STUDYING WHILE MULTITASKING: EFFECTS OF COGNITIVE STYLE AND WORKING MEMORY CAPACITY

A Dissertation

by

CRINA SILASI-MANSAT

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Chair of Committee,	Darrell Worthy
Committee Members,	Takashi Yamauchi
	Charles Samuelson
	Jeff Liew
Head of Department,	Douglas Woods

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ABSTRACT

The current project asked in two studies whether individual differences in working memory capacity (WMC) and cognitive style influence learning under multitasking conditions. In both studies, a median split on the Word-relation task and OSPAN test divided participants into categorical-relational thinkers and into high – low WMC groups, respectively. A reading comprehension task was utilized to assess learning in both studies. In study 1, the multitasking condition was created by asking all participants to perform in a visual monitoring task while reading a passage in the reading comprehension task. In Study 2, half of the participants performed in in the visual monitoring task, while the other half listened to music while reading a passage in the reading comprehension task. Thus, Study 2 was designed as a replication and extension of Study 1. It was predicted that in both studies, relational thinkers with low WMC will show the most decrease in the reading comprehension performance under multitasking conditions due to the lack of sufficient cognitive resources needed to perform well in the task. In study 1, results from a mixed factorial ANOVA showed a significant WMC x cognitive style interaction within the multitasking, but not the single task condition. As predicted, low WMC relational thinkers showed the highest decrease in the reading comprehension performance in the multitasking condition compared to any other group. Results replicated in Study 2 within each multitasking context. These results suggest that the relational cognitive style is more cognitively demanding and requires more working memory resources than categorical cognitive style. At a broader level, they emphasize the need to consider both personal and environmental factors for a better understanding of multitasking behavior. Future directions and implications of the studies are also discussed.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Nowadays, situations where doctors perform medical procedures while giving instructions to nurses or where pilots attend to information from several sources while attending to additional subtasks are ubiquitous. Handling two or more tasks in the same general time period, or multitasking (Delbridge, 2001), clearly characterizes our working environment. Nowhere is the presence of multitasking more obvious, however, than on college campuses (Junco & Cotten, 2012). Born and raised as part of a digital generation, students extensively use information and social technologies while attending classes, doing homework or studying for exams (Cotten, McCullough, & Adams, 2011). Thus, multitasking has become a characteristic of their learning environment and even more, a way of life (Lui & Wong, 2012).

Understanding what factors influence learning under multitasking conditions is relevant not only because the pervasiveness, but also because of the well-documented negative effects of multitasking on cognitive performance. Research showed, for example, that students took longer to read a passage from a textbook and performed poorly in reading comprehension and memory tasks when chatting via instant-messaging (Bowman, Levine, Waite, & Gendron, 2010) or watching TV (Armstrong, Boiarsky, & Mares, 1991; Pool, Koolstra, & van der Voort, 2003), respectively. Such negative effects have been shown in the classroom also, where listening to a lecture while browsing on the laptop led to a poor performance on traditional memory measures compared to listening to the lecture without using the laptop (Heembrooke & Gay, 2003).

While the empirical evidence that supports the negative effects of multitasking on cognitive performance is compelling, less is known about the individual differences that influence such effects. The current project focuses precisely on this caveat and takes an individual difference approach to two potential factors, namely working memory capacity (WMC) and cognitive style, to determine how they influence learning under multitasking conditions. More precisely, the current project focused on comprehension, which is considered the foundation for an efficient learning process (Paris, Lipson, & Wixson, 1983; Sporer, Brunstein, & Kieschke, 2009).

Working memory capacity

One factor that has been shown to influence learning and multitasking processes is individual differences in working memory capacity (WMC). WMC represents the ability to store and manipulate information and is a limited resource (Berti & Schröger, 2003; Kane & Engle, 2002). Plenty of research shows an advantage for people with high WMC in learning performance. For example, high levels of WMC have been associated with higher ability to acquire knowledge and new skills (Cowan & Alloway, 2008; Gathercole, Pickering, Knight, & Stegmann, 2003), with better reading achievement (Swanson & Beebe-Frankenberger, 2004), math outcomes (Gathercole et al., 2003; Swanson & Sachse-Lee, 2001), and computational skills (Bull & Scerif, 2001; Geary, Hoard, & Hamson, 1999).

More importantly higher levels of WMC have been related to better comprehension skills (Daneman & Carpenter, 1980; Daneman & Green, 1986) even at the ages of 8 - 11 years (Cain, Oakhill, & Bryant, 2004). In this direction, the capacity theory of comprehension (Just & Carpenter, 1992) suggests that the advantage for high WMC people in comprehension tasks relates to their higher amount of available cognitive resources needed to successfully engage in storing and processing information when performing in the tasks. Thus, high working memory resources lead to better comprehension, especially for more complex material (Carretti, Borella, Cornoldi, De Beni, 2008; Cornoldi & Vecchi, 2003).

The same advantage for people with high WMC has been observed in multitasking performance. For example, participants with high WMC accurately identified various stimuli while attending to other tasks (Konig, Buhner, & Murling, 2005), and performed better in two visuospatial tasks when asked to attend to them simultaneously (Colom, Martinez-Molina, Shih, & Santacreu, 2010). In this direction, research shows that WMC is involved in processes such as storing and transforming stored information, connecting and organizing pieces of information, monitoring ongoing cognitive processes, or detection of irrelevant information (Oberauer, Suß, , Schulze, Wilhelm, & Wittmann (2000); Carretti et al., 2009; Jaschinski & Wentura, 2002; Kane & Engle, 2003). Such processes are also relevant for multitasking (Meyer & Kieras, 1997). Successfully engaging in such processes does not seem to be problematic when sufficient working memory resources are available or when the tasks at hand are low in cognitive demands. Multitasking, however, imposes high cognitive demands on multitaskers' working memory resources and higher availability of such resources is necessary for a successful engagement in the process. It follows, then, that higher levels of WMC would be advantageous in multitasking contexts and would be associated with better multitasking performance.

Cognitive style

Cognitive style represents people's way of processing and organizing information when attending to cognitive tasks (Sternberg & Grigorenko, 2001). Multiple styles (e.g., adaptor-innovator, intuitive-analytical; see Kozhevnikov et al. 2014 for a review) have been proposed and studied within various contexts, such as management or decision-making. This project focuses, however, on the categorical and relational cognitive styles due to their involvement in the learning process and their influence on learning outcomes (Robinson, Navea, & Ickes, 2013; Tausczik & Pennebaker, 2009). Research shows that when processing information, people with a *categorical* cognitive style, or categorical thinkers, tend to focus on the common features of objects and things, which they use to group information within categories (Figure 1a). The developed categories will further be nested within broader categories, generating a hierarchical, taxonomic-like organization of information (Robinson, Navea, & Ickes, 2013; Pennebaker, Chung, Frazee, Lavergne, & Beaver, 2014). For example, if presented with the words bus, train, and tracks, categorical thinkers would generate a superordinate level (i.e., vehicle) to group bus and train within one category.

