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Abstract

Reading comprehension is an important skill for college academic success. Much of the research pertaining to reading in general, and reading comprehension specifically, focuses on the success of primary and secondary school-age students. The present study goes beyond previous research by extending such investigation to the reading comprehension of college-age student participants. Using the Cattell-Horn-Carroll (CHC) theoretical model, this study investigates the effects of seven broad factors on the reading comprehension of college-age students. Of the seven broad factors identified within the CHC theoretical model, only crystallized intelligence and visual-spatial thinking demonstrate statistically significant direct effects on reading comprehension. Although crystallized intelligence consistently has been identified as playing an integral role in the reading comprehension of primary and secondary school-age students, this study represents the first time visual-spatial thinking has been found to have a statistically significant direct effect on reading comprehension, in any population. This study provides hypotheses to explain the effects of visual-spatial thinking on college-age students' reading comprehension and offers instructional strategies to assist faculty in improving student learning in higher education settings.

Keywords

CHC factors, Reading comprehension

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Abstract

Reading comprehension is an important skill for college academic success. Much of the research pertaining to reading in general, and reading comprehension specifically, focuses on the success of primary and secondary school-age students. The present study goes beyond previous research by extending such investigation to the reading comprehension of college-age student participants. Using the Cattell-Horn-Carroll (CHC) theoretical model, this study investigates the effects of seven broad factors on the reading comprehension of college-age students. Of the seven broad factors identified within the CHC theoretical model, only crystallized intelligence and visual-spatial thinking demonstrate statistically significant direct effects on reading comprehension. Although crystallized intelligence consistently has been identified as playing an integral role in the reading comprehension of primary and secondary school-age students, this study represents the first time visual-spatial thinking has been found to have a statistically significant direct effect on reading comprehension, in any population. This study provides hypotheses to explain the effects of visual-spatial thinking on college-age students' reading comprehension and offers instructional strategies to assist faculty in improving student learning in higher education settings.

Introduction

Reading is one of the most import skills for college success, yet not all students are accomplished readers. In an effort to advance empirical knowledge and assist education professionals, many researchers have investigated the relative effects of specific areas of intelligence on students' reading performance. Much of this research, however, has been conducted within contexts that lack consistent theoretical modeling and construct identification (Floyd, Keith, Taub, & Mc Grew 2007). The lack of a common theoretical framework and nomenclature to account for the constellation of specific areas or components of intelligence important for reading success, across studies, makes organizing results from diverse publications difficult. Although a common nomenclature has not been used to describe the components of intelligence essential for reading success, it appears that researchers consistently identify five specific broad areas responsible for reading success. These five areas are: auditory processing, memory, retrieval,

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vocabulary/comprehension, and visual-spatial processing (e.g., Hoskyn & Swanson, 2000; Kuhn & Stahl, 2003; Stuebing et al., 2002).

The first area, auditory processing, is believed to be important in auditory discrimination, perception, and the manipulation of sound (Keith, 1999; Lonigan, Burgess, & Anthony, 2000; Scarborough & Brady, 2002). The second area important to successful reading is memory. This component is responsible for tasks that include retention of information in immediate awareness and mental manipulation of words and sounds; this is also referred to as immediate memory, phonological memory, and working memory (e.g., McGrew, Flanagan, Keith, & Vanderwood, 1997; Swanson, 2000; Wagner, et al., 1997). Third is a mental retrieval component. This component is involved in accessing previously acquired knowledge and in activities requiring speed in accessing information, such as serial naming, rapid automatized naming, phonological retrieval, and rate of access (Tiu, Thompson & Lewis, 2003; Wolfe, Bowers, & Biddle, 2000). The vocabulary/ comprehension as area consists of word knowledge, verbal intelligence, syntactical knowledge, semantic processing, language, receptive vocabulary, and verbal reasoning (e.g., Butler, Marsh, Sheppard, & Sheppard, 1985; de Jong & van der Leij, 1999). Finally, the visual-spatial area is referred to as alphabetic coding, letter-identification, orthography, and visual discrimination (Chall, 1996; Kuhn & Stahl, 2003).

