The Role of Cattell-Horn-Carroll (CHC) Cognitive Abilities in Predicting Writing Achievement During the School Age Years

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Dr. Kevin McGrew is a coauthor of the WJ IV battery and discloses that he has a financial interest in the WJ IV.

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In press: PITS-2015-0269

Abstract

Writing is a complex academic task—it involves numerous mental processes. Given the necessity for developing writing skills from elementary to secondary school, this study aimed to investigate the role of broad cognitive abilities derived from the Cattell-Horn-Carroll (CHC) theory of intelligence in predicting skills associated with writing achievement. The normative sample from the fourth edition of the Woodcock Johnson Tests of Cognitive Abilities and the Woodcock Johnson Tests Academic Achievement were used to examine the relationships between broad CHC abilities and academic achievement in writing. The findings of this study suggest that the broad CHC abilities Comprehension-Knowledge, Processing Speed, and Fluid Reasoning are especially important predictors of basic writing skills and written expression during the school age years. In general, changes in the strength of the association between cognitive abilities and academic achievement in writing are observed over time, as the cognitive demands involved in the writing increase in complexity in later grades.

Keywords: cognitive abilities, CHC, academic achievement, writing, school psychology.

The Role of Cattell-Horn-Carroll (CHC) Cognitive Abilities in Predicting Writing Achievement During the School Age Years

Writing is one of the most complex communication tasks students are expected to master during their school years. Writing is a learned skill (Graham & Harris, 1997) that involves the acquisition, coordination, and integration of multiple processes and strategies (De La Paz & Graham, 2002). The ability effectively communicate in writing has been identified as a necessary skill for successful participation in educational, work, and social settings (Rutenberg, 2009). Despite its importance to work and career performance, 72% of employers rate high school graduates as deficient in writing skills (National Endowment for the Arts, 2007). It is therefore not surprising that educators and researchers seek to understand the development of writing skills during the school years to develop and identify evidence-based writing instructional and academic intervention strategies.

The use of standardized, norm-referenced measures of cognitive abilities and academic achievement remains a core functional competency of psychologists working in schools (Ysseldyke et al., 2006). As such, it is important for psychologists to understand the relationships between measures of cognitive abilities and the skills assessed by measures of academic achievement. Previous research has identified a number of cognitive abilities that contribute to the development of writing achievement (Floyd, McGrew, & Evans, 2008; McGrew & Knopik, 1993). However, the measures used in previous studies are outdated and no longer in use in practice. As existing psychometric measures are revised in light of cutting edge advancements in both theory and applied psychometrics, it is necessary to re-examine the relationships between cognitive abilities and academic achievement. The purpose of this study is to investigate how cognitive abilities are related to academic achievement, as measured by a popular battery of norm-referenced tests. The results should provide practical information to psychologists working in schools to inform their interpretation and recommendations.

Cognitive Theories of Writing

The Cognitive Process Theory of Writing (CPTW; Flower & Hayes, 1981) describes how multiple mental processes are involved in the generation of written language. This theory provides a framework of how cognitive abilities are involved during the writing process. The CPTW, with the exception of long-term memory, involves higher-order constructs that likely involve the use of a number of cognitive processes. For example, the CPTW identifies planning, translating, reviewing, and monitoring as major components, which are all likely to involve the use of numerous cognitive abilities, such as working memory, long-term memory, and processing speed. Kellogg's Memory Model of Writing (1996), as the name implies, places primary focus on aspects of memory in the production of written language. Collectively, these writing-specific theories has influenced much of the research on writing conducted during the past few decades (e.g., Berninger, 1994; Kellogg, Whiteford, Turner, Cahill, & Merlens, 2013; McCutchen, 1988; Vanderberg & Swanson, 2007). Much of the research examining the cognitive underpinnings of various writing tasks has focused on working memory, long-term memory and attention (Olive, 2012). However, Fayol, Foulin, Maggio, and Lété (2012) explained that processing speed is likely to be related to writing skills, despite very few studies having been conducted to examine the influence of this specific cognitive ability on writing. Conversely, Olive (2012) noted that there is a trade-off between working memory capacity and processing speed in that limitations in one will result in a greater demand placed on the other ability.

In summary, cognitive theories of writing allow for a broad view of the cognitive processes involved in writing (e.g., the CPTW) and of how specific cognitive abilities are used to complete writing tasks (e.g., Kellogg's Working Memory Model of Writing). Both approaches have their merits in writing instruction or, in the case of the latter, specific supports that could be developed for students with limited working memory. However, neither provides empirical evidence to help psychologists explain the results from cognitive test batteries, which allow for the assessment of many of the cognitive abilities known to be relevant to learning (see McGrew & Wendling, 2010, for a review).

Limiting research questions to only one, or a few, of the cognitive abilities relevant to writing may lead to what Floyd, Evans, and McGrew (2003) described as *specification error*. Floyd and colleagues explained that "failure to include measures of potentially important constructs in the extant mathematics research, specification error may cloud the current understanding of the cognitive predictors of mathematics achievement" (p.156). The same principle applies to research examining the relationships between cognitive abilities and writing achievement. Research examining the relationships between cognitive abilities and areas of academic achievement related to writing (e.g., basic writing skills, spelling, written expression), should be grounded in a comprehensive theory that accounts for most of the known cognitive abilities that may be involved in the writing process. Doing so should minimize the reporting of potentially erroneous findings based on biased estimates of these relationships.

The Cattell-Horn-Carroll (CHC) Model of Cognitive Abilities

The Cattell-Horn-Carroll (CHC) model of cognitive abilities provides a comprehensive taxonomy of all currently known human cognitive abilities (McGrew, 2009). CHC theory is an integration of two previously accepted models of human cognitive abilities: Cattell-Horn's fluid and crystallized intelligence theory (Horn & Noll, 1997) and Carroll's three-stratum theory (Schneider & McGrew, 2012). CHC theory is organized as a three-stratum model, which consists of many narrow abilities (stratum I), a few broad abilities (stratum II), and general intellectual functioning, represented as *g* (stratum III; Schneider & McGrew, 2012). CHC theory has been recognized as the most comprehensive psychometric explanation of cognitive functioning (McGrew, 2009). As such, most standardized tests of cognitive abilities are either based directly on CHC theory, or have recognized the contributions of CHC theory (Keith & Reynolds, 2010), such as the Woodcock-Johnson Tests of Cognitive Abilities—Fourth Edition (WJ IV; Schrank, MGrew, & Mather, 2014a), Kaufman Assessment Battery for Children—Second Edition (Kaufman & Kaufman, 2004), the Stanford-Binet Intelligence Scales—Fifth Edition (Roid, 2003), and the Wechsler Intelligence Scale for Children—Fifth Edition (Wechsler, 2014).