People with a *relational* cognitive style, or relational thinkers, however, tend to focus on the possible actions that connect objects and things (Figure 1b). As a result, if presented with the same three words, relational thinkers would connect train and tracks because trains move on tracks. Thus, when trying to find logical patterns of information, relational thinkers develop a matrix-like organization of information consisting in multiple action-based relations between pieces of information (Kray, Galinsky, & Wong, 2006; Robinson et al., 2013; Williams, 2002).

(a) (b)

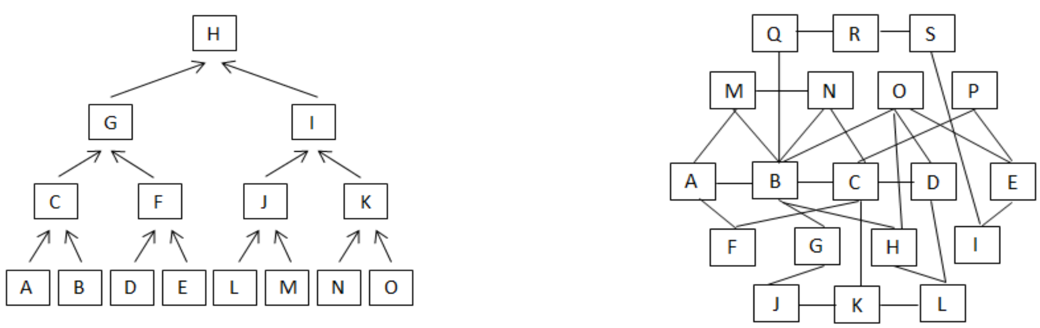

Figure 1: *(a) Categorical cognitive style and (b) Relational cognitive style*

The distinction between the categorical and relational thinkers has emerged in various contexts. For example, the two styles have been associated with people's patterns of word usage, such that a greater noun use was associated with a categorical cognitive style, while a greater verb use was associated with a relational cognitive style (Pennebaker et al., 2014; Robinson et al., 2013; Tausczik & Pennebaker, 2009). This is not surprising, given that nouns serve the function of labeling and categorizing objects and things, while verbs serve the function of tracking action or conveying a relationship between objects and things.

More importantly, however, categorical and relational cognitive styles have been shown to be predictors of academic performance in college (Pennebaker, 2011; Pennebaker et al., 2014), even after controlling for individual differences in intelligence, socio-economic status, conscientiousness, sociability, negative affect, and course engagement (Ferrell, Tucker-Drob, & Pennebaker, 2015). Thus, after a linguistic analysis of word usage in a corpus of over 50,000 essays identified students with categorical or relational cognitive style, results showed that a categorical cognitive style was consistently associated with higher academic performance, as it reflected in students' testing performance and overall GPA. A relational cognitive style, however, was consistently associated with lower academic performance. Such evidence leads, then, to the conclusion that a categorical cognitive style is advantageous for learning.

Current project

Thus, empirical evidence clearly shows that both person (i.e., cognitive style, WMC) and environmental characteristics (i.e., multitasking requirements) influence learning, whether it reflects in comprehension of material, successfully acquiring new skills, testing performance, or overall GPA. Although it seems logical that a comprehensive view of the learning process would require observing the interaction between these characteristics, no research has taken such an approach. The purpose of this project is to fill in this gap by asking two important questions in two studies. The first question addressed in the current studies is whether people's level of WMC and their cognitive style influence learning, as reflected in comprehension of read material, within a multitasking context. The second question, addressed in Study 2, is whether the pattern of results obtained in Study 1 replicates and extends to different multitasking contexts.

To answer these questions, participants' cognitive style and their level of WMC was assessed. Comprehension of read material was assessed in both studies by a reading comprehension task, where the presence of multitasking requirements (multitasking condition) was manipulated for the reading section, but not for the testing of comprehension section of the task. In addition, multitasking context was manipulated in Study 2, which makes Study 2 not only a replication, but also an extension of Study 1.

Regarding the first question, I predict that individual differences in cognitive style will significantly interact with individual differences in WMC. However, such an interaction will emerge only in the multitasking condition. This prediction stems from previous research suggesting that different cognitive styles are characterized by different levels of complexity and cognitive demands when performing in cognitive tasks (Riding, Grimley, Dahraei, & Banner, 2003). Within the categorical – relational style context, a categorical cognitive style is characterized by a well-ordered organization of information. It allows for a more direct and easier to navigate path towards the information needed to perform in cognitive tasks (Zhang, Sternberg, & Rayner, 2012). As opposed to categorizing information, generating a multitude of action-based associations between various pieces of information leaves the relational thinker with a large amount of associations to juggle (Williams, 2002). The result is a dense and difficult to navigate structure of information. Thus, while both categorical and relational thinkers strive to achieve the same goal - a good comprehension of the material - relational thinkers seem to engage in a more cognitively demanding task as opposed to categorical thinkers to achieve it.

Following this rationale and considering the limited capacity of people's working memory, it seems plausible to predict that performers' levels of WMC would interact with their cognitive style and influence overall reading comprehension performance, whether multitasking occurs or not. It seems just as plausible, however, that this interaction would matter the most when cognitive resources are challenged to the maximum due to multitasking, and matter the least, if at all, when performing in the reading comprehension task under single-task conditions. Thus, I predict that, while reading comprehension performance will decrease for all participants when performing in the multitasking condition, this decrement will be attributed to the performance of relational thinkers with low levels of WMC. This group of participants will show the largest decrease in performance when multitasking. Thus, for relational thinkers, availability of cognitive resources will become essential in order to perform well.

Regarding the second question, I predict that the pattern of results obtained in Study 1 will not only replicate, but also generalize to the additional multitasking context used in Study 2. Thus, the multitasking context will not have a significant effect on reading comprehension performance. However, the same interaction between individual differences in cognitive style and WMC will emerge across both multitasking contexts, but only within the multitasking condition.

STUDY 1

The question of interest in Study 1 is whether individual differences in cognitive style interact with individual differences in WMC and if such an interaction accounts for the detrimental effects of multitasking on learning. To answer the question, performance on the Word-relation task (Knight & Nisbett, 2007) and the Automated OSPAN test (described in the section below; Unsworth, Heitz, Schrock, & Engle, 2005) were used to assess participants' cognitive style and WMC, respectively. Both tasks have been previously used in multiple studies with the same purpose (Knight & Nisbett, 2007; Beilock & Carr, 2005). Participants also performed in a reading comprehension task, which assessed their comprehension of material after reading the tested material under single task and multitasking conditions. To create a multitasking setting, a visual monitoring task was performed along with the reading comprehension task.

The reason for creating this specific multitasking setting is twofold. First, both tasks have been used in previous research to assess people's multitasking performance (Brunken, Steinbacher, Plass, Leutner, 2002; Thompson, Schellenberg, & Letnic, 2011). Such research showed that the visual monitoring task interferes with the reading comprehension task, which leads to a decrease in performance in both tasks. Second, reading while attending to other visual stimuli, such as watching TV, are activities in which students often engage in simultaneously (Ophir, Nass, & Wagner, 2009). Performing in this multitasking setting, then, mimics real life situations and increases somewhat the ecological validity of the study.

