HHS Public Access
Author manuscript
J Learn Disabil. Author manuscript; available in PMC 2023 September 01.

Published in final edited form as:
J Learn Disabil. 2022 ; 55(5): 427–442. doi:10.1177/00222194211047631.

Development of an Abbreviated Adult Reading History Questionnaire (ARHQ-Brief) Using a Machine Learning Approach

Luxi Feng[1], **Roeland Hancock**[1], **Christa Watson**[2,3,4], **Rian Bogley**[2,3,4], **Zachary A. Miller**[2,3,4], **Maria Luisa Gorno-Tempini**[2,3,4], **Margaret J. Briggs-Gowan**[5], **Fumiko Hoeft**[1,3,5,6,7]

[1]Department of Psychological Sciences, Brain Imaging Research Center (BIRC), University of Connecticut

[2]UCSF Weill Institute for Neurosciences, University of California San Francisco

[3]Department of Neurology, Memory and Aging Center, University of California San Francisco

[4]Dyslexia Center, University of California San Francisco

[5]Department of Psychiatry, University of Connecticut School of Medicine

[6]Haskins Laboratories, Yale University

[7]Department of Neuropsychiatry, Keio University School of Medicine

Abstract

Several crucial reasons exist to identify whether an adult has had reading disorder (RD) and to predict a child's likelihood of developing RD, which is known to be primarily genetically transmitted. The Adult Reading History Questionnaire (ARHQ) is among the most commonly used self-reported questionnaires. High ARHQ scores indicate an increased likelihood that an adult had RD as a child, and that their children may develop RD. This study focused on whether using a subset of ARHQ items (ARHQ-brief) could be equally effective and efficient in assessing adults' reading history. We used a machine learning approach, lasso (known as L1 regularization), and identified 6 of 23 items that resulted in the ARHQ-brief. Data from 97 adults and 47 children were included. With the ARHQ-brief, we report a threshold of 0.323 as suitable to identify past likelihood of RD in adults with a sensitivity of 72.4% and a specificity of 81.5%. Comparison of predictive performances between ARHQ-brief and the full ARHQ showed that ARHQ-brief explained an additional 10–35.2% of the variance in adult and child reading. Further, we validated ARHQ-brief's superior ability to predict reading ability using an independent sample of 28 children. We close by discussing limitations and future directions.

Keywords

dyslexia; reading disorder; Adult Reading History Questionnaire; reading ability; adults and children

---

Decoding-based reading disorder (RD), also known as developmental dyslexia, is a specific learning disorder of reading impairment (American Psychiatric Association, 2013), characterized by persistent poor decoding and spelling, despite adequate intelligence, sensory abilities, and educational opportunities (Lyon, Shaywitz, & Shaywitz, 2003;

Snowling, Hulme, & Nation, 2020). RD is considered to be familial and heritable that is observed in any language. Estimates of the heritability of reading abilities are higher than environmental impact in most circumstances and range from 0.10 to 0.87, with variation depending on the types of abilities, age at assessment, and orthographies (Andreola et al., 2021; Logan et al., 2013; Olson, 2002; Peterson & Pennington, 2015). Moreover, RD has been found to be largely genetically transmitted from parents to their children without evidence for environmental transmission (see Soden et al., 2015, in English and Swagerman et al., 2017, in Dutch). Consequently, children with family history of RD are more likely to be at risk of having RD (Shaywitz, 1998; van Bergen, de Jong, Maassen, & van der Leij, 2014), which indicates the importance of obtaining family history of reading.

Since the etiology of RD is related to multiple cognitive deficits, the diagnosis of RD is unlikely to be made by a one-size-fits-all approach or completed in a single and brief assessment (Berninger, Richards, & Abbott, 2015). Diagnosis of RD is cumbersome for two main reasons: 1) it relies on teachers to first identify a problem, which does not happen reliably and was essentially non-existent until recent decades; 2) a formal diagnosis typically includes multiple assessments of behavior, cognition, intelligence, language, and reading done by professional specialists one-on-one and is often resource intensive, time-consuming, and difficult to attain due to limited professionals. Additionally, there is great challenge in identifying adults as RD who were never formally diagnosed. The collection of information about adult reading history can be a proxy to evaluate the likelihood of adults having had RD, especially for those who have compensated and may no longer have apparent reading difficulties (Welcome & Meza, 2019). Identifying adults as RD is important so that they can seek help and receive accommodations as well as literacy support in their workplace and other situations. If they are parents, given the risk for RD that their children face because of the parents' reading history, parents can seek early identification and intervention for their children. Given the liability that their children will have RD, early identification and intervention could be planned for these young children. Therefore, adults with suspected RD may benefit from self-reported screening approaches that can identify those with probable RD. Prior research has shown that self-reported measures can effectively discriminate between typical and poor readers. For instance, Giménez and colleagues (2015) examined a self-reported questionnaire for Spanish-speaking adult readers, and reported that there were significant correlations between self-reported scores and reading measures, and that the response distributions of questionnaire items were significantly different between typical and poor readers. In addition, adults who were identified as RD using self-reported measures and by formal diagnoses showed similar reading abilities such as word reading accuracy, timed reading comprehension, and phonological awareness (Deacon, Cook, & Parrila, 2012). Overall, valid and reliable questionnaires can be of great value to both research and practice for identifying adults with probable RD.

One of the most widely used self-report measures is the Adult Reading History Questionnaire (ARHQ; Lefly & Pennington, 2000), a modification of the Finucci questionnaire (Finucci, Issacs, Whitehouse, & Childs, 1982) with additional items based on clinical and research experience. It is composed of 23 Likert-scale items, rating from 0 to 4 on multiple dimensions such as early childhood reading and current reading habits, and three multiple-choice items about highest education level attained and family history of reading difficulty (i.e., adults' parents, brothers, and/or sisters). The sum obtained from the answers on the 23 items is then transformed to an ARHQ combined score, which ranges from 0 to 1, with a higher score reflecting adults that have a history of poor reading. The AHRQ has demonstrated to have excellent reliability (i.e., internal consistency: Cronbach's alpha = 0.94 and 0.92; test-retest: $r = 0.81$ and 0.84) in two independent, longitudinal samples (Lefly & Pennington, 2000), and accurately classified 79% of the sample with a sensitivity of 81.8% and a specificity of 77.5%. An ARHQ score at or above a threshold of 0.3 (e.g., Bonifacci, Storti, Tobia, & Suardi, 2016; Pennington & Lefly, 2001; Schneps, Brockmole, Sonnert, & Pomplun, 2012) or 0.4 (e.g., Conlon et al., 2006; Lefly & Pennington, 2000) has been recommended and implemented in practice to indicate potential RD. Black et al. (2012) showed that the use of the ARHQ cut-off score of approximately 0.4 in their sample matched a cut-off standard score of 90 for the Test of Word Reading Efficiency (TOWRE, Torgesen, Rashotte, & Wagner, 1999) Phonemic Decoding Efficiency (PDE) subtest. With results from correlational analyses, they concluded that ARHQ scores served as a good indicator of an adult's past and current reading ability. The ARHQ has been adapted to multiple languages, such as Icelandic (e.g., Bjornsdottir et al., 2014), Portuguese (e.g., Alves & & Castro, 2005) and Polish (e.g., Krasowicz-Kupis et al., 2014). There are also several revised versions of the ARHQ (i.e., ARHQ-R), which are also translated into languages other than English (e.g., French, see Fichten et al., 2014). For instance, Parrila, Corkett, Kirby, and Hein (2003) divided their 27 ARHQ-R items to three components: Elementary School, Current Status, and Current Reading Motivation. The internal consistency of eight Elementary School items was between 0.77 and 0.93 (Deacon et al., 2012; Deacon, Tucker, Bergey, Laroche, & Parrila, 2017; Fitchen et al., 2014; Metsala, Parrila, Conrad, & Deacon, 2019; Mourgues et al., 2014; Stack-Cutler, Parrila, & Torppa, 2015), while that of the 12 Current Status items was between 0.70 and 0.80 (Mourgues et al., 2014; Stack-Cutler et al., 2015), and that of the seven Current Reading Motivation items was above 0.64 (Mourgues et al., 2014). Parrila, Georgiou, and Corkett (2007) proposed another version of ARHQ-R with only 10 items related to Elementary Education with its internal consistency between 0.90 and 0.96 (Al Dahhan et al., 2014; Parrila et al., 2007). Kirby, Silvestri, Allingham, Parrila, & La Fave (2008) implemented an ARHQ-R (internal consistency = 0.96) with 56 items, in which 15 items focused on Elementary School Experiences, 19 on Secondary School, and 22 on Current Status. While some questionnaires (e.g., Parrila et al., 2007) were brief like the one proposed in the current study, none of these studies reported sensitivity and specificity of their ARHQ-R, predicted adult reading, or predicted their children's reading ability.