CHC theory identifies the following seven core broad cognitive abilities: Fluid Reasoning (Gf), Comprehension Knowledge (Gc), Short-Term Memory (Gsm), Visual Processing (Gv), Auditory Processing (Ga), Long-Term Storage and Retrieval (Glr), and Processing Speed (Gs) (McGrew, 2009). Fiorello and Primerano (2005) discussed how psycho-educational assessment practices had previously focused on predicting academic achievement from an individual's overall IQ score. They noted, however, that contemporary approaches have shifted to place a greater emphasis on using specific cognitive abilities to predict academic achievement, as they have been considered to be more informative than an individual's overall IQ (Fiorello & Primerano).

CHC theory and writing achievement. In line with current practices, research has been conducted investigating the relationships between the CHC broad cognitive abilities and specific areas of academic achievement (e.g., reading, mathematics, and writing) among children and adolescents. To date, the effects of the broad and narrow CHC abilities on academic performance have largely been focused on reading and mathematics (e.g., Evans, Floyd, McGrew, &

LeForgee, 2002; Floyd, Bergeron, & Alfonso, 2006; Floyd, Evans, & McGrew, 2003; Proctor, Floyd, & Shaver, 2005), with a limited number of studies focusing on writing achievement (Bruning & Horn, 2000; Floyd, McGrew, & Evans, 2008; McGrew & Knopik, 1993). Research on relations between CHC abilities and writing achievement suggests that seven CHC domains (i.e., Gf , Gc , Gsm , Gv , Ga , Glr, and Gs) have a direct influence on writing achievement. Of note, Ga, Gsm, Gs, and Gc have demonstrated the strongest and most consistent relation to writing achievement across different age levels (Flanagan, Ortiz, & Alfonso, 2013; Flanagan, Ortiz, Alfonso, & Mascolo, 2006; Saklofske, Reynolds, & Schwean, 2013). Research focusing on CHC abilities and their relationship to academic achievement in writing, is, therefore, likely to be useful in explaining strengths and weaknesses in academic achievement (McGrew & Wendling, 2010).

Limitations of Previous Research

Much of the extant literature on writing has focused on distinct age ranges within the school age population (e.g., Abbott, Berninger, & Fayol, 2010; Maggio, Lété, Chenu, Jisa, & Fayol, 2012; Rieben, Ntamakiliro, Gonthier, & Fayol, 2005). Age ranges may be limited for practical reasons, or to focus on understanding the development of specific writing skills, such as punctuation, connectives, and verbal tense (Fayol, 2012). Psychologists are left to piece together the literature to infer the potential relationships that may exist between various cognitive abilities and academic achievement. This was one of the primary reasons for the development of the previous CHC-based studies conducted by McGrew and Knopik (1993), as well as Floyd and colleagues (2008).

The two comprehensive investigations of CHC abilities and their relationship to writing achievement (McGrew & Knopik, 1993; Floyd, McGrew, & Evans, 2008) are noteworthy because not only did they include all broad CHC abilities relevant to writing achievement, but they also provided a systematic evaluation of these relationships over the school years (i.e., ages 5 to 79 and ages 7 to 18, respectively). Relying on these previous studies, however, may lead to erroneous inferences being made by practicing psychologists, as the measures used in these studies, the Woodcock-Johnson Psycho-Educational Battery—Revised (WJ-R; Woodcock & Johnson, 1989) and the Woodcock Johnson Tests of Cognitive Abilities, Third Edition (WJ III; Woodcock, McGrew, & Mather, 2001), are no longer in use. The WJ III was recently replaced with the release of the fourth edition of this cognitive battery—the WJ IV. Therefore, although the broad cognitive abilities listed in the CHC theory have remained unchanged, the measurement of these abilities has evolved. It is, therefore, possible that the associations between cognitive abilities and academic achievement in writing have changed, given that the tools that measure these abilities have been revised to better represent current theoretical models of these constructs and to incorporate cutting edge statistical techniques in their development (Reynolds & Niileksela, 2015).

Current Study

This study aims to investigate the associations between cognitive components derived from the Cattell-Horn-Carroll (CHC) theory of intelligence and writing achievement during the school-age years. The fourth edition of the Woodcock-Johnson Tests (WJ IV; Schrank, McGrew, Mather, & Woodcock, 2014a, 2014b) was used for examining the role of broad CHC clusters in the areas of Basic Writing Skills and Written Expression. The WJ IV is a broad-scope assessment system for individual evaluation of academic achievement, cognitive abilities, and oral language. The two co-normed WJ IV batteries, the Woodcock-Johnson IV Tests of Achievement (WJ IV ACH) and the Woodcock-Johnson IV Tests of Cognitive Abilities (WJ IV COG), were used together to examine the relations between cognitive clusters and writing ability. The findings of this study provide insights into the role of cognitive abilities in writing achievement across the school age years.

Method

Sample

The normative samples for the Woodcock Johnson Tests of Cognitive Abilities, Fourth Edition (WJ IV COG; Schrank, McGrew, & Mather, 2014a) and the Woodcock Johnson Tests of Academic Achievement, Fourth Edition (WJ IV ACH; Schrank, Mather, & McGrew, 2014b) were used to examine the relationships between broad CHC abilities and areas of academic achievement in writing[1]. The WJ IV COG and WJ IV ACH batteries are co-normed (McGrew, LaForte, & Schrank, 2014). The norming sample included 7,416 people ranging from ages 2 to over 90 and, using a stratified random sampling method, it was designed to be representative of the U.S. population across 46 states and the District of Columbia (McGrew et al., 2014). The sample used for this study only included the school-age sub-sample, which ranges from 6 to 19 years of age, inclusively. The total sample size for this study was 4,189. The sample was divided into 14 age groups. Only subjects with scores on all WJ IV COG and WJ IV ACH writing clusters were included to ensure equal sample sizes at each age group for the analyses run with each of the writing cluster scores (see Table 1).

Measures

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[1] Standardization data from the *Woodcock-Johnson*™ *IV* (*WJ IV*™). Copyright © 2014 by The Riverside Publishing Company. All rights reserved. Used with permission of the publisher.

CHC clusters. The WJ IV COG is comprised of a standard battery of 10 tests and an extended battery of 8 additional tests. CHC cluster scores are calculated from pairs or trios of tests included in the standard or extended batteries. Aside from the two-test Gf, Gc, Gwm, Glr, Gv, Ga, and Gv broad clusters, three-test "extended" broad CHC clusters are also available for Gf, Gc and Gwm. Only the two-test broad CHC clusters were used in the current study. The individual tests and their corresponding CHC broad clusters are: Oral Vocabulary and General Information for Gc; Number Series and Concept Formation for Gf; Verbal Attention and Numbers Reversed for Gwm[2]; Letter-Pattern Matching and Pair Cancellation for Gs; Phonological Processing and Nonword Repetition for Ga; Story Recall and Visual-Auditory Learning for Glr; and Visualization and Picture Recognition for Gv.