The five areas of intelligence identified above can be classified into five broad factors within a contemporary theory of intelligence. The Cattell-Horn-Carroll (CHC) theoretical model of intelligence offers a comprehensive framework and nomenclature which may assist with integrating results across studies. Applying a consistent theoretical framework and nomenclature may also help educators understand relations between areas of intelligence, which are labeled as broad cognitive factors in CHC nomenclature, and reading achievement (e.g., Floyd et al., 2007).

Potential benefits from research identifying the relationship between CHC factors and reading comprehension include improved curricula and student learning; core outcomes within the scholarship of teaching and learning (Hutchings, Huber, & Ciccone, 2011). Since all students are not accomplished readers, identifying strategies to accommodate students who display difficulty with reading comprehension assists faculty as they apply strategies to improve their teaching and instruction. This is the tradition of research in the scholarship of teaching and learning, to expand discipline-based knowledge in an effort to enhance education (Burke, Johnson, & Kemp, 2010). Strategies to improve learning outcomes include those that increase students' opportunity to learn or reduce the time needed to learn (Bloom, 1968). Although any learning requires the opportunity to learn, time alone is not sufficient to ensure mastery of a task, instructional unit, or curriculum (Carroll, 1989). It is what goes on during this time that makes the difference. Thus a key goal of this study is to identify strategies faculty may apply to enhance student learning as well as approaches students may use to improve learning outcomes.

Cattell-Horn-Carroll Theory

The CHC theoretical model is considered one of the most empirically supported and theoretically sound models of intelligence (Carroll, 1993; 2003; Flanagan, McGrew & Ortiz, 2000; McGrew & Wendling, 2010; McGrew & Flanagan 1998; Stankov, 2000). The CHC model is hierarchical in nature. The CHC model places the general factor of intelligence, g, at its highest level. The second level consists of seven broad factors (i.e., seven separate areas of intelligence). The seven broad factors located at the second level of the CHC model include auditory processing, crystallized intelligence, fluid reasoning, long-term retrieval, processing speed, short-term memory, and visual-spatial thinking. A brief description of each of the seven CHC broad factors is presented in Table 1. The CHC model provides a common nomenclature for educators, practitioners, and researchers to use when discussing areas of intelligence and their relationship with the acquisition and maintenance of academic knowledge and skills (McGrew 1997; McGrew & Wendling, 2010). In keeping with the CHC nomenclature, the five areas previously identified as important in reading achievement are the broad CHC factors: auditory processing (e.g., auditory discrimination, perception, and the manipulation of sound), short-term memory (e.g., immediate memory, phonological memory, and working memory), long-term retrieval (e.g., accessing previously acquired knowledge), crystallized intelligence (e.g., word knowledge, verbal intelligence, syntactical knowledge, semantic processing), and visual-spatial thinking (e.g., visual discrimination), respectively.

Table 1. Descriptions of the Seven Cattel-Horn-Carroll (CHC) Broad Factors

CHC Factor	**Description**
Auditory Processing	Analyze, discriminate, and synthesize auditory stimuli
Crystallized Intelligence	The depth and breadth of an individual's acquired knowledge, the communication of this knowledge, and to reason using previously learned experiences or procedures.
Fluid Reasoning	Solveing problems using inductive and deductive reasoning as well as forming concepts using novel or unfamiliar information or procedures
Long-Term Retrieval	The storage, retrieval, and use concepts or facts fluently from memory
Processing Speed	Speed of mental processing under conditions requiring sustained attention and concentration, cognitive efficiency

Short-term memory	The conscious holding of information, storage of information, and use of information within a few seconds (includes working memory capacity)
Visual-spatial thinking	Analyzing, perceiving, synthesizing and thinking with visual stimuli including the ability to store and recall visual representations

Purpose of the Study

The purpose of the present study is threefold. The first purpose is to go beyond earlier investigations by using structural equation modeling (SEM) to identify the effects of the seven CHC broad factors and general intelligence on reading comprehension. The second purpose is to extend research examining the effects of these factors on the reading comprehension of college-age students. The third purpose is to extend the results from this study in reading comprehension and CHC theory to improve student learning.

