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The Effects of Stress on Reading: A Comparison of First-Language Versus Intermediate Second-Language Reading Comprehension

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This study investigated how resource-demanding reading tasks and stressful conditions affect 1st-language (L1) and intermediate 2nd-language (L2) reading comprehension. Using the attentional control theory framework (Eysenck, Derakshan, Santos, & Calvo, 2007), we investigated the roles of central executive working memory (WM) resources, reading task difficulty, trait reading anxiety, and social evaluative stress on L1 and L2 readers' comprehension. Eighty-six L2 Spanish readers and 70 L1 English readers were tested for comprehension using noninference (fact), bridging inference, and pragmatic inference questions under either no-stress or social-evaluative stress conditions. Stress reduced processing efficiency (producing longer reaction times) for L2 readers who were high in reading anxiety and increased processing efficiency for L1 readers who were high in WM capacity. Stress did not affect reading effectiveness (accuracy). Thus, stress only impaired reading efficiency when task difficulty was high due to high inferential complexity or reading in an L2 and when anxious thoughts competed for limited central executive WM resources. Theoretical and practical implications of these findings are discussed.

Keywords: reading comprehension, stress, first language, second language, working memory

Imagine yourself taking a stressful reading comprehension test. Would you read as quickly or as accurately as you normally do under less stressful circumstances? What would happen if the reading test were given in a foreign language rather than in your first language? Would any such effects on your reading speed and accuracy also differ on the basis of your disposition (whether you are an anxious reader or not) or your overall working memory capacity? And would any such effects further differ based on the types of reading questions you were asked, for example, simple factual questions or those requiring you to draw inferences? The current study was carried out in an effort to answer these questions about the often complex effects of stress on reading comprehension.

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Psychosocial stress is well known to negatively affect performance on a variety of real-world tasks, ranging from mathematical problem-solving, to verbal reasoning, to hitting a baseball (Baumeister, 1984; Beilock & Carr, 2005; Derakshan & Eysenck, 1998; Gray, 2004). But does psychosocial stress affect reading comprehension, and if so, how and under what conditions? If psychosocial stress (hereafter, *stress*) negatively affects reading performance, it would be important to understand how it does so to potentially counteract such problems. Here, we were specifically interested in whether and how stress differentially affects native language (L1) and foreign language (L2) reading under varying conditions of cognitive load. Attentional control theory (Eysenck, Derakshan, Santos, & Calvo, 2007; see also Derakshan & Eysenck, 2009; Eysenck & Derakshan, 2011) provides a useful framework within which to answer these questions. According to this theory, anxiety affects cognitive processing by depleting resources available to the central executive of working memory (Baddeley, 1996, 2003), but this occurs only under certain conditions, such as when an individual is performing difficult or multiple tasks, or when experiencing personal, social, or environmental stress (Baumeister, 1984; Beilock & Carr, 2005; Eysenck et al., 2007; Rai, Loschky, Harris, Peck, & Cook, 2011). When such resource depletion occurs, it may manifest itself either through decrements in effectiveness (i.e., accuracy), efficiency (i.e., reaction time), or both, depending on other factors, such as how much control the person has over when to make his or her response. Under stressful conditions, people, especially those high in state or trait anxiety, trade efficiency for effectiveness, resulting in speed–accuracy tradeoffs in performance.

It is important to distinguish between stress and anxiety in considering the relationship between stress and working memory (WM). Anxiety is "an aversive motivational state in which level of perceived threat to the individual is high" (Derakshan & Eysenck, 2009, p. 168). Anxiety may be either a trait or a state, with the former being a relatively stable aspect of personality and the latter being a transient state of mind. Both state and trait anxiety can influence the effects of stress by depleting central executive WM resources. Consistent with these ideas, some studies have shown that those who are high in trait anxiety have lower WM capacities than those low in trait anxiety (Darke, 1988a; MacLeod & Donnellan, 1993; Visu-Petra, Cheie, Benga, & Packiam Alloway, 2011), but other research has shown that this only occurs under stressful conditions (Calvo, Ramos, & Estevez, 1992).