A number of statistical procedures were used to assess and report the reliability of the tests included in the WJ IV COG. The Rasch model (Rasch, 1960/1980) was used for item calibration and scale development for all dichotomously scored and polytomously scored items. Overall, reliability estimates for individual tests demonstrated an average reliability coefficient of 0.88, ranging from 0.74 to 0.97. Test-retest reliability was used to assess the reliability of timed tests. The median test-retest reliability coefficients for ages 7 to 11 and ages 14 to 17 are $r = 0.91$ and $r = 0.88$, respectively. Across the entire norming sample, the median CHC-cluster reliability coefficients for Gc, Gf, Gwm, Gs, Ga, Glr, and Gv are .93, .94, .91, .94, .92, .97, and .86, respectively. The CHC-cluster reliability coefficients for each age level throughout the

[2] McGrew et al. (2014) recommended that Gsm be replaced in the CHC model with the more contemporary notion of broad working memory (Gwm). In the introduction of this manuscript the Gsm notation was used given that it was used in the prior research. Gwm is used in the remainder of this manuscript given the operationalization of Gwm in the WJ IV.

school years (i.e., ages 6 to 19, inclusively) range from .88 to .98. Extensive evidence of content, predictive, and criterion validity are provided in the WJ IV COG technical manual (see McGrew et al., 2014). Independent reviews have described the WJ IV COG as "an excellent measure of psychometric intelligence. The theoretical basis of the test and transparency in test development described in the Technical Manual are exceptional" (Reynolds & Niileksela, 2015). The WJ IV ACH battery has received similar positive independent reviews (Villerral, 2015)

Writing achievement clusters. The WJ IV ACH is comprised of a standard battery of 11 tests and an extended battery of an additional 9 tests. Writing achievement cluster scores are calculated from pairs of tests included in the standard or extended batteries. The individual tests and their corresponding writing achievement clusters are: Spelling and Editing (Basic Writing Skills); Writing Samples and Sentence Writing Fluency (Written Expression). The reliability of the individual WJ IV ACH tests was assessed at multiple levels. With the exception of the speeded tests, reliability coefficients were calculated across age levels (McGrew et al., 2014). The median cluster score reliability (r_{cc}) for Basic Writing Skills and Written Expression range from r_{cc} = .94 to r_{cc} = .95 and r_{cc} = .91 to .92, respectively, for ages 6 to 19. The median r_{11} values for Spelling ranges from r_{11} = .90 to .93 for ages 6 to 19. The median r_{11} values for Editing ranges from r_{11} = .89 to .92 for ages 7 to 19 (editing is not administered to children under the age of 7). The median r_{11} values for Writing Samples ranges from r_{11} = .90 to .91 for ages 7 to 19. The speeded test within the WJ IV ACH writing clusters is Sentence Writing Fluency. The reliability of the Sentence Writing test was evaluated using a test-retest procedure. Across all age groups of interest to this study, the median test-retest reliability coefficient range from r_{12} = .76 to r_{12} = .88. The validity evidence for the WJ IV ACH is also extensive and includes a strong evidence of construct, internal, external and criterion validity (see McGrew et al., 2014; Villarreal, 2015).

Data Analysis

The data analysis consisted of two steps. First, a series of multiple regression analyses were completed to examine the linear relationship between the seven WJ IV broad CHC cluster scores and the two WJ IV ACH writing clusters at each of the 14 age groups (ages 6 to 19, inclusively). The regression models included all seven broad CHC cluster scores (i.e., Gc, Gf, Gwm, Gs, Ga, Glr, and Gv) as predictors. Separate regression analyses were conducted using the WJ IV ACH writing clusters of Basic Writing Skills and Written Expression as criterion variables. Age-based standard scores (M = 100; SD = 15) were used for all analyses. The standardized regression coefficients from each regression model were then interpreted to determine the degree of association between the predictors and the outcome variables. Second, based on the results from multiple regression analyses, post hoc multiple regression models were completed to better understand some of the novel findings from the broad CHC cluster level analysis with Written Expression as the criterion variable. It should be noted that post hoc analyses were not completed for Basic Writing Skills because the findings were not at extreme odds with previous research.

The relatively high and consistent standardized regression coefficients for the WJ IV Gf cluster seen across the age range examined for Written Expression were at odds with the extant research literature presenting the associations between the WJ III and written expression (see Floyd, McGrew, & Evans, 2008). A review of the correlations between the two WJ IV Gf cluster tests (i.e., Number Series and Concept Formation) and the WJ IV tests contributing to the composite score for Written Expression (i.e., Writing Samples and Sentence Writing Fluency) in the WJ IV technical manual (McGrew et al., 2014) indicated the Number Series test as the possible reason for this new finding given that the correlation between Number Series and Writing Sample and Sentence Writing Fluency was considerably higher than Concept Formation (Number Series: $r = .62$ and $r = .54$, respectively; Concept Formation: $r = .28$ and $r = .40$, respectively).

It was hypothesized that Number Series may be accounting for the majority of the variance in the regression models for Written Expression. The underlying cause of this finding was first hypothesized to be the result of the Number Series test serving as a proxy for general intelligence (*g*). However, this hypothesis was not supported when individual the test *g*-loadings were examined in in the WJ IV Technical Manual (see Table 5-6, McGrew et al., 2014). As indicated by McGrew et al. (2014), it appears that neither Gf test is serving as a proxy for *g* in the multiple regression models, given that the tests Object-Number Sequencing (i.e., a Gwm test), Oral Vocabulary (i.e., a Gc test), and Phonological Processing (i.e., a Ga test) demonstrate *g*-loadings that exceed those of Concept Formation and Number Series for all age groups tested (e.g., 6-8, 9-13, 14-19, 20-39, and 40-90+). Therefore, a secondary analysis was conducted to better understand the relationship between individual tests and the results observed at the CHC cluster level for Written Expression.

The post hoc regression models focused on the individual test level, instead of the broad CHC cluster level, with Written Expression as the criterion variable, again for each of the school-age years (i.e., ages 6 through 19, inclusively). Although multiple regression models could have been used to evaluate all of the 14 test-level effects, seven-test models were used instead of 14-test models, to avoid the potential influence of multicollinearity that may be introduced due to the various pairs of tests within each of the seven broad CHC clusters. In addition, a seven-test model is more parsimonious, thereby increasing the ease of interpretation of the results.

A two-step procedure was used to examine the unique contribution of Gf above and beyond the other CHC components in explaining the variability in Written Expression. The seven tests used were tests 1-7 in the standard battery: Oral Vocabulary (Gc), Numbers Series (Gf), Verbal Attention (Gwm), Letter-Pattern Matching (Gs), Phonological Processing (Ga), Story Recall (Glr), and Visualization (Gv). These tests were selected because of their inclusion in generating the General Intellectual Ability cluster score; they have been established as the best indictors of broad CHC domains based on multiple criteria specified in the WJ IV Technical Manual (McGrew et al., 2014).