Method

Participants

Participants in this study were drawn from one of five age groups within the Woodcock-Johnson III's (WJ III) standardization sample (Woodcock, McGrew & Mather, 2001). The age of participants ranged from 20 to 39 (n = 1423). Thus, the sample is representative of traditional students who have completed at least one year of college as well as non-traditional students through age 39.

Instruments

Test indicators for the study consisted of 4 tests from the WJ III Tests of Achievement (ACH) 18 tests from the WJ III Tests of Cognitive Abilities (COG) and 5 tests from the WJ III Diagnostic Supplement (Woodcock, McGrew, Mather, & Schrank, 2003).

The Passage Comprehension and Reading Vocabulary tests from the WJ III ACH served as indicators of the dependent variable, reading comprehension. The Passage Comprehension test required participants to read and comprehend contextual information while the Reading Vocabulary test required participants to use synonyms, use anonyms, and solve analogies.

Data Analysis

The AMOS 7.0 (Arbuckle, 2007) statistical program was used to conduct all SEM analyses. Input data were the correlations and standard deviations of scores. Participants were randomly divided into two separate subsamples as recommended by MacCallum, Roznowski, Mar, and Reith (1994). Dividing the sample permitted the use of one dataset for model generation and calibration, whereas the second dataset was used for model cross-validation. Employing independent calibration and validation datasets provides results which are more stable and replicable.

Models. The CHC model used in this investigation is presented in Figure 1. The CHC model is hierarchical in nature. Tests presented on the left side of Figure 1 serve as indicators of the seven CHC broad factors. General intelligence (g) is present at the apex of the model. As can be seen, there are at least three different indicators (tests) for each of the seven CHC factors presented in Figure 1. Three indicators per factor are used to ensure adequate construct representation for data analysis purposes. The dependent variable, reading comprehension, is located on the right side of Figure 1. The SEM measurement model presented in Figure 1 is consistent with previous research and has empirical support (e.g., Floyd et al., 2007; McGrew & Woodcock, 2001; Taub & McGrew, 2004).

