  and  $\leq$  the median (4.8) and absolute deviation from that median all significantly predicted symptoms ( $\rho(17) = 0.52$ ,  $p = 0.02$ , slope = 0.176,  $\rho(17) = -0.64$ ,  $p = 0.001$ , slope = -0.217,  $\rho(35) = 0.52$ ,  $p = 0.0009$ , respectively), while analogous prenearwork AC/A ratios did not ( $\rho(17) = -0.06$ ,  $p = 0.78$ ,  $\rho(17) = -0.13$ ,  $p = 0.55$  and  $\rho(35) = -0.002$ ,  $p = 0.99$ , respectively).

Indeed, a similar predictive capacity of postnearwork, nearpoint phoria and postnearwork AC/A ratio is to be expected given the high correlation between these two measures ( $\rho(35) = 0.94$ ,  $p < 0.0001$ ). However, one might perhaps have expected an even higher predictive capacity for the AC/A ratio because it incorporates both nearpoint and farpoint phoria measurements; instead, it appears that incorporating far phoria adds little additional predictive power.

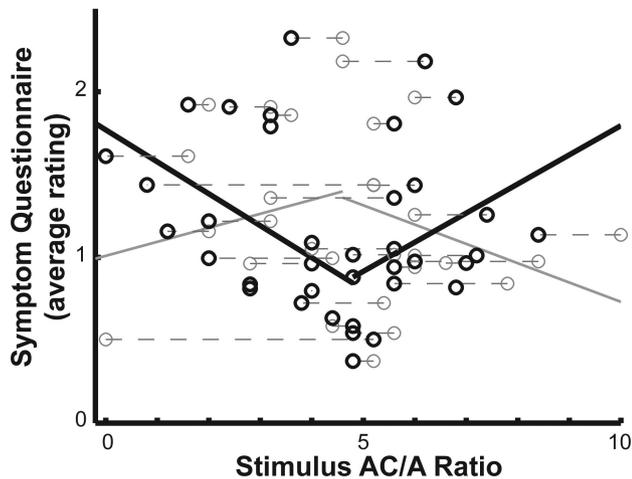


FIGURE 2.

Relationship between stimulus AC/A ratio and ADHD questionnaire self-ratings. Same as Fig. 1, except x axis is stimulus AC/A ratio calculated from near and far phorias (for formula, see Methods). Best fit (least-squares) lines are shown separately for AC/A ratios  $\geq$  and  $\leq$  the median, both pre- (median = 4.6) and postnearwork (median = 4.8). The equations for these lines are as follows:

$$S = 0.18 \times (ACA_{\text{posthigh}} - 4.8) + 0.88$$

$$S = -0.15 \times (ACA_{\text{postlow}} - 4.8) + 0.90$$

$$S = -0.12 \times (ACA_{\text{prehigh}} - 4.6) + 1.36$$

$$S = 0.08 \times (ACA_{\text{prelow}} - 4.6) + 1.40$$

where  $S$  is symptoms,  $ACA$  is AC/A ratio, subscripts pre and post are pre- and postnearwork, respectively, and subscripts high and low are  $\geq$  and  $\leq$  median AC/A ratio, respectively. The  $r$ -squared values for these four linear fits are 0.14, 0.23, 0.09, and 0.04, respectively.

Correlations between symptoms and postnearwork AC/A ratios were robust to substantial jittering of the median value. Absolute deviation from any AC/A value between 3.8 and 5.5 correlated significantly with symptoms ( $p < 0.05$ ). Change in AC/A from pre- to postnearwork did not correlate with symptoms ( $r(35) = -0.02$ ,  $p = 0.91$ ).

### Far Phorias Do Not Predict Symptoms

Far phorias predict symptoms neither pre- nor postnearwork, neither for phorias  $\geq$  the median,  $\leq$  the median, nor for absolute deviation from median phoria (all  $p$ 's  $> 0.32$ , except correlation with postnearwork far phorias  $\leq$  median,  $\rho(17) = -0.36$ ,  $p = 0.08$ ).

Despite the clear dissociation whereby postnearwork phorias at nearpoint, but not at farpoint, predicted symptoms, postnearwork phorias measured at nearpoint and farpoint did predict each other ( $\rho(35) = 0.57$ ,  $p = 0.0002$ ). This correlation is the equivalent of a test-reliability computed between measures of two similar but distinct phenomena. A correlation, this high suggests that the dissociation did not result from unreliable farpoint phoria measurement. Rather, these results suggest that there are core mechanisms common to both nearpoint and farpoint phorias that did not relate to the symptoms we assessed, while the influence of a separate mechanism only at nearpoint did relate to symptoms.