The first regression model included all seven tests as predictors. This model will be referred to as the *full model*. The second regression model included only six of the seven tests, with Number Series excluded from these analyses. This model will be referred to as the *reduced model*. Because of the nested structure of the full and reduced models, a direct comparison between the models can be made based on the change in R-squared (R^2) value that represents the amount of additional variability explained by the full model compared to the reduced model. To test the R^2 change between the full model and the reduced model, the following $R^2\Delta$ *F-test* was used:

$$F = \frac{\left(R^2_{full} - R^2_{reduced}\right) / \left(k_{full} - k_{reduced}\right)}{\left(1 - R^2_{full}\right) / \left(N - k_{full} - 1\right)} \tag{1}$$

where R^2_{full} is the R-squared value from the full model, $R^2_{reduced}$ is the R-squared value from the reduced model, k_{full} is the number of predictors in the full model, $k_{reduced}$ is the number of predictors in the reduced model, and N is the sample size. The resulting value is a F-ratio with degrees freedom of $\left(k_{full} - k_{reduced}\right)$ and $\left(N - k_{full} - 1\right)$. A statistically significant *F*-ratio from this test suggests that Number Series explains a significant amount of variability in the WJ IV ACH Written Expression cluster, above and beyond the other CHC individual test scores. Due to the relatively large number of tests to be run ($N = 28$), an alpha value of .001 was used to determine statistical significance of the model comparison tests.

Results

Standardized regression coefficients for each age group (ages 6 to 19, inclusively) were produced to examine the simultaneous contributions of each of the broad CHC abilities (e.g., Gc, Gf, Gwm, Gs, Ga, Glr, and Gv) to Basic Writing Skills and Written Expression, individually. A total of 28 regression models (14 age groups; 2 domains of writing achievement) were produced to obtain standardized regression coefficients for the aforementioned broad CHC abilities throughout the school years. Smoothed regression weight curves were produced using a distance weighted least squares (DWLS) smoother with a tension of .50 (SYSTAT, 2009). The tension parameter is varied by the user until a smoothed LOWESS curve (locally weighted scatterplot smoothing, see Cleveland, 1979) is produced that best represents trends in the data by not allowing the curve to be greatly influenced by divergent data points. McGrew and Wrightson (1997) described data smoothing procedures as being "used to provide better estimates of the reliability, uniqueness, and general factor characteristics" (p.181). Further, smoothed curves are considered the best approximation of the population parameters because the age-differentiated point values contain an unknown degree of sampling error (see McGrew & Wrightson, 1997).

Only models with standardized regression coefficients consistently at or above .10 are presented here, due to values below .10 representing no practical significance (McGrew, 1993; McGrew & Hessler, 1995; Evans et al., 2002, Floyd et al., 2003). Each figure includes two parallel lines corresponding to standardized regression coefficients of .10 and .30. These lines serve as guides for interpreting the significance of the smoothed regression coefficient values and correspond to the rules-of-thumb used in prior WJ studies (Evans et al., 2002; Floyd et al., 2003; McGrew, 1993; McGrew & Hessler, 1995; McGrew & Knopik, 1993). As indicated by Evans et al. (2002), “these rules operationally define practical significance to be associated with standardized regression coefficients of .10 or above. Coefficients ranging from .10 to .29 are classified as representing *moderate* effects, whereas those .30 or above are classified as strong effects” (p. 251).

The results of the statistically significant regression models are summarized in Figures 1, 2, 3, and 4. A supplementary document was produced, which includes summary tables of the regression coefficients for all the multiple regression analyses and the complete set of figures showing the smoothed standardized regression coefficients of every broad CHC ability and writing achievement cluster, including those that were not statistically or practically significant.[3]

Writing Achievement and Broad CHC Abilities

Basic writing skills. Results of the multiple regression analyses suggest that a number of broad CHC abilities contribute to performance in Basic Writing Skills (see Figures 1 and 2). Although Gf is strong predictor of Basic Writing Skills at the age of 6, Gc appears to be the strongest predictor of Basic Writing Skills from the age of 8 onwards. Ga and Gwm were consistently moderate predictors of Basic Writing Skills across all age groups. Gv and Glr were not observed to be consistent and significant predictors of Basic Writing Skills across the school years (i.e., ages 6-19).

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[3] This document can be obtained by contacting the first author.

Written expression. Results of the multiple regression analyses, again, suggest that a number of broad CHC abilities contribute to Written Expression performance (see Figures 3 and 4). Across the entire span of ages examined, Gf is a strong predictor of Written Expression. It should be noted, however, that Gs demonstrated a similar predictive value for ages 15 and 16, and a moderate to strong predictive effect across the school years. Despite Gc being a stronger predictor of Basic Writing Skills, it does not appear to contribute significantly to performance in Written Expression, when controlling for other broad CHC abilities. Ga was a predictor of Written Expression with a moderate effect size until age 10. However, its effect diminished starting at age 11 through the rest of childhood and adolescence. Gwm did not seem to be a strong predictor of Written Expression until late adolescence (age 17 and later). Similar to the results for Basic Reading skills, Gv and Glr, did not have a significant association to Written Expression, when controlling for other broad CHC abilities.

Post Hoc Analysis

The results of the post hoc multiple regression analyses suggest that Number Series had a relatively strong predictive effect on Written Expression. Despite the results being statistically significant across all age groups included in the analyses, the strength of the association between Number Series and Written Expression, when controlling for tests loading onto other broad CHC abilities, varies from ages 6 to 19, inclusively (see Table 1). Although the overall R-square values for the full model are relatively consistent across the school-age groups, the most consistent strong association between Number Series and Written Expression was observed between the ages of 6 and 11, inclusively.

Discussion

In recent decades, there has been significant growth in establishing an evidence base regarding the relationships between CHC abilities and academic achievement. There has been a particular focus on reading and mathematics whereby researchers have demonstrated important associations between CHC broad and narrow abilities and achievement (e.g., Evans et al., 2002; Floyd et al., 2003, 2006; Proctor et al., 2005). However, to date, there have been only a few published studies examining the effects of CHC abilities on writing achievement (e.g., Floyd et al., 2008; McGrew & Knopik, 1993). The current study aimed to contribute to the limited literature in this area with the goal of providing new information on the relations between CHC cognitive abilities and writing achievement.

Writing is a complex communication task requiring the acquisition, coordination, and integration, and several other cognitive processes (De La Paz & Graham, 2002; Flower & Hayes, 1981). The strong cognitive requirements of writing tasks may result in significant challenges for writing effectively, especially at early ages (Flower & Hayes, 1981). The cognitive requirements of writing tasks may differ depending on what kind of writing domains are involved in the writing process. This study focused on the empirical relations between seven broad CHC broad cognitive abilities and two writing achievement domains (Basic Writing Skills and Written Expression). We discuss our findings with respect to these specific domains in the following sections.

Basic Writing Skills

Gc. Floyd et al. (2008) noted that vocabulary knowledge and knowledge of the domain as a part of Comprehension-Knowledge (Gc) is the strongest and most consistent predictor of Basic Writing Skills in upper elementary school and they remain as important predictors through adolescence. The findings of the current study were consistent with the previous finding, as Gc was the strongest predictor and its impact increased from moderate to strong with age. As children transition from childhood to adolescence, they rapidly expand their vocabulary and comprehend the relationship between complex words and phrases. It is, therefore, not surprising that the influence of Gc on basic writing skills would increase over time, as older children and adolescents' depth of vocabulary knowledge will influence their ability to spell and edit text (Webb, 2013), instead of relying on decoding strategies to determine correct spelling (Wald & Wolf, 2013).