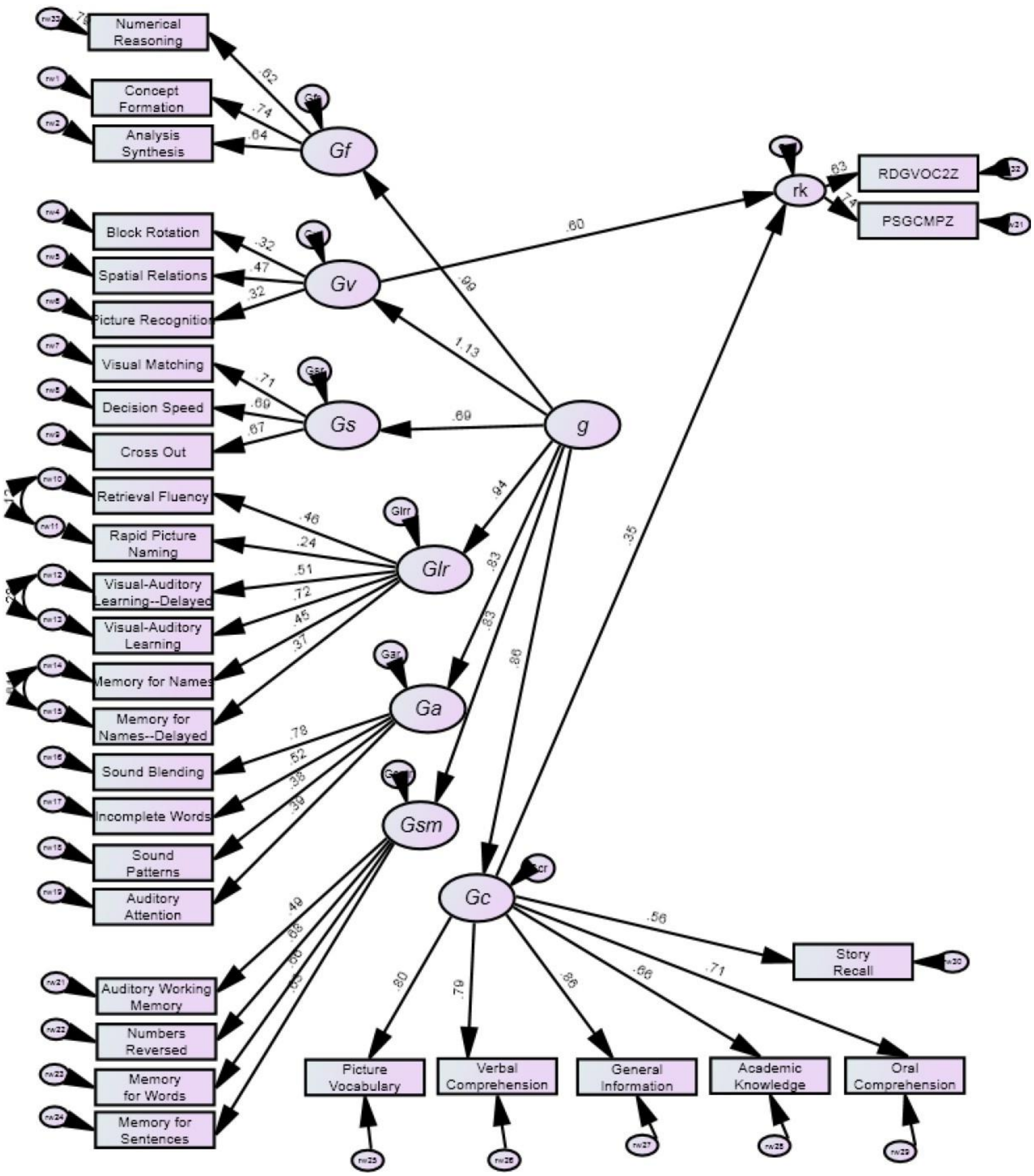

Figure 1. The standardized path coefficients of the validation model for the college-age sample's scores on reading comprehension. Ga = auditory processing, Gc = crystallized intelligence, Gf = fluid reasoning, Glr = long-term retreieval, Gs = processing speed, Gsm = short-term memory, Gv = visual-spatial thinking, g = general intelligence.

Analysis. In the first Phase of the analysis, Phase 1, the calibration data was used for initial model estimation. This provides an opportunity to evaluate and identify the combination of CHC broad factors that are statistically significant predictors of the dependent variable, reading comprehension. Analyses were conducted in stages. During the first stage, a baseline model was identified. The baseline model included all structural paths presented in Figure 1. After baseline model generation, all structural paths with critical values below 1.96 ($p \geq .05$) or paths with negative values were removed. Eliminating paths with low critical values and negative values resulted in the generation of a new model. The new model only contained paths above the critical threshold and positive values. In the next stage, the model was re-estimated, after which an examination of modification indices was conducted to evaluate the need to add any of the eliminated paths. The process of removing all paths with low critical values and all negative paths and estimating the new model was conducted until a final model was obtained that contained only positive paths with values above the critical threshold. In Phase 2, the validation phase, the final model generated from Phase 1 was cross-validated using the independent validation dataset (MacCallum et al., 1994).

Results

This study examined the effects of the seven CHC broad factors and a general intelligence factor on participants' reading comprehension. The study consisted of two phases, Phase 1, a calibration phase and Phase 2, a validation phase. Two datasets were analyzed, one in each phase of the study. The calibration dataset was used for initial model generation and specification. Several goodness of fit indices were examined to provide evidence of the fit of the final model to the data. These fit indices include the comparative fit index (CFI), root mean square error of approximation (RMSEA), and the Tucker-Lewis index (TLI). Lower values on the RMSEA indicate a better fit to the model. In contrast, higher scores on the CFI and TLI indicate a better fit of the model to the data, with 1.0 indicating a perfect fit (Byrne, 2001).