I predict that individual differences in cognitive style and WMC will interact, but only within the multitasking condition. Thus, cognitive style and WMC might not be of great importance in the single task condition. However, they will be relevant in the multitasking condition, such that relational thinkers with lower levels of WMC will show the greatest decrease in performance due to multitasking.

Method

Participants

Undergraduates (*N* = 96) at Texas A&M University participated in the study for course credit (66 were female and 30 were male, with an average age of 19 and an age range between 18 and 22). Participants were divided into low or high WMC groups and into categorical or relational cognitive style groups based on a median split of their Operations Span task scores (OSPAN, Unsworth et al., 2005) and Word-Relation task scores (Knight & Nisbett, 2007), respectively. There were 47 participants in the high WMC group, out of which 26 had a categorical cognitive style and 21 had a relational cognitive style. There were 49 participants in the low WMC group, out of which 27 had a categorical cognitive style and 22 had a relational cognitive style.

Materials

Reading comprehension task. In order to assess participants' ability to understand, analyze, and apply concepts from written information (Martinson & Ellis, 1997), two reading comprehension passages (*Appendix 1*) were taken from the online practice Graduate Management Admission Test (GMAT). Each passage was approximately 450 words and was presented on a computer screen in black letters on a white background. One passage discussed a proposed theory about the onset of the ice age (i.e., passage 1), while the other passage discussed the revival of the Byzantine Empire (i.e., passage 2). Reading comprehension was assessed by 6 multiple-choice questions about the content of each passage (e.g., "In the passage, the author is primarily interested in:…"), each question providing participants with 5 possible answers to choose from.

Visual monitoring task. The visual monitoring task involved monitoring and responding to the change in color of a stimulus, specifically the letter "A" (font size of 28), displayed on the top section of the screen. The color of the letter alternated between black (the initial color) and red at random intervals ranging between 5 – 10 s. Participants pressed the space bar when they detected the letter changing from black to red. The time elapsed between the appearance of the letter in red and the participants' response was recorded. Once a response was made, the letter returned to the color black and the next countdown started. Within the multitasking condition, the reading comprehension passage was also displayed on the computer screen below the letter, while a timer was displayed in the right corner of the screen.

Word-relation task. The Word-Relation Task involved presenting participants with 20 sets of three words each (e.g., monkey, bananas, panda) and asking them to choose which two words in each set belong together (e.g., monkey – bananas, panda – bananas). Participants were presented with three possible options to choose from, each option representing a possible pairing of two out of three words in each set. Ten sets contained test items and ten sets contained filler items (*Appendix 2*). The three words in any of the testing set (e.g., monkey, bananas, panda) were grouped in three ways: (a) based on thematic relations if they suggested an object/subject – context relationship (e.g., monkey – bananas); (b) based on categorical relationship if they suggested shared features or category membership (e.g., monkey – panda); (c) neither relational nor categorical (e.g., bananas – panda). The grouping of the words included in the filler sets (e.g., Monday – Wednesday – Friday), while recorded, was not relevant to the study and was not included in the analyses.

The Automated OSPAN test. OSPAN is an extensively used task that assesses people's WMC level by requiring them to remember a series of letters while performing arithmetic problems. Participants saw an equation on the computer screen, such as "(4*3) + 5=?", and attempted to mentally solve it. After viewing a possible solution on the next screen, they pressed "True" or "False" depending on whether they considered the provided solution as being correct or incorrect. After each response, a letter was presented on the screen (for 800ms) for later recall. The task consisted in 3-7 equation-letter presentations, followed in the end by 12 letters presented on the screen within a 4 x 3 matrix. Each matrix contained the 3-7 letters presented in the previous sequence, randomly situated in the matrix, and was completed with non-viewed letters to fill the matrix. Participants were asked to recall and select, in order, the sequence of letters viewed after each equation. The tasks consisted of a total of 15 letter recall sequences that varied between 3-7 letters in length (three sequences for each sequence length), summing up to a total of 75 randomly presented equation-letter presentations.

Procedure

All participants completed the reading comprehension task (in both single and multitasking conditions), the visual monitoring and the OSPAN tasks using Psychtoolbox for Matlab (version 2.5). All participants also performed in the Word-Relation Task, which was presented via an online survey created in Google Forms. Ordering of the tasks presentation was counterbalanced. When performing in OSPAN, participants read a short description of the task and were instructed to maintain at least 85% accuracy in solving the arithmetic problems. After the practice trials, they proceeded to the actual OSPAN task. Their accuracy in solving the arithmetic problems was displayed on the right side of the screen in form of % correct throughout the entire task. A score was calculated for each participant by summing up all perfectly recalled letter sequences (Beilock & Carr, 2005), with higher scores representing higher levels of WMC. Performing in the OSPAN task lasted for approximately 20 min.

Participants were then given instructions to proceed to the next section where they performed in in the visual monitoring task for 3 min. Each participant's average RT was recorded to obtain an individual baseline for their visual monitoring performance. Participants performed next in the reading comprehension task with and without the additional visual monitoring task.

In the reading comprehension task, participants read a short description of the tasks and were then presented with one of the two reading passages. The order of the two passages was counterbalanced between the single task and multitasking conditions, such that half of the participants read passage 1 in the single task condition and passage 2 in the multitasking condition, while the other half read passage 2 in the single task condition and passage 1 in the multitasking condition. In the single task condition, one of the two passages and a timer were displayed on the screen and participants were allowed 4 min to read the passage. After 4 min, six multiple choice questions about the presented material were successively displayed on the screen. Participants were informed that they have 3 min to answer all questions by pressing the number corresponding to the chosen answer on the keyboard. After selecting one of the 5 possible answers for each question, participants pressed the space-bar to move to the next question without having the option to return to it. The RT, or the time elapsed between the presentation of each question and making a response, was recorded and averaged for each participant, along with the accuracy for each answer. One point was allocated for each correct answer, while zero points were allocated for each incorrect or missing answer (Furnham & Allass, 1999). A composite score was computed for each participant by adding all the accumulated points. This composite score was then transformed into % from a total possible of 6 points. Thus, higher scores represented better reading comprehension performances.

In the multitasking condition, participants performed in the visual monitoring task and the reading comprehension task simultaneously. That is, they monitored and responded to the letter's changes in color throughout the entire 4 min of reading the passage. Like the single task condition, the RT and accuracy in answering the six multiple-choice questions was recorded. In addition, performance on the visual monitoring task was also assessed by computing each participant's average RT. Each reading comprehension task, regardless of condition, lasted approximately 8 min.

Lastly, participants performed in the Word-Relation Task. They were instructed to read each set of words and choose which two words in each set belonged together. Each set, along with the three possible word combinations to choose from, was displayed successively on the screen and participants responded by clicking on the pairing of the words that they considered that belonged together. Each test item response was awarded 1 point or 0 points based on whether they used a categorical or a relational cognitive style when pairing the words, respectively. Answers that did not fit either style were excluded from analyses. The 10 test items scores were averaged for each participant, resulting in a proportion ranging between 0 and 1. Higher values indicated the use of a categorical cognitive style, while lower values indicated the use of the relational cognitive style. This section lasted approximately 5 min. Overall, the study lasted approximately 45 min.