Gs. Prior CHC-based studies reported a moderate effect of Gs (i.e., Processing Speed) on Basic Writing Skills (Floyd et al., 2003, 2008; McGrew & Knopik, 1993). The findings of this study also indicated a consistent, moderate effect of Gs on Basic Writing Skills; however the effect of Gs appears to not be significant during adolescence, when controlling for other cognitive abilities. The gradually decreasing effect of Gs may be due to children's mastering basic skills at an early age (i.e., the automatization of skills) and consequently not needing higher memory allocation for basic writing tasks. It may also be due to the increase in working memory that occurs in late childhood, thereby reducing the need for quick processing of information, as more information can be held in working memory as they accomplish basic reading tasks. The increase in working memory is the second part of a developmental cascade that occurs from childhood to adolescence involving processing speed, working memory, and fluid intelligence (Fry & Hale, 1996).

Gwm. Working Memory (Gwm), which was called Short-term Memory (Gsm) in earlier forms of the CHC theory, demonstrated moderate effects increasing with age on Basic Writing Skills. This finding is consistent with those from Hale, Fiorello, Kavanagh, Hoeppner, and Gaither (2001) and Floyd et al. (2008). Working memory can contribute to individual and developmental differences in writing skills for children (Alloway et al., 2005; Bourke & Adams, 2003; McCutchen, 1996). Specifically, an effective use of working memory increases compositional fluency and accuracy of writing (Berninger, Whitaker, Feng, Swanson, & Abbott, 1996; Swanson & Berninger, 1996) and leads to the appropriate use of punctuation, planning, and revising (Beard, Myhill, Riley, & Nystrand, 2009).

Ga. Auditory processing (Ga) has a moderate effect on Basic Writing Skills throughout most of childhood and adolescence and the effect of Ga increases slightly with age. In previous studies, McGrew and Knopik (1993) found moderate effects of Ga on Basic Writing Skills using the WJ-R Auditory Processing cluster, whereas Floyd et al. (2008) found negligible effects of Ga on Basic Writing Skills using the WJ III Auditory Processing cluster. Our results regarding Ga based on the WJ IV Auditory Processing cluster resemble those of McGrew and Knopik (1993). Floyd et al. (2008) suggested that the differential functioning of Ga across the WJ batteries might be due to either differences in the definition of Ga within these batteries or due to potential changes in the environmental and instructional experiences for school-age children over time. Given that the WJ IV Ga or auditory processing cluster is completely different from both the prior WJ-R and WJ III research studies, the most likely hypothesis for the different findings in the current study is the changed mix of auditory abilities measured by the WJ IV Ga cluster.

Gf. Another CHC cognitive cluster for which previous research provided inconsistent results were the association between Fluid Reasoning (Gf) and Basic Writing Skills. McGrew and Knopik (1993), using the WJ-R norming sample, found moderate effects of Gf on Basic Writing Skills based on the WJ-R Fluid Reasoning cluster. Floyd et al. (2008), however, using the WJ III norming sample, found negligible effects of Gf on Basic Writing Skills until late adolescence. In our study, Gf was a strong predictor of Basic Writing Skills at an early age and its effect diminished throughout the rest of childhood and adolescence. The variability in the findings between these studies could again be attributed to the differential functioning of the cognitive ability cluster (i.e. Gf) across batteries (Floyd et al. 2008). However, our findings regarding the lack of association between Gf and Basic Writing Skills in late childhood and through late adolescence may also be due to a limited need at these ages to use induction (i.e., identifying and categorizing stimuli, defining rules) for basic writing skills (McGrew, LaForte, & Schrank, 2014), as these skills are likely already mastered and accounted for by Gc.

Gv. The results for Gv in the current study replicated those found in previous studies (e.g., McGrew & Knopik, 1993; Floyd et al. 2008), with Gv failing to show a significant association to basic writing skills, when controlling statistically for other broad CHC abilities. Floyd and colleagues explained that: “it is likely that orthographic coding skills, which were not targeted in this study, account for the expected relations between visual processing abilities and writing skills” (p.142). This association appears to continue to be consistent with current research findings (Dinehart, 2014).

Glr. Although the Visual-Auditory Learning test is consistently included in the Glr cluster score across different editions of the WJ, the second test contributing to this cluster has changed in every edition of the WJ since the WJ R. The current version uses Story Recall as the second score, whereas Retrieval Fluency was used in the WJ III. Previous findings in the association between Glr and basic writing skills suggests that Retrieval Fluency may have contributed significantly to the observed association between Glr and basic writing skills (Floyd et al., 2008). Thus, the substitution of this test for Story Recall may have contributed to Glr no longer demonstrating a significant association with basic writing skills, when controlling statistically for other broad CHC abilities.

Written Expression

Gf. This study indicated that Gf was the strongest predictor of Written Expression until late adolescence. These findings are different from those of McGrew and Knopik (1993) who found moderate effects of Gf on from age 5 to age 12 and Floyd et al. (2008) who found negligible effects of Gf until late adolescence. These differences are most likely due to the WJ IV Gf clusters accounting for more of variance in written expression performance than the WJ-R and WJ III Gf clusters. This finding suggests that the cognitive complexity involved in writing, in particular the coordination of numerous cognitive abilities, can result in cognitive overload. Cognitive overload can create significant challenges for writing effectively and has been noted as a fundamental problem in writing performance (Flower & Hayes, 1981).

Gs. Written Expression appears to have a parabolic relationship with Gs, depending on age. The moderate effect of Gs on Written Expression increases until age 15 and then decreases through late adolescence. These findings are consistent with those from McGrew and Knopik (1993) and with those from Floyd et al. (2008). Of note, in the current study, the Gs cluster was not as strong of a predictor of Written Expression when compared to the results of Floyd et al. (2008). Nonetheless, Gs remains as an important factor for Written Expression. Specifically, a writer with strong Gs ability will be able to quickly process and apply basic writing skills (e.g., rules, structures, etc.), which frees up other cognitive abilities for more complex tasks involved in written expression (e.g., planning, coordination and application of rules, use of vocabulary in context).

Ga. The role of Ga in predicting performance in Written Expressing appears to vary considerably, as it oscillates between being a significant and non-significant predictor of written expression across the age span used in this study. Floyd et al. (2008) observed a similar trend with respect to Ga. In the early years, Ga may contribute to written expression, as young children are more likely to read aloud as they compose basic sentences. At later ages, however, the re-reading of complex texts to improve clarity in written text by ensuring appropriate flow and continuity may explain why Ga re-emerges as a significant predictor of written expression. The inconsistent use of this strategy, however, may explain the oscillation between significant and non-significant findings. The changing composition of the Ga cluster across the WJ-R, WJ III, and WJ IV also most likely accounts for differences in findings across the different editions of the WJ cognitive assessment batteries.

Gwm. Unlike Basic Writing Skills, Written Expression does not seem to be influenced by Gwm until late adolescence. The effect of Gwm on Written Expression remains negligible as Gwm is more involved in Basic Writing Skills, such as word or letter identification or punctuation, at an early age. After Basic Writing Skills are mastered adequately, verbal working memory may be more involved in retrieving information and organizing more complex ideas in writing during late adolescence.