The goodness of fit indices for participants' scores using the calibration dataset on the RMSEA, CFI, and TLI are .065, .842, and .826, respectively. The best calibration dataset model identified during Phase 1 was validated using an independent validation dataset in Phase 2. Results of the final analysis using the validation dataset, presented in Figure 1, indicated that all structural paths were statistically significant. Goodness of fit indices also were examined to provide evidence of the fit of the final model to the data. The goodness of fit indices on the validation dataset for the college-age participants' scores on the RMSEA, CFI, and TLI are .067, .848, and .833, respectively and indicate an adequate fit of the model to the data. The results from this study indicate that the CHC-based broad factors crystallized intelligence and visual-spatial thinking were the only factors having a *direct* effect on the reading comprehension dependent variable. The effect of general intelligence on reading comprehension was *indirect.* The direct effect of crystallized intelligence on reading comprehension was .35 while the direct effect of visual-spatial thinking on reading comprehension was .60.

Discussion

The purpose of this study was threefold. The first purpose was to go beyond earlier investigations by using SEM to identify which of the seven CHC broad factors are most important in reading comprehension. The second purpose was to extend research in the effects of the CHC-based factors to include college-age students' performance on reading comprehension activities. The final purpose of the study is to extend the results from research in CHC theory and reading comprehension to improve student learning.

Results from this study indicate that the CHC-based factors crystallized intelligence and visual-spatial thinking have statistically significant direct effects on reading comprehension. There is a strong body of research linking crystallized intelligence and verbal ability (e.g, lexical processing, language development) with reading achievement (e.g., Dufva, Niemi, & Voeten, 2001; Evans, Floyd, McGrew, & Leforgee, 2002; Floyd et al, 2007; Vellutino, Scanlon, & Lyon, 2000). Crystallized intelligence represents the depth and breadth of one's knowledge, whereas reading comprehension requires the acquisition of declarative and procedural knowledge, thus there is a logical connection between the two.

Previous research also found a strong and consistent relationship between crystallized intelligence and reading achievement of participants ages 9 to 19 (e.g., Benson, 2010; Evans et al., 2002; 2007; Keith, 1999; McGrew et al., 1997; McGrew & Hessler, 1995). Thus, it was not surprising to find that crystallized intelligence was statistically related to college-age students' reading comprehension.

In a previous research investigating the effect of CHC broad factors and *g* on basic reading skills, visual-spatial thinking was not identified as a statistically significant CHC factor. This is consistent with other (non CHC-based) research investigating the relationship between abilities generally associated with visual-spatial processing and reading (eg., Nation, Clarke, & Snowling, 2002).

It is important to note that CHC theory includes seven broad factors or areas of intelligence. The model used in this study included all seven broad factors. Thus, the emergence of crystallized intelligence and visual-spatial thinking's statistically significant effects on reading comprehension occurred with the other five CHC broad factors in the model. This means that crystallized intelligence and visual-spatial thinking accounted for a statistically significant portion of variance in the prediction of reading comprehension in a model which initially contained the other five CHC factors (i.e., auditory processing, fluid reasoning, long-term retrieval, processing speed, and short-term memory).

In an attempt to explain the statistically significant effect of visual-spatial thinking on college students' reading comprehension, two hypotheses are offered. The first hypothesis accounts for the role of visual-spatial thinking within a physiologically-based framework. The second hypothesis offered is an attempt to explain why visual-spatial thinking is not statistically significantly related to reading comprehension until the college years.