So far, there have been two studies that examined the underlying factor structure of the ARHQ, and their findings had certain commonalities. Using an Icelandic sample and excluding one item due to the culture of their local school systems, Bjornsdottir et al. (2014) extracted three latent factors and characterized them as Dyslexic Symptom, Current Reading, and Memory. Since the Icelandic ARHQ dropped one item, Bjornsdottir et al. (2014) recalibrated the ARHQ threshold to 0.43 with a sensitivity of 84.5% and a specificity of 83.7%. Welcome and Meza (2019) excluded four items due to insufficient factor loadings and identified six latent factors with the rest of the 19 items including Childhood Reading, Spelling, Reversal, Memory, Current Reading Attitude, and Print Media Use. However, they indicated great overlap between Dyslexic Symptom in Bjornsdottir et al. (2014)

and their factors Childhood Reading, Spelling, and Reversal; as well as between Current Reading and Current Reading Attitude and Print Media Use. Bjornsdottir's three factors (i.e., Dyslexic Symptom, Current Reading, and Memory) serve as good indicators of adult readers with RD: 1) poor reading in childhood is associated with the persistence of RD into adulthood (Hatcher, Snowling, & Griffiths, 2002; Nergård-Nilssen & Hulme, 2014), and even compensated readers continue to struggle with spelling and phonological processing (Parrila et al., 2007); 2) adults with RD are more likely to exhibit a negative attitude toward current reading (Leinonen et al., 2001); and 3) deficits in short-term and working memory have been known as a major weakness and predictor of RD (Fostick & Revah, 2018; Nergård-Nilssen & Hulme, 2014; Smith-Spark & Fisk, 2007). Together these studies show the usefulness of the constructs derived from this measure in predicting adult reading, their likelihood of past reading problems, and predicting risk for their children's reading outcome.

While the major utility of the ARHQ is to screen adult populations to identify who have a history of poor reading, it has also been useful in identifying children who are at risk for developing RD, with risk being defined as parents having struggled with or have a history of reading difficulty. To this end, research has suggested significant associations between the scores of the ARHQ or ARHQ-R in parents and the reading performances of their children (Bach, Richardson, Brandeis, Martin, & Brem, 2013; Black et al., 2012; Bonifacci, Montuschi, Lami, & Snowling, 2014). However, unsurprisingly, the significance of the predictive ability of the ARHQ was reduced when additional cognitive and behavioral predictors are jointly used to predict child's reading ability. Conlon et al. (2006) found that the parental ARHQ scores became a non-significant predictor of children's word recognition, reading comprehension, and spelling when reading-related variables, processing speed, and reading attitude were included in the analytic model. Still, it should be noted that family history measured in a variety of ways has been shown to be a significant predictor for reading outcome in young children of ages 4–8 above and beyond reading-related measures in a number of studies (e.g., Pennington & Lefly, 2001; Thompson et al., 2015; Wagner et al., 2019).

One concern of the ARHQ is that a completion of the questionnaire can be time consuming, especially if adults struggle with reading, potentially resulting in high participant burden and a low response rate. Although several aforementioned ARHQ-R versions have already cut down the total number of items included (i.e., between 10 and 67), the entire process of how the various ARHQ-R versions have been developed has not been made publicly available including measures such as sensitivity and specificity. Moreover, the effectiveness of the ARHQ-R has not been demonstrated in comparison to the original ARHQ in terms of both predicting adults' but also children's reading abilities. Further, the ARHQ-R not only adopted items from the ARHQ, but also included new items without providing clear rationale for creating these additional items. Finally, the most frequently used items of the ARHQ-R focused on Early Childhood Experience without providing a strong rationale (e.g., Parrila et al., 2007). The goal of our study is to develop an abbreviated version of the 23-item ARHQ while maintaining accuracy in predicting parental reading history and their children's reading abilities. Since the diagnostic tests may not have been available for some adults during their childhood, rather than relying on reports of their prior formal diagnoses, we include their current reading performance as a proxy for the parental RD diagnosis, although this may lead to some false negatives due to possible remediation. Specifically, our study has three aims:

1. To construct an abbreviated version of the ARHQ questionnaire (i.e., ARHQ-brief) where items from the full version of the ARHQ are selected such that it is optimized for brevity while maintaining effectiveness.
2. To examine the association between this newly constructed ARHQ-brief questionnaire and adult reading performances, in comparison to the full ARHQ.
3. To examine the predictive ability of the ARHQ-brief on child reading abilities, including the children of these adults as well as in an independent sample for validation.

Methods

Participants and Measures

Training Set.—In the machine learning literature, training set refers to the data used to train the model to select items from ARHQ and estimate coefficient parameters during the learning process. Our training set consisted of both adults and children. Participants were recruited from the San Francisco Bay Area of the United States for a longitudinal NIH-funded research project on children's reading and neurological development from the beginning of kindergarten to the end of Grade 2. The participants included in the present retrospective analysis were native English-speaking children (29 boys and 22 girls) and their biological parents from 49 families. Parents included 97 adults (48 males and 49 females). This longitudinal project had three measurement occasions, and the present study only used the last one when the children were around Grade 2. Descriptive information of the training set is provided in Table 1. Four children were excluded because they did not complete any reading assessment at the last measurement occasion, which led to the size of child participants to become 47 (29 boys and 18 girls, ages of testing: $M = 8.253$ years, $SD = 0.435$ years). None of the children received a formal diagnosis of RD or reading intervention (for their RD), but 12 of them received certain reading-related in-class accommodation and/or after-school tutoring. Reading assessments were obtained from both adults and their children. All children in this sample were within the age range that standardized instruments had standard scores available. The rationale to use the last measurement occasion rather than earlier ones is to mimic the sample described in the recent literature where parents' reading history predicted children's reading abilities above and beyond cognitive and environmental factors (Esmaeeli et al., 2019). This sample were children two years after the beginning of formal reading instruction.

Several standardized instruments and their age normed scores were used to evaluate adult and child reading performances. Word reading abilities were measured by the Word Identification (WID-WRMT) and Word Attack (WA-WRMT) subtests of the Woodcock Reading Mastery Tests-Revised/Normative Update (WRMT-R/NU, Woodcock, 1998), as well as the TOWRE Sight Word Efficiency (SWE) and PDE subtests. These tests are both untimed (i.e., WID-WRMT and WA-WRMT) and timed (i.e., SWE and PDE), and examine the participant's ability to accurately read words and pseudowords. Reading comprehension abilities were assessed by the Passage Comprehension (PC) subtest of the WRMT-R/NU in which participants read a passage with missing words silently first, and then fill in blanks according to what the participant feel is most appropriate. In the present study, there were 81 adults and 47 children that had a complete set of reading measures. Since the adult participants were beyond the normalized age range of the TOWRE, we ran regression analyses between SWE and PDE raw scores and adult ages to partial out the age effect. Results indicated that neither one of them was statistically significantly predicted by age at testing within this age-range (both *p*-values > .05). Furthermore, we ran regression analyses on the WRMT-R/NU measures in adults and failed to find the age at testing as a significant predictor for WID-WRMT, WA-WRMT, and PC. Therefore, we used raw scores of reading measures for adults but standard scores for children to construct the ARHQ-brief and compared its predictive performances to the ARHQ.

The families in the training set were recruited from local newspapers, school mailings, flyers, and mother's clubs. All families in the study provided informed consent. Except for learning disabilities, these children did not have any neurological or psychiatric disorders, were not on medication, and had no contraindications to MRI. The recruitment of child participants was not on the basis of their reading and cognitive abilities. The ARHQ was delivered to parents as either a hard or digital copy and completed on their own. Reading assessments on children and parents were completed one-on-one by trained research assistants in the laboratory. Overall, among the 49 families, the present study included reading measures from 81 adults and 47 children, and ARHQ from 97 adults.

Test Set.—In order to validate the predictive ability of the shortened questionnaire, a sample of children with RD and their biological parents from another NIH-funded project was included. Test set refers to the independent data used to test the performance of ARHQ-brief constructed through the training phase, in predicting reading. There were 28 dyslexic children (20 boys and 8 girls) with English as their primary language, ages between 7.7 and 16.2 years old (*M* = 11.464 years, *SD* = 2.400 years), from 24 families, and 45 adults (22 males and 23 females) who were their biological parents and completed the full ARHQ. Over 90% of these children (26 out of 28) had prior experience on receiving some reading-related tutoring and/or attending a school specialized in learning differences. Only children completed reading assessments in this sample, including the Letter-Word Identification (WID-WJ) and Word Attack subtests of the Woodcock Johnson Test of Achievement-IV (age norm-referenced scores; Shrank, Mather, & McGrew IV, 2016), and the TOWRE SWE and PDE. We used standard scores for child reading. Descriptive information of this test set, including age is also given in Table 1. Information from the test set, including adults' ARHQ and child reading, is only used to validate the predictive abilities of the ARHQ-brief.

Data was retrieved from a study conducted by a separate laboratory at a university 40 miles away from the other dataset. The families were recruited into the project from local schools that specialize in serving students with learning disabilities. Each parent signed informed consent. Children were excluded from the project, if they were unable to complete MRI, had general intelligence estimates below the 9th percentile, or reported no history of reading difficulties and/or single word reading scores above the 25th percentile. The ARHQ was delivered to parents as either a hard or digital copy and completed on their own. Reading assessments were conducted one-on-one by research coordinators or trained graduate assistants, in one visit or over multiple sessions based on participants' availability. Because our research interest was related to the heritability of RD, children without biological parental ARHQ were excluded from the present study and the sample size ended up being 28 children.