Results

Tests for the median split differences

In order to establish if the two WMC (high and low) and cognitive style (categorical and relational) groups are different in their scores on the OSPAN and Word-Relation Task, respectively, we conducted independent samples t-tests. Results showed a significant difference between the high and low WMC groups on the OSPAN scores, $t(94) = -13.81$, $p < .01$, such that the high WMC group ($M = 55.65$, $SD = 12.14$) had significantly higher OSPAN scores than the low WMC group ($M = 27.45$, $SD = 9.14$). Similarly, results showed a significant difference between the participants with categorical or relational cognitive style in their Word-Relation

Task scores, *t*(105) = - 20.14, $p < .01$, such that participants with categorical cognitive style (*M* = .92, *SD* = .06) scored significantly higher on the Word-Relation Task than participants with relational cognitive style (*M* = .35, *SD* = .15).

Mixed ANOVA analysis

All participants achieved at least 85% accuracy on the arithmetic section of the OSPAN task. To test whether people's levels of WMC and their cognitive style influence comprehension differently when reading occurs under single task or multitasking conditions, we performed a 2 (WMC: high or low) X 2 (Cognitive style: categorical or relational) x 2 (Task condition: single task or multitasking) mixed ANOVA on participants' reading comprehension performance. Figure 2 shows participants' performance in the reading comprehension task for each group in each task condition. Results showed a significant ME for WMC, $F(1,92) = 38.82$, $p < .01$, $\eta_p^2 = .30$, such that participants with high WMC (*M* = 57.28, *SD* = 10.56) performed better in the reading comprehension task than participants with low WMC (*M* = 45.06, *SD* = 10.78). Results showed a significant ME for Cognitive style, $F(1,92) = 22.50$, $p < .01$, $\eta_p^2 = .20$, such that participants that employed a categorical cognitive style (*M* = 54.68, *SD* = 9.68) performed better in the RC tasks than participants that employed a relational cognitive style (*M* = 44.63, *SD* = 10.82). There was also a significant ME for Task condition, $F(1,92) = 266.13$, $p < .01$, $\eta_p^2 = .74$, such that participants performed better when reading occurred under single task conditions (*M* = 69.93, *SD* = 14.60) than under multitasking conditions (*M* = 34.15, *SD* = 12.93).

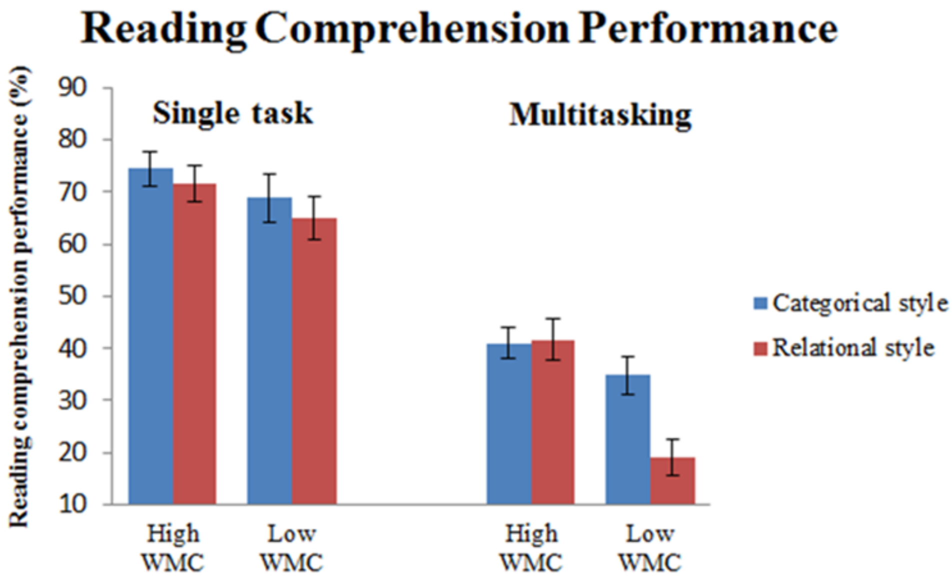

Figure 2: *Participants' performance in the reading comprehension task for each WMC and Cognitive style group within each task condition (Study 1).*

Most importantly, however, results showed a significant WMC x Cognitive style x Task condition interaction, $F(1,92) = 5.82$, $p = .02$, $\eta_p^2 = .06$. When further interpreting the interaction, a 2 (WMC: high or low) x 2 (Cognitive style: categorical or relational) between-participants ANOVA on participants' reading comprehension performance within the single task condition showed no significant WMC x Cognitive style interaction, $F(1,92) = 1.01$, $p = .32$. However, the same analysis showed a significant WMC x Cognitive style interaction within the multitasking condition, $F(1,92) = 5.02$, $p = .03$, $\eta_p^2 = .05$. When interpreting this interaction, pairwise comparisons within the high WMC group showed no difference in reading comprehension performance based on cognitive style, $t(45) = -.76$, $p = .45$. Within low WMC group, however, participants with a categorical cognitive style ($M = 34.83$, $SD = 14.32$)

performed better on the reading comprehension task than participants with relational cognitive style (*M* = 19.17, *SD* = 13.76), $t(45) = -4.00$, $p < .01$. There were no other significant effects.

Auxiliary analyses

We also tested for possible effects of order of task presentation and passage allocation to the two task conditions on the OSPAN, Word-Relation Task, and reading comprehension results. Results showed no significant effects (all *p*'s > .10). In addition, we tested whether there were any significant differences in participants' RTs when performing in the single task as opposed to multitasking condition. A paired-sample t-test showed that participants responded faster (*M* = 24.67, *SD* = 5.75.) in the multitasking condition as opposed to the single task condition (*M* = 22.19, *SD* = 6.49), $t(94) = 3.80$, $p < .01$. Lastly, we tested whether multitasking had an impact on participants' performance in the visual monitoring task. A paired-sample t-test showed that participants had longer RTs, thus took longer to detect a change in the letter's color, when multitasking (*M* = 2.58, *SD* = .44) than when attending solely to the visual monitoring task (*M* = .44, *SD* = .56).

Discussion

When looking at the effect of each individual difference factor in isolation, results showed that overall, high levels of WMC and a categorical cognitive style are beneficial for reading comprehension performance. Results also showed a decrease in reading comprehension performance when multitasking, which supports the view that multitasking is detrimental for cognitive performance (Foerde, Knowlton, & Poldrak., 2006; Gilbert, Tafarodi, & Malone, 1993; Monsell, 2003). When looking at the interaction between the three factors, however, a different pattern of results emerged. Thus, as opposed to the single task condition, in the multitasking condition low WMC relational thinkers performed significantly worse than all other groups in this condition. In fact, this group of participants showed the worst decrease in performance compared to all other groups in any condition.