Previous research investigating visual-spatial thinking and the reading comprehension of college-age participants' identified an active spatial encoding process during reading activities. This process is evidenced by readers stating where on a page (e.g., bottom left) the answer to a specific question was located (e.g., Rothkopf, 1971; Zeichmeister &

McKillip, 1972). The role of the spatial encoding process was also identified as responsible for resolving linguistic difficulties, meaning the eye is capable of backtracking to the exact area in the sentence where information needed to resolve ambiguity is found (Murray & Kennedy, 1988). More recently, neurocognitive studies found that sensory cortices are involved in reading tasks wherein participants engage in both conscious and unconscious visual imagery when reading. The importance of these sensory cortices was also demonstrated through neurocognitive mechanisms via functional magnetic resonance imagining studies (e.g., Buccino et al., 2005; Olaf & Friedemann, 2004). It is possible that visual discrimination, visual memory, as well as neurologically-based encoding processes and sensory cortices, play a more critical role in reading comprehension than is indicated in previous research investigating the relationship between visual-spatial processing in general and reading comprehension.

The appearance of visual-spatial thinking's effect on reading comprehension within a sample of college-age participants, but not in the reading comprehension of younger participants, may be due, in part to developmental differences. Growth curves created using the WJ III standardization data (McGrew & Woodcock, 2001) indicate that most CHC factors developmentally peak and asymptote within the developmental range of the present study's participants. So it is possible that as visual-spatial thinking abilities continue their growth, abilities associated with other factors reach their asymptote. This creates an opportunity for visual-spatial thinking abilities to come online and supplement the reading process.

Another key finding from this study is general intelligence has only an indirect effect on reading comprehension of college-age students. When we say a person is *academically intelligent* this is analogues to saying this person is high on general intelligence. The results from the present study indicate that an individual's level of general intelligence has an indirect effect on students' reading comprehension, whereas crystallized intelligence and visual-spatial thinking have a statistically significant direct effect on college-age students' reading comprehension.

Limitations

The findings from this study are limited by the dataset used in the analyses; specifically all data used in this research came from a single battery of tests. Second, the reading comprehension dependent variable in the present study was specific to the tests administered, meaning all methods of measuring reading comprehension and all skills associated with reading comprehension were not accounted for by the battery of tests administered in the study. There are several strengths within the study as well. The study's input data are derived from well-respected standardized instruments measuring both reading comprehension and areas of intelligence. The use of a separate calibration dataset for model specification and estimation as well as a dataset for model validation is also strength of the study. This is because the use of two datasets provides more stable results when compared to using a single dataset.

Implications for Educators

The results from this study indicate that crystallized intelligence and visual-spatial thinking play an important role in the successful reading comprehension of college-age students. Therefore, students may benefit from explicit strategies addressing these two CHC factors. For example, crystallized intelligence is composed of the depth and breadth of one's acquired knowledge. Readers must relate his/her own acquired knowledge to the text. If students do not have sufficient background knowledge to integrate content within a text with previously acquired knowledge, faculty may consider providing students with explicit and systematic instruction prior to requiring students to read to learn (Vacca, et al., 2003). Additionally, students may apply megacognitive strategies that involve self-monitoring of understanding (e.g., Koch, 2001; Thiede, Anderson, & Therriault, 2003). Such strategies include identifying areas (e.g., content areas, word definitions, and expository information) which are unclear and making a brief note on a piece of paper to obtain clarification.

Learners also can capitalize on intrapersonal strengths to improve learning outcomes. For example, strategies designed to link new information with previously acquired knowledge (crystallized intelligence) may assist student learning. Such strategies might include processing information in immediate awareness through note taking, rehearsing, semantic mapping, semantic feature analysis, and underlining (e.g., Blanchard, & Mikkelson, 1987; Anders, & Bos, 1986; Bos, & Vaughn, 2001; Nist, Sharman, & Holschuh, 1996).
The second CHC broad factor identified as important in reading comprehension is visual-spatial thinking. Instructional strategies which may assist students' visual-spatial understanding of reading material may include drawing attention to areas which may be visually confusing such as charts, columns, maps, and webpages. Additional instructional strategies designed to link various content within graphics may also improve student learning (Mather & Jaffee, 2002). Students with highly developed visual-spatial thinking skills are often holistic learners. They may benefit from the use of visual imagery rather than words to connect ideas (e.g., picture a web or mind map linking ideas together).

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