The attentional control theory distinguishes between goal-directed (top-down) attention, controlled by the central executive, and stimulus-driven (bottom-up) attention, which occurs more frequently when central executive resources are taxed. When attention is stimulus-driven, performance on tasks requiring the marshaling of goal-directed attention suffers. In the context of reading, different factors, including social evaluative stress, difficult reading tasks, or limits in reading ability can tax the central executive. Kintsch's (1998) construction integration model of comprehension distinguishes several levels of memory representation of text, including the surface level (exact words), the text-base level (ideas or propositions), and the situation model level, which goes beyond the text by integrating it with information from long-term memory (such as inferring information from text material that is not explicitly mentioned). In reading, the central executive is particularly important for processing texts at the situation model level of representation. For those who lack the necessary skills to fluently decode text into representations at the surface and text-base levels, it becomes even more difficult to integrate material from long-term memory to construct the appropriate situation model, and thus, they are unable to focus on the central information and theme of the text (Miller & Keenan, 2011). This lack of fluency can come from various sources, including limited word recognition ability, poor syntactic parsing skills, or difficulty in maintaining local text coherence. For readers so challenged, the efforts needed to decode the text into representations at the surface and text-base levels consume much of their central executive resources, leaving insufficient resources to construct a situation model. Such readers' attention therefore is focused on the surface and, to some extent text-base, levels of representation—the levels largely invoking stimulus-driven attention. In sum, nonfluent readers may lack the central executive resources to utilize their goal-directed attentional system and thus read ineffectively and inefficiently, particularly when inferences are required for comprehension.

Central executive processes are clearly important for reading (Ardila, 2003; Daneman & Carpenter, 1980; Harrington & Sawyer, 1992; Juffs, 2004; Leeser, 2007; Miyake, 1998; Walter, 2004). The attentional control theory posits three basic control functions of the central executive: inhibition of irrelevant stimuli and responses, shifting attention between tasks, and "updating and monitoring of WM representations" (Miyake et al., 2000, p. 56). All three control functions are potentially important for reading. For example, Gernsbacher's (1990; Gernsbacher & Faust, 1991) structure building framework emphasizes the importance of inhibitory processes in comprehension. Similarly, the ability to shift attention between various reading subtasks (e.g., guessing the meaning of unfamiliar vocabulary from context vs. inferring unstated implications) and their associated levels of memory representation (surface vs. situation model) without disrupting discourse coherence is both critically important and very difficult for beginning readers (Samuels & Flor, 1994). However, it is the updating function that seems particularly critical for processing text at the situation model level, because of its demonstrated importance in the processes involved in drawing pragmatic inferences while reading (Calvo, 2001, 2005; Estevez & Calvo, 2000; Linderholm, 2002; Rai et al., 2011; St. George, Mannes, & Hoffman, 1997).

Based on this information, it seems that the demands put on the executive WM updating function should vary as a function of the complexity of a reading task, which in turn should depend on the need to use the situation model of representation. A simple reading task is to understand factual statements, which should only require using representations at the surface and text-base levels (e.g., "The waiter dropped a plate" requires understanding that there is an entity, "The waiter," who performed an action "dropped [object]," and that the object was "a plate"). A slightly more complex reading task is to make bridging inferences at the text-base level involving connective operations across clauses, such as using basic grammatical rules to compute pronominal or anaphoric referents necessary to maintain basic cohesion (e.g., inferring from "The waiter dropped a plate. He quickly went to get a dustpan and broom," that "he" in the second sentence refers to "The waiter" in the first sentence; Erlam, 2003; Kaiser & Trueswell, 2008). However, a substantially more complex reading task is to draw appropriate pragmatic inferences across clauses in the text using the situation model level of representation. Drawing such pragmatic inferences is necessary to maintain coherence across gaps in the text-base representation by filling them in with appropriate knowledge retrieved from long-term memory (Graesser, Singer, & Trabasso, 1994), which requires WM updating (e.g., inferring from "The waiter dropped a plate. He quickly went to get a dustpan and broom," that the plate broke on the floor, which created a mess, which the waiter needed to clean up, which caused him to go get a dustpan and broom; Calvo, 2001; Calvo & Castillo, 1996, 1998; Harris & Monaco, 1978; Whitney, Ritchie, & Crane, 1992). Such demands on the executive WM updating function can explain the difficulty in constructing situation models during reading comprehension (Kintsch, 1998), especially under conditions with high executive WM resource demands (Calvo, 2001, 2005; Estevez & Calvo, 2000; Linderholm, 2002; Rai et al., 2011; St. George et al., 1997). In sum, creating a situation model requires executive WM updating, so when the central executive is taxed, higher level comprehension processes, such as drawing appropriate pragmatic inferences, are impeded.