Analytic Overview

Aim 1. Construction of the ARHQ-brief and Determination of Optimal Threshold.—

To address our first aim, we started with exploratory factor analysis (EFA) to uncover the underlying structure within the ARHQ items using adult ARHQ scores in the training set. We ran EFA using all 23 items and then repeated with 22 and 19 items respectively following Bjornsdottir et al. (2014) that used 22 of the 23 items, and Welcome and Meza (2019) that used 19 of the 23 items to examine the variation in the latent factor structure and the pattern of item loadings given the inclusion of different ARHQ items. EFA was conducted using maximum likelihood estimator with oblique rotation (Costello & Osborne, 2005). No missing values were found in the adult ARHQ scores. The Kaiser-Meyer-Oklin (KMO) test and Bartlett's Test of Sphericity (BTS) were used to evaluate the suitability and sample adequacy for EFA. The KMO value ranges from 0 to 1 and a value more than 0.7 suggests sufficient sampling adequacy. The BTS examines the hypothesis that variances are equal across groups or samples and thus a statistical significance from the BTS suggests that factor analyses should be performed. We evaluated the EFA models based on the eigenvalues, model convergence, and interpretability of latent factor structures. Items were identified as loaded on a certain latent factor if the loading was greater than 0.4 (DeVellis, 2012).

Based on the results of the EFA, a subset of the ARHQ items were selected as candidates to construct the ARHQ-brief. The rationale of this selection was related to the work of Welcome and Meza (2019), which suggested that the items loaded on the Childhood Reading Ability, Current Reading Attitude, and Spelling Skill factors from the ARHQ were sufficient to construct a shortened version of the ARHQ with equal effectiveness to identify current adult poor reading abilities. With evidence that parametric statistics could be applied to ordinal Likert scores (Norman, 2010), scores of each ARHQ item were first standardized. We then used the least absolute shrinkage and selection operator (lasso, Tibshirani, 1996) technique in a machine learning approach to identify which items were critical predictors to the reading composite scores of adults and children. As one of the penalized partial likelihood methods, lasso has a penalty function on the sum of absolute regression coefficients, which shrinks regression coefficients by the same amount, and thus performs better by consistently selecting meaningful variables, filtering out noise variables, and achieving a sparse regression model. Lasso has been suggested as a superior alternative to traditional predictor selection methods, such as stepwise, forward selection, and backward elimination, to avoid overfitting and determine the coefficients (McNeish, 2015; Zhao & Yu, 2006). This method is applicable when the ratio between the sample size and the number of candidate predictors tends to be small (Finch, 2014). In addition, given the small sample, we used leave-one-out cross-validation (LOO-CV) to select the penalty parameter within one standard error of the minimum value (Friedman, Gastie, & Tibshirani, 2010; McNeish, 2015). Given LOO-CV, the sample with N participants is split into two parts: one with N-1 participants to estimate a model, and the other with only one participant to validate the learning algorithm. The process repeats N times and the average error is computed to evaluate the model. In the context of variable selection in our study, the model is selected when the prediction error is the smallest. With our small training set, LOO-CV enables us to evaluate the model with independent data not used in the training set to create the model (de Rooij & Weeda, 2020). Unlike traditional selection methods which heavily rely on p values, meaningful predictors are selected regardless of whether the effect is statistically significantly different from zero. In other words, when running a regression using predictors selected by lasso, it would be possible to find the p-values of certain predictors to be above an α level of 0.05. Finally, we relaxed lasso for interpretation and used standardized regression coefficients to show the predictive effects of the selected ARHQ items, which were found to be meaningful by lasso regressions.

After the ARHQ-brief was constructed, we identified the threshold using receiver operating characteristic (ROC) curve analysis with LOO-CV. Since a formal diagnosis of dyslexia was uncommon in this adult cohort, we identified poor adult readers based on either TOWRE PDE standard scores below 90 (n = 29, see Achal, Hoeft, & Bray, 2016 and Black et al., 2012) or self-reported prior formal diagnoses of dyslexia in childhood (n = 6). The mean comparisons between typical and poor adult readers on ARHQ and reading scores are provided in the appendix (see Table 6). We generated a binary dependent proxy to identify poor readers. The optimal threshold was determined by maximizing the Youden index (Youden, 1950) which balances the tradeoff between sensitivity and specificity. We compared how accurately the ARHQ-brief threshold identified poor readers with the ARHQ threshold used in previous literature. Given the variation of recommended ARHQ thresholds that have been used in research, the comparison was conducted with the ARHQ thresholds at both 0.3 and 0.4.

Aims 2 & 3: Association between the ARHQ-brief and reading abilities in adults, and children's reading ability.—In order to achieve the last two aims, we conducted a series of regression analyses in the training set using LOO-CV to identify how well the ARHQ-brief could explain the variance of their own (adult) and their children's reading abilities in the training set. We also compared its predictive performance to that of the ARHQ. In addition, to validate the predictive ability of the ARHQ-brief, we included a test set with child reading and ran regression analysis after controlling for the children's ages, since children in this sample encompassed a broad age range, between early childhood and adolescence. In both samples, we included scores of each reading measure and a composite score by extracting the factor score from factor analysis on all reading measures.

Results

In the training set, the ARHQ scores of 97 adults ranged between 0.065 and 0.783 and the overall internal consistency of the 23-item ARHQ was 0.881. In the test set, the range of ARHQ scores of 45 adults was between 0.087 and 0.804, with Cronbach's alpha at 0.910. Details of descriptive statistics and item-level alpha for each item are given in Table 2. Both samples suggested the ARHQ has high internal consistency.

Aim 1: Construction of the ARHQ-brief and Determination of Optimal Threshold

Exploratory Factor Analysis.—We first ran EFA with all 23 ARHQ items in the training set. We examined model solutions with increasing numbers of factors, ranging from one to six. In our sample, models failed to converge when four or more latent factors were configured. The three-factor model was selected after considering model convergence along with the scree plot of eigenvalues. The KMO value was 0.821 and the BTS yielded statistical significance (χ^2 (253) = 1325.71, $p < .001$). All three factors achieved eigenvalues above 1 and together explained 54% of the total variance. We found that each of the 23 items loaded uniquely (>0.4) on one of the three latent factors, except four items (i.e., Items 12, 21, 22, and 23) whose loadings were below 0.4 for all three factors. We further examined the factor structure and item loading pattern after these four items with inadequate loadings were excluded (KMO = 0.855; BTS χ^2 (171) = 1205.91, $p < .001$) and the three-factor model converged well without much change on the item loading pattern. Following the naming conventions by Bjornsdottir et al. (2014), we referred to the three factors as Dyslexic Symptoms, Current Reading, and Working Memory (see Table 3).

Next, we ran EFA with two subsets of the ARHQ items based on the studies of Bjornsdottir et al. (2014) and Welcome and Meza (2019), which had 22 and 19 items in their factor analyses, respectively. Using the present sample, EFA showed satisfactory performance for both subsets. Following Bjornsdottir et al. (2014), the KMO was 0.817 and the BTS was statistically significant (χ^2 (231) = 1285.492, $p < .001$) using 22 items (i.e., Item 15 was excluded). Moreover, KMO was 0.811 along with significant BTS (χ^2 (171) = 1170.195, $p < .001$) when we included 19 items (i.e., Items 1, 8, 12, and 15 were excluded) as Welcome and Meza (2019) did. Similarly, the three-factor models converged and were preferred. The item loadings for each EFA attempt are provided in Table 3. Given that the variation of item subsets did not alter the item loading patterns, we proceeded to select candidates of the ARHQ-brief based on the EFA results using the full 23 items from the ARHQ.

The three factors (i.e., Childhood Reading Ability, Current Reading Attitude, and Spelling Skill factors) recommended by Welcome and Meza (2019) included 11 items with loadings above 0.4 on at least one of the factors. All these items loaded on the first two factors in our EFA results (i.e., Dyslexic Symptoms and Current Reading). In addition, in these two factors, five additional items were included (i.e., Items 1, 4, 8, 15, and 19). Three of the five were excluded by Welcome and Meza (2019) and the other two loaded on the Reversal factor in their study. In order to achieve a full coverage of all the items proposed by the work of Welcome and Meza (2019), we decided to include all 16 items that loaded on our first two factors as candidates of ARHQ-brief. The internal consistency reliability of this subset of ARHQ was 0.913.

Selection by Lasso Regression.—To determine which of these 16 items within the subset should be selected to construct ARHQ-brief, we conducted lasso regressions using adult and child reading composite scores as dependent variables. Composite reading scores for adults and children were constructed based on all of their reading measures, including WRMT-R/NU WID, WA and PC, and TOWRE SWE and PDE subtests. EFA results indicated that the one-factor models fit both adult (KMO = 0.79; BTS χ^2 (10) = 184.799,

$p < .001$) and child reading (KMO = 0.84; BTS χ^2 (10) = 205.332, $p < .001$). The factor scores were preserved as adult and child reading composites to perform lasso regression.

Regression coefficient estimates of adult and child reading are given in Table 4. We first selected the items using adult reading as a dependent variable. The estimated penalty parameter was 0.253 and lasso suggested four items (i.e., Items 2, 4, 5, and 14) as meaningful predictors. The items were: Item 2 “How much difficulty did you have learning to read in elementary school”, Item 4 “Did you ever reverse the order of letters or numbers when you were a child”, Item 5 “Did you have difficulty learning letter and/color names when you were a child”, and Item 14 “How would you compare your current spelling to that of others of the same age and education”. In total, these four items explained 51.2% of the variance of adult reading composite (adjusted R^2 = 48.6%). The standardized coefficients suggested that: if the score of Item 2 increases one standard deviation (SD) unit, the adult reading composite decreases 0.308 SD; if the score of Item 4 increases one SD unit, the adult reading composite decreases 0.150 SD; if the score of Item 5 increases one SD unit, the adult reading composite decreases 0.179 SD; and if the score of Item 13 increases one SD unit, the adult reading composite decreases 0.251 SD. All of these four items indicated negative impacts on adult reading, which is consistent with the scale of the ARHQ in which adults with a higher ARHQ score have an increased likelihood of reading difficulties.