These results fall in line with our predictions and bring empirical support to the important role played by individual differences in WMC and cognitive style in people's ability to attend to school-related work while multitasking. While Study 1 represents an important first step in this direction, more research is needed to support these findings and to test the parameters within which they tend to replicate. Thus, Study 2 was designed with this purpose and it attempts to not only replicate, but also extend the first study to an additional multitasking context.

STUDY 2

In Study 2, the same tasks used in the first study were used to assess participants' WMC, cognitive style, and comprehension ability. In addition, multitasking context was manipulated. In one multitasking context (visual monitoring context), participants performed in the same visual monitoring task used in Study 1 while reading the passages. In the second multitasking context, participants read the passages while music was playing in the background (music context). Previous research (Furnham & Allas, 1999; Thompson et al., 2011) used a similar methodology to create multitasking conditions and showed that similarly to the visual monitoring task, music interferes with the reading comprehension task by reducing the cognitive resources allocated to the task. A decrease in reading comprehension performance follows. Also similarly to Study 1, this context attempts to mirror a commonly encountered real-life situation where students attend to school related work while listening to music (Ophir et al., 2009).

The same question asked in Study 1 was asked in Study 2. Does the interplay between WMC and cognitive style account for the detrimental effects of multitasking on learning? I predict a replication of the first study's results, along with its extension to the additional multitasking context. Accordingly, results will show a significant interaction between the individual differences in WMC and cognitive style, but only across in the multitasking condition. Even more, this interaction will be identical across both multitasking contexts, showing that the manipulation of the multitasking context will not change the patterns of results observed in the first study.

Method

Participants

Undergraduates (*N* = 112) at Texas A&M University participated in the study for course credit (77 were female and 25 were male, with an average age of 19 and an age range between 18 and 23). Five participants were excluded from the analyses due to technical difficulties in collecting their data. Like Study 1, a median split on the OSPAN scores was used to determine the high and low WMC groups, while a median split on the Word-Relation Task scores was used to determine participants with categorical or relational cognitive style. The distribution of participants for each WMC and cognitive style group within each multitasking context is presented in Table 1.

	Visual monitoring context (53)		**Music context (54)**		**Total**
	High WMC	Low WMC	High WMC	Low WMC	
Categorical style	13	13	13	15	**54**
Relational style	12	15	16	10	**53**
Total	**25**	**28**	**29**	**25**	**107**

Table 1. *Distribution of participants for each WMC and cognitive style group within each multitasking context, where each number represents N*.

Materials

The same reading comprehension task, visual monitoring task, Automated OSPAN, and Word-Relation Task used in Study 1 have also been used in Study 2. Also identically to Study 1, all participants performed in the reading comprehension task in both single task and multitasking conditions. As opposed to Study 1, however, the multitasking context was manipulated and included as an independent variable in the analyses. One multitasking context replicated the multitasking context from Study 1, where participants read the reading comprehension passages while performing in the visual monitoring task. In the other multitasking context, participants read the reading comprehension passages while listening to music. Previous research showed that fast tempo music has the most detrimental effects on reading comprehension performance (Thompson et al., 2011). Therefore, the song “House Trip” by DJ Jurgen was selected from a list of songs included in Brodsky’s (2002) study concerning the effects of music type on performance. Brodsky (2002) subjected various audio tracks, including “House Trip”, to tempo criterion ratings in accordance with a Swiss-made analog Cadenzia pocket Metronome. “House Trip”, which has no lyrics, was categorized as a fast song (132 bpm) and was played on the computer via YouTube. Headphones were used to eliminate any additional distracting sounds.

Procedure

The procedure followed in Study 2 was similar to the procedure used in Study 1. Participants performed in the OSPAN, the Word-Relation Task, and in the visual monitoring task, along with the reading comprehension task in both single task and multitasking conditions. The ordering of the tasks presentation was counterbalanced. In addition, participants were randomly assigned to one of the two multitasking contexts, such that half participants multitasked while performing in the visual monitoring task (visual monitoring context), while the other half multitasked while listening to music (music context). The procedure for the participants assigned to the visual monitoring context was identical to the one used in Study 1. Participants assigned to the music context were instructed to read the reading comprehension task’s instructions. Then, they were asked to place the headphones with the music already playing on their ears and perform in the reading comprehension task. The music played for the entire 4 minutes that the passage was displayed on the screen.

Results

Tests for the median split differences

In order to establish if the two WMC (high and low) and cognitive style (categorical and relational) groups are different in their scores on the OSPAN and Word-Relation Task, respectively, we conducted independent samples t-tests. Results showed a significant difference between the high and low WMC groups on the OSPAN scores, $t(105) = -13.16$, $p < .01$, such that the high WMC group ($M = 55.65$, $SD = 7.95$) had significantly higher OSPAN scores than the low WMC group ($M = 29.63$, $SD = 12.14$). Similarly, results showed a significant difference between the participants with categorical or relational cognitive style on the Word-Relation Task scores, $t\ (105) = -20.14$, $p < .01$. Participants with categorical cognitive style ($M = .95$, $SD = .05$) scored significantly higher on Word-Relation Task than participants with relational cognitive style ($M = .30$, $SD = .14$).

Mixed ANOVA analysis

All participants achieved at least 85% accuracy on the arithmetic section of the OSPAN task. A 2 (Multitasking context: visual monitoring or music) x 2 (WMC: high or low) X 2 (Cognitive style: categorical or relational) x 2 (Task condition: single task or multitasking) mixed ANOVA on participants' reading comprehension performance showed a significant ME for Task condition, $F(1,99) = 253.63$, $p < .01$, $\eta_p^2 = .72$, such that participants performed better when reading occurred under single task conditions ($M = 69.85$, $SD = 21.72$) than under multitasking conditions ($M = 28.94$, $SD = 13.58$). Results also showed a significant ME for Cognitive style, $F(1,99) = 20.30$, $p < .01$, $\eta_p^2 = .24$, such that participants that employed a categorical cognitive style ($M = 61.87$, $SD = 9.42$) performed better in the RC tasks than participants that employed a relational cognitive style (*M* = 47.15, *SD* = 9.74). Results showed no significant ME or interactions for the Multitasking context, all *p*s > .05. Figure 3 shows the participants' performance in the reading comprehension task for each WMC and Cognitive style group within each task condition for each multitasking context.

Similarly to the results from Study1, in Study 2 results showed a significant WMC x Cognitive style x Task condition interaction, $F(1,99) = 4.76$, $p = .03$., $\eta_p^2 = .05$. Figure 4 shows participants' performance in the reading comprehension task for each WMC and Cognitive style group within each task condition. Here, the data was collapsed across the two multitasking contexts. When further interpreting the interaction, a 2 (WMC: high or low) x 2 (Cognitive style: categorical or relational) mixed ANOVA on participants' reading comprehension performance within the single task condition showed no significant WMC x Cognitive style interaction, $F(1,103) = .13$, $p = .81$. However, the same analysis showed a significant WMC x Cognitive style interaction within the multitasking condition, $F(1,103) = 6.13$, $p = .02$, $\eta_p^2 = .06$. When interpreting this interaction, pairwise comparisons within the high WMC group showed no difference in reading comprehension performance based on cognitive style, $t(51) = 1.43$, $p = .16$. Within low WMC group, however, participants with categorical cognitive style (*M* = 37.26, *SD* = 14.88) performed better on the reading comprehension task than participants with relational cognitive style (*M* =21.10, *SD* = 10.29), $t(52) = -2.18$, $p = .03$. There were no other significant results.