Gc, Glr, and Gv. The consistent, non-significant associations between Gc, Glr, and Gv written expression may be surprising, especially when one considers the requirement for retrieval of vocabulary involved in written expression, which likely implicates Gc and/or Glr abilities. Some of the aforementioned reasons for non-significant associations between certain broad CHC abilities and basic writing skills could again be considered as contributors to this effect. It should again be noted that these findings for individual CHC abilities control statistically for all other broad abilities. This implies that although Gc, Glr, and Gv likely play a role in the process of written expression, no additional variance in written expression is explained when the broad CHC abilities described above are taken into account.

Post Hoc Models. The results of the post hoc regression analyses supported the notion that Gf, and in particular the Number Series test, accounts for a significant proportion of the variance in written expression. This is especially true at younger ages with the R^2 change values ranging from .09 to .13 from ages 6 to 13, inclusively. The potential explanation for this finding is that the Number Series test appears to be a measure of the ability to engage in cognitively complex tasks that involve an interaction between the cognitive load placed on work memory and the relational complexity of the stimuli included in the task (Bertling, 2012). The Cognitive Process Theory of Writing argues that the complexity involved in writing, in particular the coordination of numerous cognitive abilities, can result in cognitive overload (Flower & Hayes, 1981). Cognitive overload, in turn, creates significant challenges for writing effectively and has been noted as a fundamental problem in writing (Flower & Hayes, 1981). Thus, it is possible that the Number Series test may be providing information on the extent to which an individual is able to handle the cognitive demands of written expression. The overall findings of this study provide further support for this potential explanation given that Gf was *not* associated with the simpler tasks represented in basic writing skills. It should be noted, however, that the underlying causes of the cognitive complexity associated with written expression might change over time. Future research may help to explain why the associations between Number Series and written expression occur at different ages (i.e. different stages of cognitive development).

Implications and Future Directions

This research offers a model of the cognitive variables that are involved in various aspects of writing (e.g., spelling, editing, generating text, and generating text quickly). As suggested by Schneider (2013), it is possible to use this model to explain strengths in weaknesses when assessing cognitive abilities and academic achievement. However, the development and explanation of such a model is beyond the scope of this study. Nonetheless, this study does provide evidence that the relationship between cognitive abilities and academic achievement in writing do change over time, which suggests that psychologists cannot use the same working model of these associations across the school age years. Further, it appears that some noteworthy changes have occurred as measures of cognitive abilities and academic achievement have been revised. This makes it imperative for practitioners to be aware of these changes, so they can adapt their interpretations according to current empirical evidence and not rely on previous findings to inform decisions made using the revised measures (Flanagan, Ortiz, & Alfonso, 2013).

Much of the work on writing has focused on working memory, long-term memory and attention (Kellogg & Whiteford, 2012; Olive, 2012). However, fluid reasoning appears to have a significant relationship with writing achievement. Future research may want to incorporate this particular ability in models of writing. This is actually in line with the general view that the production of written language is a problem-solving process (Zins & Hooper, 2012; Hooper, 2002). In addition, an understanding of how strengths in a particular area compensates for weaknesses in another or how specific strengths or weaknesses impact the writing process would help to better inform recommendations for intervention and other instructional supports. Some of this work has begun to emerge with regard to linguistics (e.g., Hooper, Wakely, de Kruif, & Swartz, 2006; Wakely, Hooper, de Kruif, & Swartz, 2006). However, a multi-disciplinary approach to understanding writing may be needed to develop a comprehensive understanding of the interaction between identified cognitive, linguistic and environmental factors. Even if the focus were limited to cognitive variables, a cross-battery approach to understanding writing, with an integration of measures of CHC theory and other leading cognitive theories, such as the

Planning, Attention, Simultaneous, Successive (PASS) theory of intelligence (Naglieri, Das, & Goldstein, 2012) and general information processing models, may provide greater insight into the cognitive processes involved in writing. Finally, to examine the relationship between cognitive abilities and writing achievement, writing scores from the WJ IV batteries were used in this study. Other writing competency assessments should also be used to explore the relations between the WJ IV cognitive measures and writing achievement as operationalized by other tests (e.g., Wechsler Individual Achievement Test—Third Edition, Kaufman Test of Educational Acheivement—Third Edition) to see if these results can be replicated and to provide battery-specific recommendations to practitioners who may not be using the WJ IV.

Limitations

The interpretation of the findings of this study should take into account several limitations. First, the analyses were limited to four tests of writing skills: (a) Spelling; (b) Editing; (c) Writing Samples; and Sentence Writing Fluency. These tests represent the ability to spell words correctly, demonstrate knowledge of the mechanics of writing, use text to communicate ideas clearly, and generate text under timed conditions, respectively (Schneider & McGrew, 2012). Although these tests represent many of the fundamental aspects of written expression, these highly structured tasks do not provide information on how cognitive abilities may be involved in the creative or problem solving aspects of writing (Fayol, 2012). Second, we did not attempt to model the writing process. In other words, this research does not provide information about how the acquisition of various writing skills build on each other and how the writer uses learned academic skills to produce text. Further, we did not measure how the use of cognitive abilities may change in response to various writing tasks. Finally, the external representations, which have been described an important component of the writing process according to the distributed cognition framework (Klein & Leacock, 2012), were not accounted for in the current study.

Conclusion

Understanding how specific cognitive abilities contribute to performance in various aspects of writing is an important area of inquiry given that only approximately one quarter of Grade 8 and 12 students are able to produce writing that fully meets grade level expectations (National Centre for Education Statistics, 2012). The current study provides evidence to suggest that certain cognitive abilities contribute significantly to the process of written expression, which may help practitioners consider why certain students struggle or excel in writing achievement at various age levels.

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Table 1

Comparison of Test-Level Multiple Regression Models Including and Excluding Number Series for Written Expression.

		R-square Values			F-values	
Age	*N*	With NS[1]	Without NS[1]	Change	Test for R^2 Change	Critical Value (α = .001)
6	241	0.52	0.42	**0.10**	47.08	11.10
7	291	0.59	0.49	**0.10**	67.32	11.05
8	333	0.57	0.44	**0.13**	96.14	11.02
9	306	0.51	0.41	**0.10**	59.39	11.04
10	313	0.54	0.44	**0.10**	64.78	11.03
11	329	0.46	0.34	**0.12**	69.78	11.02
12	317	0.49	0.40	**0.09**	53.29	11.03
13	307	0.53	0.43	**0.10**	62.13	11.04
14	299	0.47	0.36	**0.11**	58.94	11.04
15	277	0.55	0.50	**0.05**	29.11	11.06
16	284	0.53	0.49	**0.04**	22.89	11.06
17	254	0.50	0.39	**0.11**	52.58	11.08
18	276	0.58	0.51	**0.07**	43.50	11.06
19	295	0.55	0.49	**0.06**	37.33	11.05

[1]Number Series

Note. Boldface font indicates that the test of r-square change yielded a result that exceeded the critical value, indicating a statistically significant change in the r-square between the two models.