Next, we included child reading scores to select ARHQ items through lasso. Since we had ARHQ scores from both parents for almost all children (except for one whose father’s ARHQ score was not available), we used the average of the parents’ ARHQ scores as a proxy of family reading indicators (see Bonifacci et al., 2014). We tested how the average of the 16 ARHQ items contributed to children’s reading composite. When child reading was used as a dependent variable, the estimated penalty parameter was 0.254 and three items (i.e., Items 2, 7, and 8) were selected by lasso as meaningful predictors. The items were: Item 2 “How much difficulty did you have learning to read in elementary school”, Item 7 “All students struggle from time to time in school, in comparison to others in your classes, how much did you struggle to complete your work”, and Item 8 “Did you experience difficulty in high school or college English classes”. In total, these three items explained 43.7% of the variance of child reading composite (adjusted R^2 = 39.8%). The standardized coefficients suggested that: if the score of Item 2 increases one SD unit, the child reading composite decreases 0.357 SD; if the score of Item 7 increases one SD unit, the child reading composite decreases 0.227 SD; and if the score of Item 8 increases one SD unit, the child reading composite decreases 0.201 SD. All three items indicated negative impacts on child reading meaning that children are more likely to struggle with poor reading when their parents show an increasing likelihood of having reading difficulty themselves.

After selecting items using adult and child reading scores as dependent variables, six items were retained to construct the ARHQ-brief. The six items were Items 2, 4, 5, 7, 8, and 14, each of which exhibited predictive contributions to the reading performances of adults and children and were negative with different magnitudes. The internal consistency reliability of the ARHQ-brief items was 0.850 and exceeded the recommended 0.8 limit (DeVellis, 2012). We also examined the item-level mean differences between typical and poor readers on the six selected items (in Appendix, see Table 7), and the results indicate that typical and poor readers were statistically significant different on these item scores.

ROC Curve and Sensitivity/Specificity.—Similar to the approach used for the original ARHQ, we used the six selected items to calculate ARHQ-brief scores for each participant by adding the total scores for the six items and dividing by the maximum possible score of 24. Among the 97 adults, the range of the ARHQ-brief was 0 to 0.938 with mean 0.274 (*SD* = 0.207). After excluding those without a PDE raw score, we had 83 adults included in this analysis, of which 29 were recognized as poor readers.

The ROC curve indicated that the 6-item ARHQ-brief performed well on differentiating poor readers from typical readers (see Figure 1). The area under the curve was 83.6% (95% confidence interval = [73.7%, 93.5%]). The optimal threshold was 0.323 with sensitivity 72.4% and specificity 81.5%. Using this threshold, 78.3% of adult participants were correctly classified in our sample, among which 81.5% of typical readers and 72.4% of poor readers were correctly classified. We compared the accuracy of the classification using the ARHQ-brief with that of the 23-item ARHQ. Given the internal dependency, the ARHQ-brief and the full ARHQ scores were highly correlated ($r = 0.906$, $p < .001$). Using the recommended threshold of 0.3 for the full ARHQ (Pennington & Lefly, 2001), the performance of the full ARHQ was poor. Only 57.8% of adult participants were correctly identified, of which 48.1% of typical readers and 75.9% of poor readers were correctly identified. Instead, using the other recommended threshold of 0.4 (Lefly &Pennington, 2000), the full ARHQ identified 80.7% of adult participants correctly, with 90.7% of typical readers and 62.1% of poor readers correctly classified. These results suggested that in the present sample, the ARHQ-brief was effective in accurately identifying the likelihood of adults with reading difficulty and its performance was competitive with that of the full ARHQ. That is, compared to using 0.3 as the ARHQ threshold, the ARHQ-brief accurately classified almost an additional 20% of participants in total. Meanwhile, compared to using 0.4 as the ARHQ threshold, the ARHQ-brief identified more than an additional 10% of poor readers accurately, although the ratio of correct classification of the total sample was 2.4% less.

Aim 2: Associations between the ARHQ-brief and Adults' Reading Performances

We evaluated the contribution of ARHQ-brief to adult reading using the LOO-CV method. Results are provided in Table 5. The ARHQ-brief scores were moderately and negatively correlated with adult reading measures (*r*s ranging between −0.402 and −0.707). In the present sample, the ARHQ-brief explained 50.5% of the variance of the reading composite (adjusted R^2 = 49.3%) and 16.3% to 44.2% of the variance of each reading test (adjusted R^2 ranging from 15.3% to 43.5%). More specifically, the ARHQ-brief explained more variances of the subtests on word reading rather than the comprehension-related subtest among adults. In contrast, the ARHQ explained 35.6% of the variance of the reading composite (adjusted R^2 = 34.7%) and 10.5% to 30.5% of the variance of each reading test (adjusted R^2 ranging from 9.4% to 29.7%), which were lower than what the ARHQ-brief achieved in general.

Aim 3: Predicting Children's Reading Performances using the ARHQ-brief

Given the heritability of reading disorder and prior research on family history predicting children's reading outcome, we examined whether the ARHQ-brief predicted the reading skill of children. In the training set, the average score of the ARHQ-brief per family was moderately and negatively correlated with child reading measures (*r*s ranged between −0.443 and −0.566). When children were in Grade 2, the ARHQ-brief explained 31.1% of the variance of the reading composite (adjusted R^2 = 29.5%) and between 19.7% and 32.0% of the variance of each reading test (adjusted R^2 ranging from 17.9% to 30.5%). On the other hand, the ARHQ explained 20.0% of the variance of the reading composite (adjusted R^2 = 18.2%) and between 10.7% and 21.7% of the variance of each reading test (adjusted R^2 ranging from 8.7% to 19.9%), which did not outperform the ARHQ-brief.

In the test set, the family-level ARHQ-brief average showed a low to moderate and negative correlation with reading scores (*r*s ranged between −0.292 and −0.513). The ARHQ-brief was a significant predictor of the reading composite measure, Word Attack, and PDE at the α = 0.05 level, whereas WID-WJ and SWE approached significance (α_{WID-WJ} = 0.059, α_{SWE} = 0.056, both approaching to 0.05 and < 0.1). Along with age, the ARHQ-brief explained 30.7% of the variance of the reading composite (adjusted R^2 = 23.4%) and between 16.9% and 30.7% of the variance of each reading test (adjusted R^2 ranging from 9.0% to 24.4%). However, the ARHQ only significantly predicted children's PDE scores (R^2 = 25.4%, adjusted R^2 = 18.6%). Overall, results from both samples indicated that the ARHQ-brief worked as a reliable indicator of child reading ability and explained 8.5% more variance than the ARHQ on average.

Discussion

In the present study, we aimed to construct the ARHQ-brief from a subset of the ARHQ items to be an equally effective but more efficient alternative to the original ARHQ in identifying reading difficulty. Consistent with previous research on the ARHQ (e.g., Welcome & Meza, 2019) and ARHQ-R (e.g., Kirby et al., 2008; Parrila et al., 2007), we identified items that asked about adult dyslexic symptoms and current reading as candidates for a shortened questionnaire. Using a machine learning approach, the resultant ARHQ-brief included six items (i.e., Items 2, 4, 5, 7, 8, and 14, see Table 4 for the actual questions). These items were related to childhood reading, reversal, and spelling skills, factors also described to be important by Welcome and Meza (2019). The inclusion of the item related to spelling is consistent with findings from previous research, that spelling difficulty could be more severe and persistent than that of reading among adults with RD (Maughan et al., 2009). In our sample, using the ARHQ-brief with the threshold of 0.323was able to accurately classify the RD status for 78.3% of adult participants. More specifically, 72.4% of poor readers were correctly identified with ARHQ-brief. Compared to ARHQ, the ARHQ-brief showed a competitive rate of accurately screening adult readers based on their reading abilities, without sacrificing the sensitivity. In addition, ARHQ-brief was found to significantly predict reading performances in both adults and their children and explained more variance in reading measures than the original ARHQ.

We examined the factor structure underlying the 23 items from the full ARHQ, and found three latent factors using our sample, including Dyslexic Symptoms, Current Reading, and Working Memory. The results are consistent with Bjornsdottir et al. (2014), although the proportion of poor readers in our sample was closer to that of Welcome and Meza (2019). The factor Dyslexic Symptoms included all the items from a similar factor in the study by Bjornsdottir et al. (2014), except that in our study, Item 11 loaded on Current Reading rather than Dyslexic Symptoms. This item asks adults to self-evaluate their current reading speed, which conceptually could be related to both latent factors. Bjornsdottir et al. (2014) suggested that Item 11 did not reach an adequate factor loading of 0.4 on the Current Reading factor; however, it should be noted that for this item, the estimate of this specific factor loading was also approaching the threshold (i.e., loading = 0.398). Another difference between our work and Bjornsdottir et al. (2014) is that we dropped the three items that are related to media use from the factor structure since the factor loadings were all below 0.4. Instead, Bjornsdottir et al. (2014) summarized these three items to be loaded on the factor of current reading, although they acknowledged that their loadings were inadequate, ranging from 0.298 to 0.318. Considering the characteristics of our sample, these items had relatively higher mean scores than other items, which differs from Bjornsdottir et al. (2014) but is similar to Welcome and Meza (2019). Therefore, it is very likely that these media use items would be grouped as an additional latent factor as in the study by Welcome and Meza (2019). However, the result that these three items failed to load as an additional factor in the present study could be due to the limitation of our relatively small sample size, since the factor structure could only converge up to three factors identified. Finally, the Working Memory factor was the only one that was identical across these three studies, including ours. Three items were consistently grouped and distinguished from all other items regardless of the specification of factor structure.