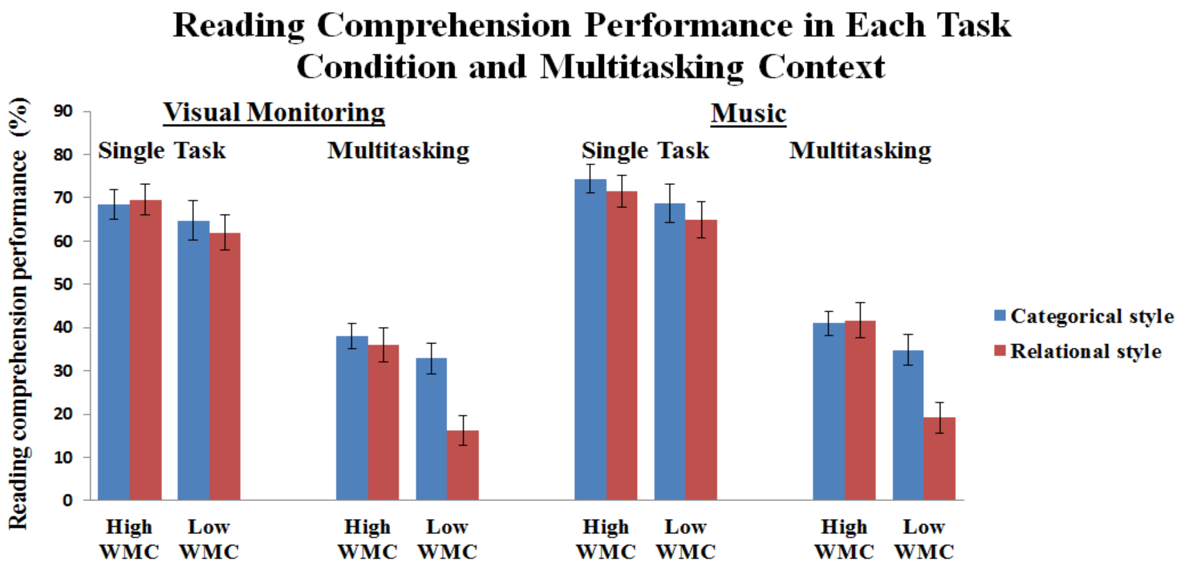

Figure 3: *Participants' performance in the reading comprehension task for each WMC and Cognitive style group within each task condition and each multitasking context (Study 2).*

Auxiliary analyses

We also tested for possible effects of order of task presentation and passage allocation to the two task conditions on the OSPAN, Word-Related Task, and reading comprehension results. Similarly to the results of Study 1, there were no significant effects (all p's $> .05$). In addition, we tested whether there were any significant differences in participants' RTs when performing in the single task as opposed to multitasking condition. A paired-sample t-test showed that, unlike the results in Study 1, there was no significant difference in participants' RTs based on task condition, $p > .05$. Lastly, we tested whether multitasking had an impact on participants' performance in the visual monitoring task. A paired-sample t-test showed that, similarly to Study 1 results, participants had longer RTs, thus took longer to detect a change in the letter's color, when multitasking (*M* = 2.54, *SD* = .54) than when attending solely to the visual monitoring task (*M* = .54, *SD* = .47).

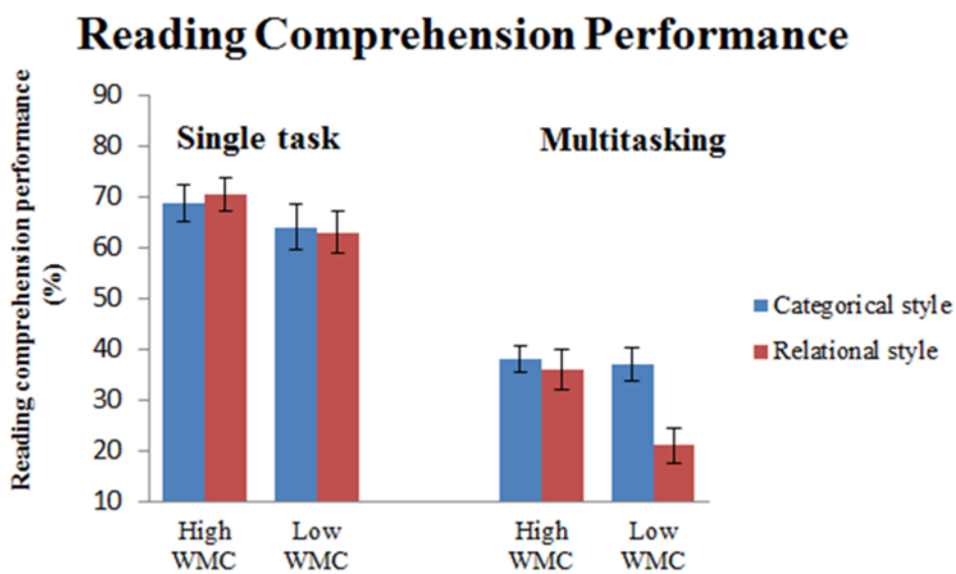

Figure 4: *Participants' performance in the reading comprehension task for each WMC and Cognitive style group within each task condition (Study 2). The data was collapsed across the two multitasking contexts.*

GENERAL DISCUSSION

In the current project, participants' WMC, cognitive style, and their learning performance under single task and multitasking conditions, as assessed by a reading comprehension task, were recorded in two studies. The goal was to test whether people's WMC and cognitive style influence learning under multitasking conditions. In Study 1, results showed that when observed in isolation, higher levels of WMC or a categorical cognitive style seem to aid the learning process. However, when differentiating the combined effects of WMC and cognitive style in the single task and multitasking conditions, a different pattern of results emerged. In this case, the combined effect of the two factors influenced performance in the multitasking, but not in the single task condition. Relational thinkers with low WMC performed the worst under multitasking conditions in comparison to any other group in any condition.

In Study 2, multitasking context was manipulated. As predicted, the same pattern of results obtained in the first study was obtained in the second study. Even more, this pattern of results emerged within the second multitasking context, also. Overall, Study 2 successfully replicated the results from Study 1 and showed that such results can be obtained in multiple multitasking contexts.

The current studies support the view that different cognitive styles are more cognitively demanding than others (Riding et al., 2003). Despite its label, very few studies took a cognitive approach to the construct of cognitive style, and none focused on the categorical – relational style. The few studies that took such an approach, while focusing on different cognitive styles, do suggest a difference in complexity between different cognitive styles. For example, analytical thinkers (who emphasize the connections between the component parts of a system) and verbalizers (who rely primarily on verbal strategies) spent fewer information processing resources than holists (who process information as a whole) and imagers (who rely primarily on imagery) when their overall learning behavior was assessed by their tutors (Riding et al., 2003). Thus, when processing information, using a simpler structure imposed lower cognitive demands and required fewer cognitive resources to perform than using a more elaborate structure.