### Correlations with Individual Categories and Items from ADHD Symptom Questionnaire

The ADHD symptom questionnaire had 21 categories of questions, listed in Table 1. Investigation of each symptom category separately revealed a consistent picture of correlations with phorias. Table 1 shows the correlation of each symptom category with nearpoint phoria, both pre- and postnearwork. As nearpoint phorias  $\geq$  and  $\leq$  the median were similarly predictive for all symptom categories (mean difference in  $\rho = 0.10$ ,  $\text{std} = 0.06$ ; no difference statistically significant), we restrict our analysis to absolute deviations from median phoria. The larger the absolute deviations from median postnearwork, nearpoint phoria, the greater symptoms were for 15 of the 21 categories (Table 1, in bold,  $p < 0.05$ ). In contrast, greater absolute deviations from median prenearwork, nearpoint phoria did not predict greater symptoms for any category (Table 1, in bold,  $p < 0.05$ ; lower symptoms were predicted for two categories). To facilitate intuition about the specific symptoms that related to phoria, we list in Table 2 every questionnaire item that received higher endorsements from those with greater absolute deviation from median postnearwork, nearpoint phoria ( $p \leq 0.10$ ; 52 out of 137 total items).

### DISCUSSION

We have found that postnearwork, nearpoint phorias predict a broad range of self-reported ADHD-related symptoms in a group of college students. Symptoms are predicted to a similar degree by phorias that differ from the median phoria in either a convergent or divergent direction. Although farpoint and prenearwork phorias correlate substantially with postnearwork, nearpoint phorias, they do not predict symptoms, suggesting that whatever binocular mechanism is driving the association with symptoms has its effect only postnearwork and at nearpoint. We hypothesize based on these findings that binocular imbalance during nearwork, but not at other times or other distances, may have important psychological and behavioral consequences.

The idea that phorias increase in diagnostic significance when measured postnearwork, while not unprecedented,<sup>35,51</sup> contrasts with standard wisdom that phoria should ideally be measured after relatively long periods of monocular occlusion to minimize the influence of slow vergence and/or accommodation.<sup>27</sup> Our results do not exclude the possibility that a "pure" phoria measure devoid of adaptation effects has clinical utility, however, they do suggest that phoria measured in the direct context of sustained nearwork is of particular clinical value.

It is possible that some clinical phoria measurements are already made under conditions functionally equivalent to our postnearwork condition. For example, reading in a waiting room or performing nearpoint tests in a standard eye examination might create similar enough conditions; indeed, repeated nearpoint phoria measurements alone have been shown to cause systematic changes in some patients, changes that could be similar to those we observed.<sup>52,53</sup> However, reading in a waiting room could happen too long before measurement and may be avoided by symptomatic patients; and nearpoint optometric tests could be too fleeting. Future research efforts should establish premeasurement

conditions necessary to produce nearpoint phorias predictive of symptoms.

Recent evidence supports diagnostic overlap between CI and ADHD symptoms.<sup>15,36–39</sup> CI and CE are characterized, respectively, by relatively divergent and relatively convergent nearpoint phorias. We found that divergent and convergent nearpoint phorias predicted ADHD symptoms to a similar degree, as did high and low AC/A ratios. Our results are therefore similar to the claim by Scheiman and Wick<sup>54</sup> that CI and CE, characterized, respectively, by low and high AC/A ratios, have identical symptoms. Because we studied a normal population, and as survey data alone is insufficient for ADHD diagnosis, our study does not support firm conclusions about clinical-level ADHD *per se*. Rather, our study links both convergent and divergent phorias to putatively subclinical ADHD-related symptoms in the population at large.

What binocular mechanism could be responsible for the change in nearpoint phoria with nearwork that caused the associations we observed? A clue is provided by Garzia and Dyer,<sup>55</sup> who found a steeper increase in fixation disparity with vergence demand in symptomatic patients postnearwork, relative to prenearwork. This change in fixation disparity may indicate an increase in vergence stress during nearwork. We speculate that nearwork-induced vergence stress is produced by abnormally slow vergence adaptation. Slow vergence adaptation, which has been previously linked to visual symptoms,<sup>27,29–34</sup> could conceivably lead to either fatigued (low-gain) or overactive (high-gain) vergence after nearwork, thereby causing a phoria. Slow decay of adaptation after nearwork might likewise cause a phoria. Alternatively, Schor and Horner<sup>31,56,57</sup> have proposed that both abnormally fast and abnormally slow vergence adaptation, relative to accommodative adaptation, may cause symptomatic AC/A ratios. Although our results do not distinguish between such causal theories, they establish a selective link between symptoms and post-nearwork phoria.

To facilitate identification of specific psychological mechanisms relating to binocular imbalance, we have listed in Table 2 each questionnaire item endorsed to a significantly greater degree by those individuals with greater absolute deviation from median nearpoint phoria after nearwork. In this list there are many items that apparently relate to the three core ADHD traits of inattention, impulsiveness, and hyperactivity.<sup>50</sup> Future work should more precisely isolate the psychological mechanisms involved, tie them firmly to associated visual symptoms, and assess their clinical magnitude. Future studies may also need to account for variations in baseline nearwork demands if they use a population with less uniformly high nearwork demands than our college student participants.

By establishing a link between phoria and ADHD, the present study represents a first step toward establishing firm, evidence-based connections between binocular visual measures and psychological constructs. Such a connection may contribute to development of optimal binocular measurement technique while also helping to establish the full consequences of binocular dysfunction.

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JBW conceived and designed the study in collaboration with GMB. JBW performed, analyzed, and wrote up the study.

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