One of our major aims was to construct a shortened questionnaire with equal effectiveness as the full 23-item ARHQ to test to the hypothesis by Welcome and Meza (2019) that not all the ARHQ items equally and significantly contributed to screening poor adult readers and a selection of them could remain powerful. Based on our sample, we suggested the 6-item ARHQ-brief as an alternative to the 23-item ARHQ. We found four items (i.e., Items 2, 4, 5, and 14) as meaningful predictors of adult reading composite. In both Bjornsdottir et al. (2014) and Welcome and Meza (2019), these four items consistently came from a similar latent factor which concerned indicators of RD, except that in the latter paper, Item 4 simultaneously and heavily loaded on the factor Reversal while Item 14 loaded on the factor Spelling. However, Welcome and Meza (2019) reported significant and positive relationships in the Reversal, Spelling, and Childhood Reading factors and suggested that these three factors overlapped with the factor Dyslexic Symptoms factor in the study by Bjornsdottir et al. (2014). Our results were concordant with these previous studies since the four items loaded on one single latent factor. Considering the heritability of reading difficulty and the importance of family history in predicting children’s reading outcome, we also included child reading composites as a dependent variable and examined whether the selection of items would vary. This selected Item 2 along with two additional items (i.e., Items 7 and 8) as meaningful predictors. Despite Item 8 having been excluded from Welcome and Meza (2019), the other two items were consistently related to the factor of early indicators of RD in both papers. Our findings suggest that items that are correlated to and predictive of both parents' current and their children's reading performances share common characteristics, and are primarily associated with the adults' childhood reading. These findings are consistent with research that show the persistence of reading difficulty (Blachman et al., 2014; Scarborough, 1984). It is also consistent with evidence that RD is a moderately heritable complex trait (Peterson & Pennington, 2015). The 6-item ARHQ-brief is shorter than previous revisions of the AHRQ, which have varied in length between 10 and 67 items (e.g., McGonnell et al., 2007; Parrila et al., 2003; Parrila et al., 2007).

After we constructed the ARHQ-brief, we examined its threshold, sensitivity, and specificity. The Icelandic version of the ARHQ used by Bjornsdottir et al. (2014) was related to but different from the 23-item ARHQ in that its threshold was 0.43 rather than the commonly used 0.3 or 0.4. Welcome and Meza (2019) used the original 23-item ARHQ and set the threshold as 0.4 based on the first study by Lefly and Pennington (2000). In comparison, we identified the threshold of the ARHQ-brief as 0.323. Both this threshold along with the versions of the ARHQ-R (e.g., Deacon et al., 2012) were below 0.4, but were still within the range of the ARHQ thresholds (i.e., either 0.3 or 0.4) that are commonly used. In fact, in our sample, ARHQ-brief had better performance than ARHQ did in identifying adults who were likely poor readers. The sensitivity was 72.4% and the specificity was 81.5%, which met the criteria of at least 70 to 80% for instruments to screen developmental disorders (Glascoe, 2005).

The scores of our ARHQ-brief were statistically significantly correlated with both adult and child reading measures in the training set, but to only some of the measures in the test set. This may be explained in part by the narrow age-range (7.51 to 9.75 years) in the training set, and large variation in the children's ages (7.7 to 17.1 years) in the test set. Since the ARHQ-brief was highly interrelated with the ARHQ, the comparison of their predictive abilities was based on how much variance was explained rather than including the two simultaneously in one regression model. Overall, we found that for both adults and children in the training and test sets, more variance was explained by ARHQ-brief than by ARHQ. The finding that parental ARHQ-brief scores were associated with their children's reading was consistent with past research that compared reading performances of children who were from families with or without reading difficulty (Conlon et al., 2006). Therefore, we conclude that ARHQ-brief was effective in predicting adult and child reading abilities.

Our study has several limitations. First, due to convenience sampling, our training set was composed of adults in their 40s that live in the Bay area and represent a relatively well-educated group with over 16 years of education on average and moderately high socioeconomic status. As a consequence, our results could have limited generalizability given the specific characteristics of the sample and may vary in a different demographic group. Second, the small sample size in the present study leads to some concerns. Particularly, it should be acknowledged that our factor analysis did not provide optimal results and failed to converge with more than three latent factors. Although we compared the factor structure with previous work for justification, the results should still be interpreted with caution, and are likely to improve in a future replication with a large sample. In addition, we constructed and tested the ARHQ-brief using the same sample. To avoid "double dipping" in the training set, we performed LOO-CV throughout the entire analytic procedure, including item selection, discriminant analysis, and regression. Although we validated the predictive abilities of the ARHQ-brief using a completely independent sample that was untouched in the construction phase, future studies are warranted using larger samples from diverse geographic, demographic, and educational backgrounds for training and test sets so that the developed measure can be more generalizable and the strength of machine learning methods could be better discovered and deployed. Third, in the present study, we treated the Likert scores of the ARHQ items as approximately continuous given how an ARHQ score is produced and implemented. Advanced methods considering the features of ordinal data could be utilized to improve the selection of a subset of meaningful items. Fourth, because ARHQ and ARHQ-brief are self-reported questionnaires, there is potential for self-report bias that is reported in the literature (Donaldson & Grant-Vallone, 2002), which was difficult to control for in our study. Finally, since the goal was to compare the predictive power of ARHQ-brief and ARHQ, we mainly relied on the questionnaire scores to predict adults and child reading performances. Including additional predictors, especially reading-related measures, could compress the significant contribution from the questionnaires (Conlon et al., 2006), but may increase the overall predictive value of a multivariate approach to predict reading outcomes. Having a broader set of external measures such as socioeconomic status and reading motivation from children would be of interest in examining the predictive ability of the parental ARHQ.

Conclusions

While there are various versions of the ARHQ that have been developed or revised over the past two decades, our study is the first to present the construction of a shortened ARHQ (i.e., ARHQ-brief), and examine its comparative effectiveness to the full 23-item ARHQ. The 16 items that were initially identified as candidates through exploring the factor structure of the original 23 items were those related to Dyslexic Symptoms and Current Reading. Using adult and child reading composites as dependent variables, we selected six items in total to construct the ARHQ-brief and determined the optimal threshold to be 0.323. The ARHQ-brief achieved a sensitivity of 72.4% and a specificity of 81.5%. We found the ARHQ-brief scores were statistically significantly associated with adult and child reading abilities, and outperformed the full 23-item ARHQ by explaining more variance of each reading measure in our sample. Future studies are warranted to replicate our findings in larger and more diverse populations.

The present study tested the hypotheses in Welcome and Meza (2019) that a subset of the ARHQ was sufficiently effective, and developed the ARHQ-brief. The ARHQ-brief demonstrated its utility by adequately screening poor adult readers and predicting child reading outcomes. Our study has practical utility in that we provide educators and researchers with the ARHQ-brief, a helpful research and clinical tool when adults without formal RD diagnoses need a quick screening for poor reading abilities and get motivated to receive neuropsychological assessments and following services. This questionnaire could be favored in large-scale studies when instruments should be robust and brief. In addition, this self-report instrument would contribute to identifying children who are more likely to be at risk for RD and thus in need of early intervention in a prompt but reliable manner, especially for those who are unable to be diagnosed before receiving formal literacy instruction (Peterson & Pennington, 2015).

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgement

The research was supported by funding from Eunice Kennedy Shriver National Institute of Child Health and Human Development (NICHD) K23HD054720, University of California Office of the President UCOP MRP-17-454926, UCSF Dyslexia Center, and Ray & Lori dePole. Author F.H. was additionally funded by NICHD R01HD094834, R01HD086168, R01HD096261, R01HD078351, P50HD052120 (PI: R. Wagner), R01HD044073 (PI: L. Cutting), R01HD092498 (PI: I. Kovelman), R37HD090153 (PI: K. Pugh) and supporters such as Gallaudet University, Decoding Dyslexia Utah, Rosenfeld/Kathleen G, and Lori and Ray DePole. Additionally, author R.H. was funded by NICHD R01HD094834, and author M.B.G. was also funded by NICHD U01MH113390. Z.A.M was funded by NIA AG048291. M.L.G.T. was funded by NIDCD DC015544.

References

Achal S, Hoeft F, & Bray S (2016). Individual differences in adult reading are associated with left temporo-parietal to dorsal striatal functional connectivity. Cerebral Cortex, 26, 4069–4081. 10.1093/cercor/bhv214 [PubMed: 26400921]

Al Dahhan N, Georgiou GK, Hung R, Munoz D, Parrila R, & Kirby JR (2014). Eye movements of university students with and without reading difficulties during naming speed tasks. Annals of Dyslexia, 64(2), 137–150. 10.1007/s11881-013-0090-z [PubMed: 24723032]

Alves RA, & Castro SL (2005). Despistagem da dislexia em adultos através do Questionário História de Leitura [Screening of dyslexia in adults through the adult reading history questionnaire]. IberPsicologia: Anales de la Revista de Psicologia General y Aplicada, 10(8.9).