The current results allow for a similar interpretation. The strong negative impact of WMC on relational thinkers' but not on the other groups' performance in the multitasking condition suggests that relational cognitive style is more cognitively demanding than categorical cognitive style. Based on this assumption, relational thinkers should perform the worst when availability of resources is low and the tasks' demands are high, which is what the current results show. By contrast, categorical thinkers, which use a more economical method of processing information, should be less sensitive to the availability of cognitive resources. The finding that categorical thinkers performed similarly in both task conditions regardless of their WMC level brings even more support for this view. This interpretation needs further investigation, however.

The current studies also make evident the importance and the need to consider both personal and environmental factors, and most importantly, the interaction between them, when analyzing behavior. While there seems to be an agreement that engaging in multitasking is detrimental for cognitive performance, current results show that the severity of the negative effects depend on the combined effect of people's level of WMC and their cognitive style. Thus, the current project departs from the individualistic approach of observing factors in isolation and recognizes the need to observe how and to what extent the interplay between such factors influences behavior.

Overall, the current project is important in multiple ways. First, it is the first of its kind, to my knowledge, to bring attention to the overlooked individual difference in cognitive style, and to the need to consider its involvement in the multitasking process, especially as it interacts with individual differences in WMC. Even more, it brings empirical evidence to support this view. Second, it brings empirical evidence that supports the assumption that different cognitive demands are possibly associated with different cognitive styles. While the idea is not novel, it has not been previously tested within the categorical – relational cognitive style paradigm. Finally, the current project represents an important step towards a more comprehensive view about the multitasking process by taking an integrative rather than an individualistic approach to the potential factors influencing it.

One limitation of the current project is that it did not consider the frequency with which participants engage in multitasking behavior. Previous research (Ophir at al., 2009) shows that, as opposed to light media multitaskers, chronic media multitaskers are more susceptible to interference from irrelevant environmental stimuli, which has a detrimental effect on task switching performance. Given that efficient task switching is an important aspect of the multitasking process (Salvucci & Taatgen, 2008; Spink, 2004), it is possible that the frequency of engaging in multitasking behavior could influence the current patterns of results. Thus, future studies should assess students' multitasking behavior and include it in the analyses. In addition, the occurrence of multitasking while studying could be recorded in real time manner by asking students to describe their multitasking behavior (e.g., time spent multitasking, activities involved in multitasking, etc.) after each study session for a period of time.

Another limitation stems from the inherent issues associated with conducting research in laboratory settings. Thus, despite the attempt to mirror real-life contexts in both studies, their ecological validity is still relatively low. Future studies should address this issue and assess behavior in real life context. As mentioned previously, the categorical – relational cognitive style has been measured with people's patterns of word usage. The Linguistic Inquiry and Word Count (LIWC; Pennebaker, Booth, & Francis, 2007) is a common text analysis tool that has been used to detect such word patterns (i.e., thinking style) by categorizing language. An advantage of LIWC is that it allows for an analysis of people's language behavior that occurred at any point in time and in any real-life context. In addition, learning performance could be assessed by test results obtained in real classroom setting. Such methodology would increase the studies' ecological validity, making the results more generalizable to the general population. Lastly, another limitation of the project is the relatively small sample size used in both studies. However, results from Study 1 replicated in Study 2, which suggests that the results are reliable.

CONCLUSIONS

The current project observed how individual differences in WMC and cognitive style interact and impact learning when multitasking. The main finding was that the combined effect of people's level of WMC and their cognitive style seems to influence the severity of such effects. Based on the current results, a reduction of multitasking behavior would be recommended for all students, but especially for relational thinkers with low WMC. On a different note, while more research is needed on the topic, findings like the current ones should be considered when matching people's skills with tasks' demands, especially when the tasks involve high risks. Perhaps fewer drastic consequences due to failed multitasking would follow.

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APPENDIX 1

Passage 1

“Milankovitch proposed in the early twentieth century that the ice ages were caused by variations in the Earth's orbit around the Sun. For some time this theory was considered untestable, largely because there was no sufficiently precise chronology of the ice ages with which the orbital variations could be matched. To establish such a chronology it is necessary to determine the relative amounts of land ice that existed at various times in the Earth's past. A recent discovery makes such a determination possible: relative land-ice volume for a given period can be deduced from the ratio of two oxygen isotopes, 16 and 18, found in ocean sediments. Almost all the oxygen in water is oxygen 16, but a few molecules out of every thousand incorporate the heavier isotope 18. When an ice age begins, the continental ice sheets grow, steadily reducing the amount of water evaporated from the ocean that will eventually return to it. Because heavier isotopes tend to be left behind when water evaporates from the ocean surfaces, the remaining ocean water becomes progressively enriched in oxygen 18. The degree of enrichment can be determined by analyzing ocean sediments of the period, because these sediments are composed of calcium carbonate shells of marine organisms, shells that were constructed with oxygen atoms drawn from the surrounding ocean. The higher the ratio of oxygen 18 to oxygen 16 in a sedimentary specimen, the more land ice there was when the sediment was laid down. As an indicator of shifts in the Earth's climate, the isotope record has two advantages. First, it is a global record: there is remarkably little variation in isotope ratios in sedimentary specimens taken from different continental locations. Second, it is a more continuous record than that taken from rocks on land. Because of these advantages, sedimentary evidence can be dated with sufficient accuracy by radiometric methods to establish a precise chronology of the ice ages. The dated isotope record shows that the fluctuations in global ice volume over the past several hundred thousand years have a pattern: an ice age occurs roughly once every100,000 years. These data have established a strong connection between variations in the Earth's orbit and the periodicity of the ice ages. However, it is important to note that other factors, such as volcanic particulates or variations in the amount of sunlight received by the Earth, could potentially have
affected the climate. The advantage of the Milankovitch theory is that it is testable: changes in the Earth's orbit can be calculated and dated by applying Newton's laws of gravity to progressively earlier configurations of the bodies in the solar system. Yet the lack of information about other possible factors affecting global climate does not make them unimportant.

Multiple-choice questions Passage 1:

1. In the passage, the author is primarily interested in:

A suggesting an alternative to an outdated research method

B introducing a new research method that calls an accepted theory into question

C emphasizing the instability of data gathered from the application of a new scientific method

D presenting a theory and describing a new method to test that theory

E initiating a debate about a widely accepted theory

2. The author of the passage would be most likely to agree with which of the following statements about the Milankovitch theory?

A It is the only possible explanation for the ice ages.

B It is too limited to provide a plausible explanation for the ice ages, despite recent research findings.

C It cannot be tested and confirmed until further research on volcanic activity is done.

D It is one plausible explanation, though not the only one, for the ice ages.

E It is not a plausible explanation for the ice ages, although it has opened up promising possibilities for future research.

3. It can be inferred from the passage that the isotope record taken from ocean sediments would be less useful to researchers if which of the following were true? B

A It indicated that lighter isotopes of oxygen predominated at certain times.