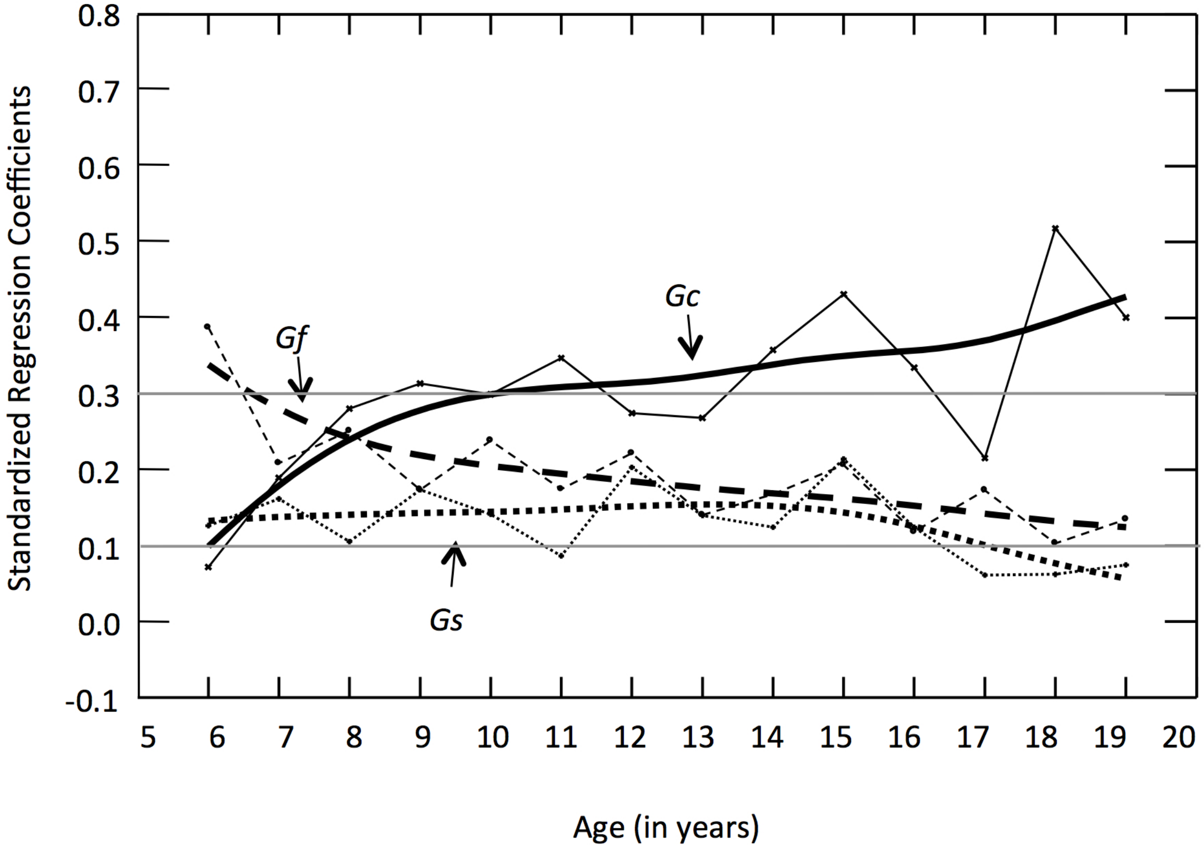

Figure 1. Basic Writing Skills and *Gf* , *Gc*, and *Gs* clusters.

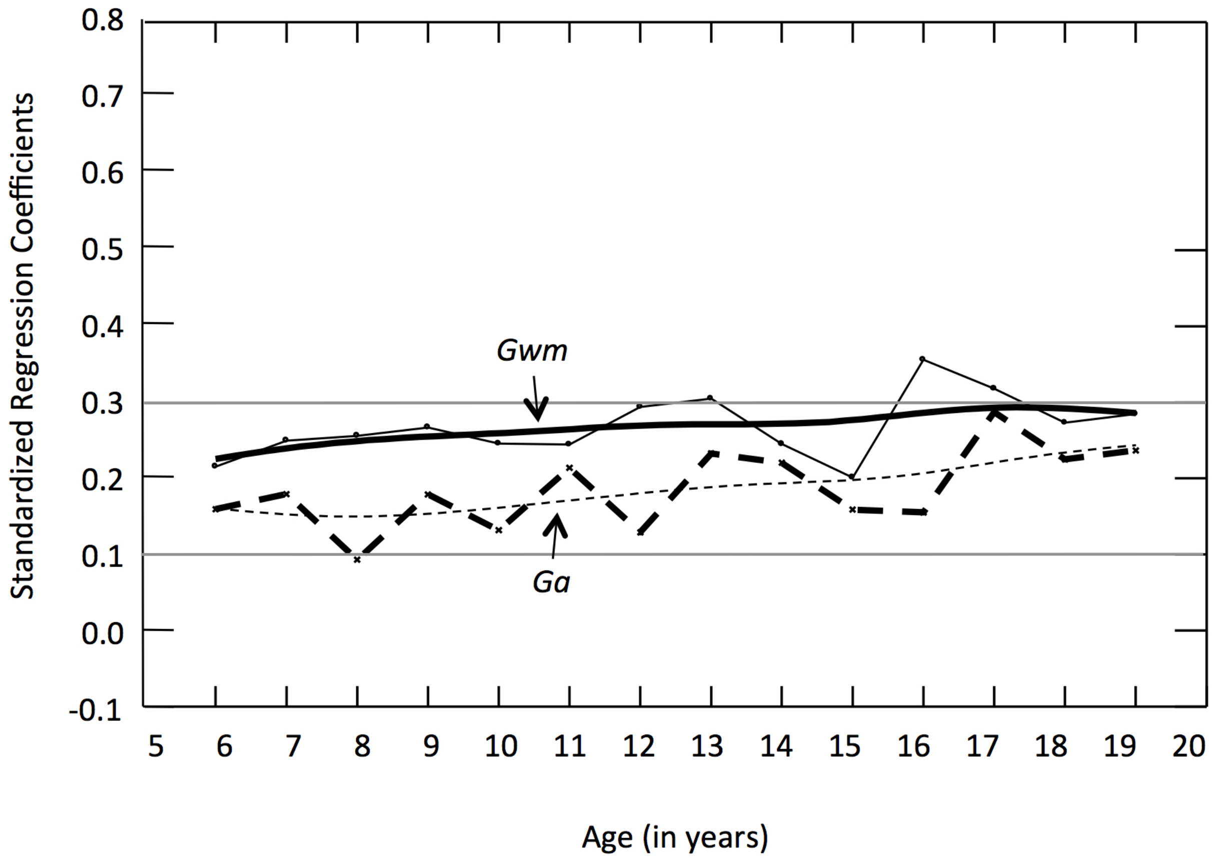

Figure 2. Basic Writing Skills and *Gwm* and *Ga* clusters.