American Psychiatric Association. (2013). Diagnostic and statistical manual of mental disorders (5th ed.).

Andreola C, Mascheretti S, Belotti R, Ogliari A, Marino C, Battaglia M, & Scaini S (2021). The heritability of reading and reading-related neurocognitive components: A multi-level meta-analysis. Neuroscience and Biobehavioral Reviews, 121, 175–200. 10.1016/j.neubiorev.2020.11.016 [PubMed: 33246020]

Bach S, Richardson U, Brandeis D, Martin E, & Brem S (2013). Print-specific multimodal brain activation in kindergarten improves prediction of reading skills in second grade. Neuroimage, 82, 605–615. 10.1016/j.neuroimage.2013.05.062 [PubMed: 23727320]

Bergey BW, Deacon SH, & Parrila RK (2017). Metacognitive reading and study strategies and academic achievement of university students with and without a history of reading difficulties. Journal of Learning Disabilities, 50, 81–94. 10.1177/0022219415597020 [PubMed: 26229067]

Bergey BW, Parrila RK, & Deacon SH (2018). Understanding the academic motivations of students with a history of reading difficulty: An expectancy-value-cost approach. Learning and Individual Differences, 67, 41–52. 10.1016/j.lindif.2018.06.008

Berninger VW, Richards TL, & Abbott RD (2015). Differential diagnosis of dysgraphia, dyslexia, and OWL LD: Behavioral and neuroimaging evidence. Reading and Writing: An Interdisciplinary Journal, 28, 1119–1153. 10.1007/s11145-015-9565-0

Bjornsdottir G, Halldorsson JG, Steinberg S, Hansdottir I, Kristjansson K, Stefansson H, & Stefansson K (2014). The adult reading history questionnaire (ARHQ) in Icelandic: Psychometric properties and factor structure. Journal of Learning Disabilities, 47, 532–542. 10.1177/0022219413478662 [PubMed: 23456983]

Blachman BA, Schatschneider C, Fletcher JM, Murray MS, Munger KA, & Vaughn MG (2014). Intensive reading remediation in grade 2 or 3: Are there effects a decade later? Journal of Educational Psychology, 106, 46–57. 10.1037/a0033663 [PubMed: 24578581]

Black JM, Tanaka H, Stanley L, Nagamine M, Zakerani N, Thurston A, … & Hoeft F (2012). Maternal history of reading difficulty is associated with reduced language-related gray matter in beginning readers. Neuroimage, 59, 3021–3032. 10.1016/j.neuroimage.2011.10.024 [PubMed: 22023744]

Bonifacci P, Montuschi M, Lami L, & Snowling MJ (2014). Parents of children with dyslexia: Cognitive, emotional and behavioral profile. Dyslexia, 20, 175–190. 10.1002/dys.1469 [PubMed: 24265066]

Bonifacci P, Storti M, Tobia V, & Suardi A (2016). Specific learning disorders: A look inside children's and parents' psychological well-being and relationships. Journal of Learning Disabilities, 49, 532–545. 10.1177/0022219414566681 [PubMed: 25609675]

Chevalier TM, Parrila R, Ritchie KC, & Deacon SH (2017). The role of metacognitive reading strategies, metacognitive study and learning strategies, and behavioral study and learning strategies in predicting academic success in students with and without a history of reading difficulties. Journal of Learning Disabilities, 50, 34–48. 10.1177/0022219415588850 [PubMed: 26025926]

Conlon EG, Zimmer-Gembeck MJ, Creed PA, & Tucker M (2006). Family history, self-perceptions, attitudes and cognitive abilities are associated with early adolescent reading skills. Journal of Research in Reading, 29, 11–32. 10.1111/j.1467-9817.2006.00290.x

Costello AB, & Osborne JW (2005). Best practices in exploratory factor analysis: Four recommendations for getting the most from your analysis. Practical Assessment Research & Evaluation, 10, 1–9. 10.4135/9781412995627.d8

de Rooij M, & Weeda M (2020). Cross-validation: A method every psychologist should know. Advances in Methods and Practices in Psychological Science, 3, 248–263. 10.1177/2515245919898466

Deacon SH, Cook K, & Parrila R (2012). Identifying high-functioning dyslexics: is self-report of early reading problems enough? Annals of Dyslexia, 62, 120–134. 10.1007/s11881-012-0068-2 [PubMed: 22446966]

Deacon SH, Tucker R, Bergey BW, Laroche A, & Parrila R (2017). Personalized outreach to university students with a history of reading difficulties: Early screening and outreach to support academically at-risk students. Journal of College Student Development, 58, 432–450. 10.1353/csd.2017.0032

DeVellis RF (2012). Scale development: Theory and applications (3rd ed.). Thousand Oaks, CA: Sage.

Donaldson SI, & Grant-Vallone EJ (2002). Understanding self-report bias in organizational behavior research. Journal of Business and Psychology, 17(2), 245–260. 10.1023/A:1019637632584

Esmaeeli Z, Kyle FE, & Ludetræ K (2019). Contribution of family risk, emergent literacy and environmental protective factors in children's reading difficulties at the end of second-grade. Reading and Writing: An Interdisciplinary Journal, Advance Published Online. 10.1007/s11145-019-09948-5

Finch H (2014). A comparison of methods for group prediction with high dimensional data. Journal of Modern Applied Statistical Methods, 13, 84–105. 10.22237/jmasm/1414814640

Finucci JM, Isaacs SD, Whitehouse CC, & Childs B (1982). Empirical validation of reading and spelling quotients. Developmental Medicine and Child Neurology, 24, 733–744. 10.1111/j.1469-8749.1982.tb13695.x [PubMed: 7152140]

Fostick L, & Revah H (2018). Dyslexia as a multi-deficit disorder: Working memory and auditory temporal processing. Acta psychologica, 183, 19–28. 10.1016/j.actpsy.2017.12.010 [PubMed: 29304447]

Friedman J, Hastie T, & Tibshirani R (2010). Regularization paths for generalized linear models via coordinate descent. Journal of Statistical Software, 33, 1–22. 10.18637/jss.v033.i01 [PubMed: 20808728]

Giménez A, Luque JL, López-Zamora M, & Fernández-Navas M (2015). A self-report of reading disabilities for adults: ATLAS. Anales de pasicología, 31, 109–119. 10.6018/analesps.31.1.166671

Glascoe FP (2005). Screening for developmental and behavioral problems. Mental Retardation and Developmental Disabilities Research Reviews, 11(3), 173–179. 10.1002/mrdd.20068 [PubMed: 16161092]

Hatcher J, Snowling MJ, & Griffiths YM (2002). Cognitive assessment of dyslexic students in higher education. British Journal of Educational Psychology, 72, 119–133. 10.1348/000709902158801 [PubMed: 11916468]

Jackson NE, & Doellinger HL (2002). Resilient readers? University students who are poor recoders but sometimes good text comprehenders. Journal of Educational Psychology, 94, 64–78. 10.1037/0022-0663.94.1.64

Kirby JR, Silvestri R, Allingham BH, Parrila R, & La Fave CB (2008). Learning strategies and study approaches of postsecondary students with dyslexia. Journal of Learning Disabilities, 41, 85–96. 10.1177/0022219407311040 [PubMed: 18274505]

Lefly DL, & Pennington BF (2000). Reliability and validity of the Adult Reading History Questionnaire. Journal of Learning Disabilities, 33, 286–296. 10.1177/002221940003300306 [PubMed: 15505966]

Leinonen S, Müller K, Leppänen PH, Aro M, Ahonen T, & Lyytinen H (2001). Heterogeneity in adult dyslexic readers: Relating processing skills to the speed and accuracy of oral text reading. Reading and Writing: An Interdisciplinary Journal, 14(3–4), 265–296. 10.1023/A:1011117620895

Logan JA, Hart SA, Cutting L, Deater-Deckard K, Schatschneider C, & Petrill S (2013). Reading development in young children: Genetic and environmental influences. Child Development, 84, 2131–2144. 10.1111/cdev.12104 [PubMed: 23574275]

Lyon GR, Shaywitz SE, & Shaywitz BA (2003). A definition of dyslexia. Annals of Dyslexia, 53, 1–14. 10.1007/s11881-003-0001-9

Maughan B, Messer J, Collishaw S, Snowling MJ, Yule W, & Rutter M (2009). Persistence of literacy problems: Spelling in adolescence and at mid-life. Journal of Child Psychology & Psychiatry, 50, 893–901. 10.1111/j.1469-7610.2009.02079.x. [PubMed: 19490310]

McGonnell M, Parrila R, & Deacon H (2007). The recruitment and description of university students who self-report difficulty acquiring early reading skills. Exceptionality Education International, 17, 155–174. 10.5206/eei.v17i2.7602

McNeish DM (2015). Using lasso for predictor selection and to assuage overfitting: A method long overlooked in behavioral sciences. Multivariate Behavioral Research, 50, 471–484. 10.1080/00273171.2015.1036965 [PubMed: 26610247]

Metsala JL, Parrila R, Conrad NJ, & Deacon SH (2019). Morphological awareness and reading achievement in university students. Applied Psycholinguistics, 40, 743–763. 10.1017/S0142716418000826

Mourgues CV, Preiss DD, & Grigorenko EL (2014). Reading skills, creativity, and insight: Exploring the connections. The Spanish Journal of Psychology, 17, 1–10. 10.1017/sjp.2014.59

Nergård-Nilssen T, & Hulme C (2014). Developmental dyslexia in adults: Behavioural manifestations and cognitive correlates. Dyslexia, 20(3), 191–207. 10.1002/dys.1477 [PubMed: 24842581]

Norman G (2010). Likert scales, levels of measurement and the “laws” of statistics. Advances in Health Sciences Education, 15(5), 625–632. 10.1007/s10459-010-9222-y [PubMed: 20146096]

Olson RK (2002). Dyslexia: Nature and nurture. Dyslexia, 8(3), 143–159. 10.1002/dys.228 [PubMed: 12222731]

Parrila R, Corkett J, Kirby J, & Hein S (2003). Adult Reading History Questionnaire-Revised. Unpublished questionnaire. University of Alberta.