B It had far more gaps in its sequence than the record taken from rocks on land.

C It indicated that climate shifts did not occur every 100,000 years.

D It indicated that the ratios of oxygen 16 and oxygen 18 in ocean water were not consistent with those found in fresh water.

E It stretched back for only a million years.

4. According to the passage, which of the following is true of the ratios of oxygen isotopes in ocean sediments? C

A They indicate that sediments found during an ice age contain more calcium carbonate than sediments formed at other times.

B They are less reliable than the evidence from rocks on land in determining the volume of land ice.

C They can be used to deduce the relative volume of land ice that was present when the sediment was laid down.

D They are more unpredictable during an ice age than in other climatic conditions.

E They can be used to determine atmospheric conditions at various times in the past.

5. It can be inferred from the passage that calcium carbonate shells

A are not as susceptible to deterioration as rocks

B are less common in sediments formed during an ice age

C are found only in areas that were once covered by land ice

D contain radioactive material that can be used to determine a sediment's isotopic composition

E reflect the isotopic composition of the water at the time the shells were formed

6. According to the passage, one advantage of studying the isotope record of ocean sediments is that it B

A corresponds with the record of ice volume taken from rocks on land

B shows little variation in isotope ratios when samples are taken from different continental locations

C corresponds with predictions already made by climatologists and experts in other fields

D confirms the record of ice volume initially established by analyzing variations in volcanic emissions

E provides data that can be used to substantiate records concerning variations in the amount of sunlight received by the Earth

Passage 2

“Between the eighth and eleventh centuries A.D., the Byzantine Empire staged an almost unparalleled economic and cultural revival, a recovery that is all the more striking because it followed a long period of severe internal decline. By the early eighth century, the empire had lost roughly two-thirds of the territory it had possessed in the year 600, and its remaining area was being raided by Arabs and Bulgarians, who at times threatened to take Constantinople and extinguish the empire altogether. The wealth of the state and its subjects was greatly diminished and artistic and literary production had virtually ceased. By the early eleventh century, however, the empire had regained almost half of its lost possessions, its new frontiers were secure, and its influence extended far beyond its borders. The economy had recovered, the treasury was full, and art and scholarship had advanced. To consider the Byzantine military, cultural, and economic advances as differentiated aspects of a single phenomenon is reasonable. After all, these three forms of progress have gone together in a number of states and civilizations. Rome under Augustus and fifth-century Athens provide the most obvious examples in antiquity. Moreover, an examination of the apparent sequential connections among military, economic, and cultural forms of progress might help explain the dynamics of historical change. The common explanation of these apparent connections in the case of Byzantium would run like this: when the empire had turned back enemy raids on its own territory and had begun to raid and conquer enemy territory, Byzantine resources naturally expanded and more money became available to patronize art and literature. Therefore, Byzantine military achievements led to economic advances, which in turn led to cultural revival. No doubt this hypothetical pattern did apply at times during the course of the recovery. Yet it is not clear that military advances invariably came first. Economic advances second, and intellectual advances third. In the 860's the Byzantine Empire began to recover from Arab incursions so that by 872 the military balance with the Abbasid Caliphate had been permanently altered in the empire’s favor. The beginning of the empire's economic revival, however, can be placed between 810 and 830. Finally, the Byzantine revival of learning appears to have begun even earlier. A number of notable scholars and writers appeared by 788 and, by the last decade of the eighth century, a cultural revival was in full bloom, a revival that lasted until the fall of Constantinople in 1453.Thus the commonly expected order of military revival followed by economic and then by cultural recovery was reversed in Byzantium. In fact, the revival of Byzantine learning may itself have influenced the subsequent economic and military expansion.

Multiple-choice questions:

1. Which of the following best states the central idea of the passage?

A The Byzantine Empire was a unique case in which the usual order of military and economic revival preceding cultural revival was reversed.

B The economic, cultural, and military revival in the Byzantine Empire between the eighth and eleventh centuries was similar in its order to the sequence of revivals in Augustan Rome and fifth-century Athens.

C After 810 Byzantine economic recovery spurred a military and, later, cultural expansion that lasted until 1453.

D The eighth-century revival of Byzantine learning is an inexplicable phenomenon, and its economic and military precursors have yet to be discovered.

E The revival of the Byzantine Empire between the eighth and eleventh centuries shows cultural rebirth preceding economic and military revival, the reverse of the commonly accepted order of progress.

2. The primary purpose of the second paragraph is which of the following?

A To establish the uniqueness of the Byzantine revival

B To show that Augustan Rome and fifth-century Athens are examples of cultural, economic, and military expansion against which all subsequent cases must be measured

C To suggest that cultural, economic. and military advances have tended to be closely interrelated in different societies.

D To argue that, while the revivals of Augustan Rome and fifth-century Athens were similar, they are unrelated to other historical examples

E To indicate that, wherever possible, historians should seek to make comparisons with the earliest chronological examples of revival

3. It can be inferred from the passage that by the eleventh century the Byzantine military forces

A had reached their peak and begun to decline

B had eliminated the Bulgarian army

C were comparable in size to the army of Rome under Augustus

D were strong enough to withstand the Abbasid Caliphate's military forces

E had achieved control of Byzantine governmental structures

4. It can be inferred from the passage that the Byzantine Empire sustained significant territorial losses

A in 600

B during the seventh century

C a century after the cultural achievements of the Byzantine Empire had been lost

D soon after the revival of Byzantine learning

E in the century after 873

5. Which of the following does the author mention as crucial evidence concerning the manner in which the Byzantine revival began?

A The Byzantine military revival of the 860's led to economic and cultural advances.

B The Byzantine cultural revival lasted until 1453.

C The Byzantine economic recovery began in the 900's.

D The revival of Byzantine learning began toward the end of the eighth century.

E By the early eleventh century the Byzantine Empire had regained much of its lost territory.

6. According to the author, "The common explanation" of connections between economic, military, and cultural development is

A revolutionary and too new to have been applied to the history of the Byzantine Empire

B reasonable, but an antiquated theory of the nature of progress

C not applicable to the Byzantine revival as a whole, but does perhaps accurately describe limited periods during the revival

D equally applicable to the Byzantine case as a whole and to the history of military, economic, and cultural advances in ancient Greece and Rome

E essentially not helpful, because military, economic, and cultural advances are part of a single phenomenon

APPENDIX 2

Word sets used in word-relation task. The highlighted ones are test items, while the rest are filler items

Word 1	Word 2	Word 3
Cow	Pig	Milk
Ring	Necklace	Hand
Door	Window	Key
Crib	Adult bed	Baby
Dog	Cat	Bone
Paintbrush	Crayons	Easel
Train	Bus	Tracks
Bee	Ant	Flower
Hanger	Hook	Dress
Sprinkler	Watering can	Grass
Monday	Wednesday	Friday
Baby	Child	Adult
Hour	Minute	Second
Camera	Lens	Tripod
Past	Present	Future
Box	Cage	Prison
Travel	Vacation	Weekend
Water	Earth	Air
House	Palace	Tent
Apple	Pear	Peach