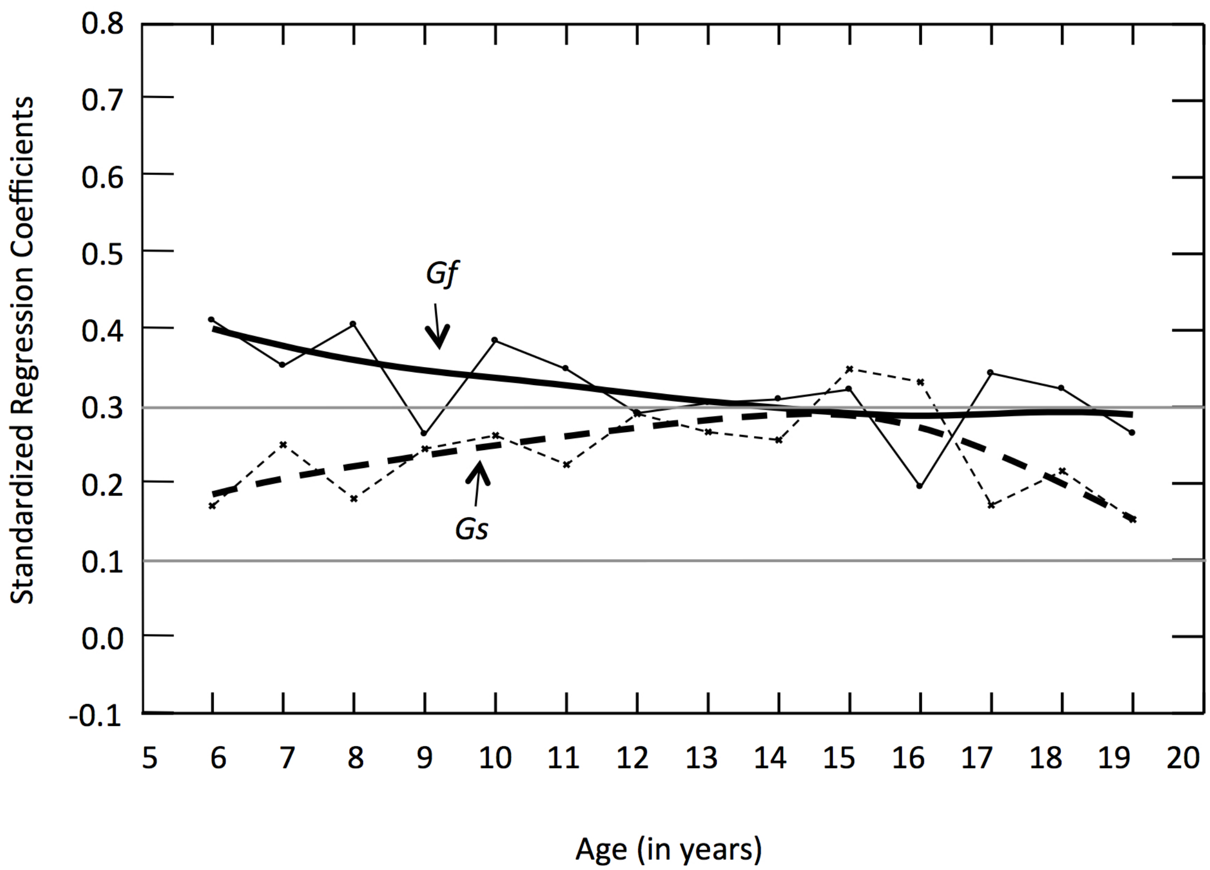

Figure 3. Written Expression and *Gf* and *Gs* clusters.

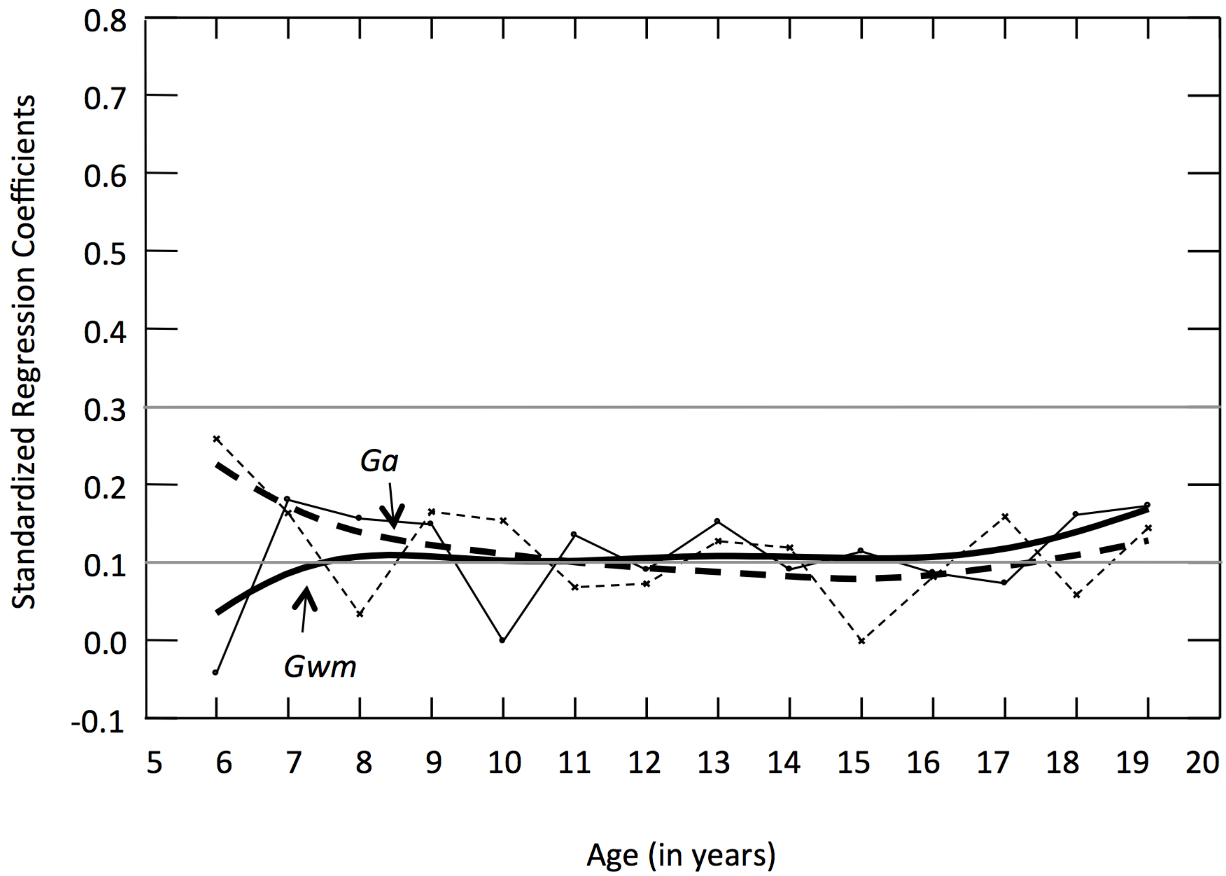

Figure 4. Written Expression and *Gwm* and *Ga* clusters.