Parrila R, Georgiou G, & Corkett J (2007). University students with a significant history of reading difficulties: What is and is not compensated? Exceptionality Education International, 17, 195–220. 10.1037/t52486-000

Pennington BF, & Lefly DL (2001). Early reading development in children at family risk for dyslexia. Child Development, 72, 816–833. 10.1111/1467-8624.00317 [PubMed: 11405584]

Scarborough HS (1984). Continuity between childhood dyslexia and adult reading. British Journal of Psychology, 75, 329–348. 10.1111/j.2044-8295.1984.tb01904.x [PubMed: 6487925]

Schneps MH, Brockmole JR, Sonnert G, & Pomplun M (2012). History of reading struggles linked to enhanced learning in low spatial frequency scenes. PLoS One, 7(4), e35724. 10.1371/journal.pone.0035724 [PubMed: 22558210]

Shaywitz SE (1998). Dyslexia. New England Journal of Medicine, 338(5), 307–312. 10.1056/NEJM199801293380507 [PubMed: 9445412]

Shrank FA, Mather N, & McGrew K IV (2016). The Woodcock–Johnson IV.

Smith-Spark JH, & Fisk JE (2007). Working memory functioning in developmental dyslexia. Memory, 15(1), 34–56. 10.1080/09658210601043384 [PubMed: 17479923]

Snowling MJ, Hulme C, & Nation K (2020). Defining and understanding dyslexia: Past, present and future. Oxford Review of Education, 46, 501–513. 10.1080/03054985.2020.1765756 [PubMed: 32939103]

Soden B, Christopher ME, Hulslander J, Olson RK, Cutting L, Keenan JM, … & Petrill SA (2015). Longitudinal stability in reading comprehension is largely heritable from grades 1 to 6. PloS one, 10(1), e0113807. 10.1371/journal.pone.0113807 [PubMed: 25602760]

Stack-Cutler HL, Parrila RK, & Torppa M (2016). University students with reading difficulties: Do perceived supports and comorbid difficulties predict well-being and GPA? Learning Disabilities Research & Practice, 31, 45–55. 10.1111/ldrp.12092

Swagerman SC, Van Bergen E, Dolan C, de Geus EJ, Koenis MM, Pol HEH, & Boomsma DI (2017). Genetic transmission of reading ability. Brain and Language, 172, 3–8. 10.1016/j.bandl.2015.07.008 [PubMed: 26300341]

Thompson PA, Hulme C, Nash HM, Gooch D, Hayiou-Thomas E, & Snowling MJ (2015). Developmental dyslexia: Predicting individual risk. Journal of Child Psychology and Psychiatry, 56, 976–987. 10.1111/jcpp.12412 [PubMed: 25832320]

Tibshirani R (1996). Regression shrinkage and selection via the lasso. Journal of the Royal Statistical Society, 58, 267–288. 10.1111/j.2517-6161.1996.tb02080.x

Torgesen JK, Rashotte CA, & Wagner RK (1999). TOWRE: Test of Word Reading Efficiency. Toronto, Ontario: Psychological Corporation.

van Bergen E, de Jong PF, Maassen B, & van der Leij A (2014). The effect of parents' literacy skills and children's preliteracy skills on the risk of dyslexia. Journal of Abnormal Child Psychology, 42, 1187–1200. 10.1007/s10802-014-9858-9 [PubMed: 24658825]

Wagner RK, Edwards AA, Malkowski A, Schatschneider C, Joyner RE, Wood S, & Zirps FA (2019). Combining old and new for better understanding and predicting dyslexia. New Directions for Child and Adolescent Development, 2019(165), 11–23. 10.1002/cad.20289

Welcome SE, & Meza RA (2019). Dimensions of the Adult Reading History Questionnaire and their relationships with reading ability. Reading and Writing: An Interdisciplinary Journal, 32, 1295–1317. 10.1007/s11145-018-9912-z

Welcome SE, Chiarello C, Towler S, Halderman LK, Otto R, & Leonard CM (2009). Behavioral correlates of corpus callosum size: Anatomical/behavioral relationships vary across sex/handedness groups. Neuropsychologia, 47, 2427–2435. 10.1016/j.neuropsychologia.2009.04.008 [PubMed: 19383501]

Woodcock RW (1998). Woodcock-Reading Mastery Tests-Revised/Normative Update. Circle Pines, MN: American Guidance Service.

Youden WJ (1950). Index for rating diagnostic tests. Cancer, 3, 32–35. [PubMed: 15405679]

Zhao P, & Yu B (2006). On model selection consistency of Lasso. Journal of Machine Learning Research, 7, 2541–2563.

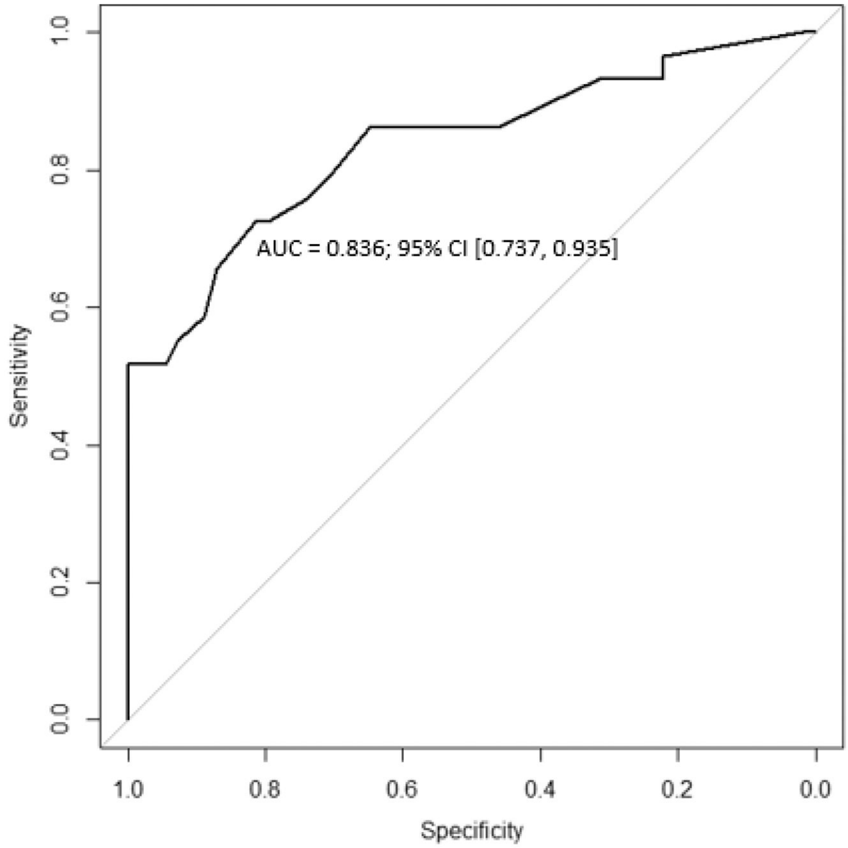

Figure 1.

ROC Curve of the ARHQ-brief Scores

Table 1

Demographic Information and Reading Assessments of Adult and Child Participants in the Samples from Training and Test Sets

	n	*Mean*	*SD*	Min	Max	*p* †
Adults in Training Set						
Age at ARHQ	97	40.521	4.863	29.05	52.77	
Females	49					
Males	48					
ARHQ	97	0.326	0.147	0.065	0.783	
Years of education	97	16.938	2.099	12	22	
Age at Reading Testing	83	42.111	5.064	30.87	54.4	
SWE raw	83	92.554	11.426	60	104	0.476
PDE raw	83	49.337	8.895	23	63	0.559
WID raw	81	98.889	4.569	84	105	0.59
WA raw	82	37.354	3.733	25	45	0.093
PC raw	82	61.232	3.856	47	67	0.221
Children in Training Set						
Age	47	8.253	0.435	7.51	9.75	
Girls	18					
Boys	29					
SES (mother education)						
Year of education	47	16.936	1.948	12	22	
SES (family Hollingshead occupation code)						
4: smaller business owners (value <$25,000)	1					
6: technicians, semi-professionals, small business owners (business valued at $50,000–70,000)	4					
7: smaller business owners, farm owners, managers, minor professionals	13					
8: administrators, lesser professionals, proprietor of medium-sized business	10					
9: higher executives and major professionals	19					
SWE SS	47	110.660	12.232	86	138	
PDE SS	47	105.979	14.415	77	144	
WID-WRMT SS	47	116.021	11.311	94	139	
WA-WRMT SS	47	114.298	13.992	90	146	
PC SS	47	114.447	9.726	99	141	
Parents in Test Set						
Age at ARHQ	43	48.814	6.734	39	73	
Females	23					
Males	22					
ARHQ	45	0.358	0.186	0.087	0.804	
Highest level of education						
Below high school	1					
High school	1					

	n	*Mean*	*SD*	Min	Max	$p^{\dagger}$
Some BS or 2-year degree	4					
BS degree	19					
Graduate or professional	21					
Children in Test Set						
Age	28	11.464	2.400	7.7	16.2	
Girls	8					
Boys	20					
SES (family gross income)						
Between $100,001 and $200,000	4					
Between $200,001 and $500,000	13					
>$500,000	5					
SES (mother education)						
Some BS or 2-year degree	3					
BS degree	12					
Graduate or professional	12					
SWE SS	25	86.240	17.915	55	126	
PDE SS	25	84.000	17.863	62	129	
WID-WJ SS	24	89.292	15.046	57	112	
WA-SS	23	92.130	11.443	67	111	

Note.

†: the *p*-values when running regressions and using parental reading measures as dependent variables and age as the independent variable. ARHQ: Adult Reading History Questionnaire. SES: socioeconomic status. Family Hollingshead occupation code: the 9-point Hollingshead Index Occupational Status Scale (Bornstein & Bradley, 2003) is used to score parental occupation, and only the highest score of any parent is used as the indicator of children's SES level. SWE: TOWRE sight word reading efficiency subtest. PDE: TOWRE phonemic decoding efficiency subtest. WID-WRMT: WRMT-R/NU word identification subtest. WA-WRMT: WRMT-R/NU word attack subtest. PC: WRMT-R/NU passage comprehension subtest. SS: standard score. BS: Bachelor.

Table 2

Means, Standard Deviations, Score Ranges, and Internal Consistency Reliability Coefficients of ARHQ Items

	Training Set (*n* = 97)					Test Set (*n* = 45)				
Item ID	***Mean***	***SD***	**Min**	**Max**	**Cronbach's alpha**	***Mean***	***SD***	**Min**	**Max**	**Cronbach's alpha**
1	1.412	1.043	0	4	0.877	1.578	1.196	0	4	0.905
2	1.18	1.271	0	4	0.866	1.289	1.532	0	4	0.902
3	1.16	1.314	0	4	0.869	0.889	1.335	0	4	0.904
4	0.82	1.208	0	4	0.869	0.711	1.308	0	4	0.905
5	0.299	0.652	0	3	0.876	0.356	0.981	0	4	0.905
6	1.438	1.212	0	4	0.867	1.822	1.370	0	4	0.904
7	1.474	1.032	0	4	0.870	1.467	1.160	0	4	0.903
8	1.232	1.048	0	4	0.873	1.289	1.218	0	4	0.905
9	0.691	0.977	0	4	0.874	1.156	1.167	0	4	0.905
10	1.588	1.053	0	4	0.879	1.778	1.428	0	4	0.904
11	1.928	1.136	0	4	0.873	2.022	1.270	0	4	0.904
12	1.418	0.999	0	4	0.885	1.089	0.996	0	3	0.908
13	1.299	1.376	0	4	0.866	1.489	1.408	0	4	0.901
14	1.562	1.255	0	4	0.870	1.778	1.277	0	4	0.904
15	0.129	0.435	0	2	0.879	0.400	0.963	0	4	0.907
16	1.845	1.263	0	4	0.878	1.844	1.551	0	4	0.911
17	1.268	1.078	0	4	0.881	1.400	1.355	0	4	0.909
18	1.165	1.138	0	4	0.877	1.333	1.168	0	4	0.910
19	0.428	0.681	0	3	0.875	0.711	1.160	0	4	0.908
20	1.675	1.260	0	4	0.876	2.289	1.408	0	4	0.910
21	1.923	1.105	0	4	0.883	2.133	1.100	0	4	0.912
22	1.778	1.503	0	4	0.890	1.644	1.554	0	4	0.913
23	2.278	1.199	0	4	0.885	2.467	1.290	0	4	0.910

Table 3

Factor Structure and Loadings of ARHQ Items ($n = 97$) in the Training Set

	23 ARHQ Items			22[a] ARHQ Items			19[b] ARHQ Items		
Item	**DS**	**CR**	**WM**	**DS**	**CR**	**WM**	**DS**	**CR**	**WM**
1	0.482			0.48			-	-	-
2	0.943			0.951			0.964		
3	0.914			0.92			0.929		
4	0.833			0.83			0.827		
5	0.495			0.486			0.48		
6	0.856			0.86			0.868		
7	0.818			0.814			0.807		
8	0.439			0.43			-	-	-
9		0.713			0.722			0.698	
10		0.907			0.918			0.942	
11		0.526			0.524			0.516	
12							-	-	-
13	0.818			0.826			0.818		
14	0.489			0.491			0.481		
15	0.496			-	-	-	-	-	-
16			0.718			0.721			0.727
17			0.98			0.971			0.973
18			0.56			0.562			0.569
19	0.624			0.619			0.604		
20		0.851			0.858			0.855	
21									
22									
23									

Note. DS: Dyslexic Symptom. CR: Current Reading. WM: Working Memory.

[a:]The 22 ARHQ items are selected based on the example of Bjornsdottir et al. (2014).

[b:]The 19 ARHQ items are selected based on the example of Welcome and Meza (2019).

Table 4

Coefficient Estimates of Lasso Regression Selection based on Adult ($n = 81$) and Child ($n = 47$) Reading in the Training Set

	Adult Reading		Child Reading	
	Unstandardized coefficient	**Standardized coefficient**	**Unstandardized coefficient**	**Standardized coefficient**
Item 2: How much difficulty did you have learning to read in elementary school? (0 = none and 4 = a great deal)	−0.224 **	−0.308	−0.390 **	−0.357
Item 4: Did you ever reverse the order of letters or numbers when you were a child? (0 = no and 4 = a great deal)	−0.112 **	−0.150	-	-
Item 5: Did you have difficulty learning letter and/color names when you were a child? (0 = no and 4 = a great deal)	−0.246 **	−0.179	-	-
Item 7: All students struggle from time to time in school. In comparison to others in your classes, how much did you struggle to complete your work? (0 = not at all and 4 = much more than most)	-	-	−0.303 **	−0.227
Item 8: Did you experience difficulty in high school or college English classes? (0 = no; enjoyed and did well and 4 = a great deal; did poorly)	-	-	−0.266 **	−0.201
Item 14: How would you compare your current spelling to that of others of the same age and education? (0 = above average and 4 = below average)	−0.187 **	−0.251	-	-
R^2 explained	51.2%		43.7%	
Adjusted R^2	48.6%		39.8%	

Note.

**: *p*-value < 0.01.

*: *p*-value < 0.05.

Table 5

Coefficient Estimates of Regressions Using ARHQ-brief and ARHQ in Training and Test Sets

	ARHQ-brief				ARHQ			
	Unstandardized coefficient	Standardized coefficient	R^2	Adjusted R^2	Unstandardized coefficient	Standardized coefficient	R^2	Adjusted R^2
Adults in Training Set								
Composite	0–3.137***	−0.707	50.0%	49.3%	0–3.772***	−0.596	35.6%	34.7%
SWE raw	−22.814***	−0.425	18.0%	17.0%	−24.725***	−0.324	10.5%	9.4%
PDE raw	−27.794***	−0.665	44.2%	43.5%	−32.792***	−0.552	30.5%	29.7%
WID-WRMT raw	−13.829***	−0.649	42.2%	41.4%	−16.671***	−0.549	30.2%	29.3%
WA-WRMT raw	0–8.827***	−0.506	25.6%	24.7%	−10.039***	−0.405	16.4%	15.4%
PC raw	0–7.285***	−0.404	16.3%	15.3%	−10.220***	−0.399	16.0%	14.9%
Children in Training Set								
Composite	0–3.906***	−0.557	31.1%	29.5%	0–4.331***	−0.447	20.0%	18.2%
SWE SS	−40.694***	−0.463	21.5%	19.7%	−48.776***	−0.402	16.2%	14.3%
PDE SS	−45.876***	−0.443	19.7%	17.9%	−46.685***	−0.327	10.7%	8.7%
WID-WRMT SS	−45.934***	−0.566	32.0%	30.5%	−52.214***	−0.466	21.7%	19.9%
WA-WRMT SS	−48.852***	−0.486	23.7%	22.0%	−49.119***	−0.354	12.5%	10.6%
PC SS	−37.555***	−0.538	28.9%	27.4%	−44.481***	−0.461	21.3%	19.5%
Children in Test Set (controlling for ages)								
Composite	−2.170*	0.781	30.7% [a]	23.4% [a]	−2.195 ◻	1.159	18.0% [a]	9.4% [a]
WID-WJ SS	−25.995 ◻	13.024	16.9% [a]	9.0% [a]	−26.353	18.493	9.8% [a]	1.2% [a]
WA-WJ SS	−25.363*	9.397	26.8% [a]	19.4% [a]	−27.019 ◻	13.645	16.5% [a]	8.1% [a]
SWE SS	−29.905 ◻	14.796	21.4% [a]	14.3% [a]	−33.848	20.184	17.4% [a]	9.9% [a]
PDE SS	−37.849*	13.859	30.7% [a]	24.4% [a]	−44.380*	19.124	25.4% [a]	18.6% [a]

Note.

***: *p*-value <.001.

**: *p*-value <.01.

[*]: p-value <.05.

[¤] $p < .10$.

SS: standard score.

[a]: estimated R^2 including age effects.