Eysenck et al. (2007) discussed a number of studies investigating the effects of anxiety on the updating function, with WM capacity operationalized in terms of the reading span or operation span tasks. Although performing the reading span task is not the same as reading extended text, the strong relationship between both tasks is well-established in the reading literature (Baddeley, 2003; Daneman & Carpenter, 1980; Daneman & Merikle, 1996; Just & Carpenter, 1992). However, Eysenck et al. (2007) concluded that "when stressful conditions are used, the findings are complicated and difficult to interpret" (p. 348). Specifically, some studies have shown that high anxiety adversely affected span measures (Calvo et al., 1992; Darke, 1988a), while other studies were less clear (Santos & Eysenck 2005; Sorg & Whitney, 1992). Notably, however, all of these studies involved educated adult participants reading in their native language (L1), which, for this population, can generally be assumed to be a highly automated skill. This is important because attentional control theory asserts that "adverse effects of anxiety on performance become greater as overall task demands on the central executive increase" (Eysenck et al. (2007), p. 341). Thus, the automated skills involved in reading in one's first language (L1) might preclude showing the effects of anxiety on the updating function. This suggests that having participants read in a nonfluent second language (L2)—which would make reading more cognitively demanding—would provide a better test of the hypothesis that anxiety affects updating (Horiba, 1996; Shimizu, 2005; see Juffs & Harrington, 2011, for a review of WM in L2 learning). For example, Rai et al. (2011) found that stress affected efficiency of drawing complex inferences while reading extended text in a nonfluent L2, a task that involves updating of the situation model level of representation. Similarly, Miller and Keenan (2011) compared participants' recall of extended text read in their L1 versus in their L2 and found a greater deficit in the L2 for information central to the theme of the text, which requires a coherent situation model, than for information peripheral to the theme of the text. However, to our knowledge, no one has directly compared the effects of stress or anxiety specifically on updating text representations in L1 versus L2 reading. By comparing L1 with L2 reading of the same text on the same task by the same general subject population, one can compare the effects of anxiety and stress on reading comprehension as a function of different levels of reading difficulty by virtue of the L1 versus L2 distinction.

Our particular interest is with intermediate-level L2 readers, who are capable of reading extended text but are still far from native-level performance. Because such L2 readers are lacking knowledge of the lexicon and syntax of their second language relative to native speakers, they expend relatively more effort on the surface and text-base levels of representation (Carrell, 1983; Horiba, 1996; Kembo, 2001; Miller & Keenan, 2011; Shimizu, 2005; Walter, 2004). Furthermore, when such L2 readers do make high-level inferences, they are often unsupported by the text (Hammadou, 1991). These difficulties in constructing accurate high-level inferences can be explained in terms of the greater amount of central executive resources needed to comprehend the surface and text-base levels, leaving fewer such resources for updating the situation model representation in WM. This results in a greater reliance on stimulus-driven attention when reading and consequently a greater emphasis on lower level details in the text, regardless of their importance.

A further possible explanation for the complex results of anxiety and stress on reading comprehension is that the measures of anxiety and manipulations of stress have been extremely variable across different studies. According to attentional control theory, "anxiety impairs processing efficiency (and sometimes performance effectiveness) on tasks involving the updating function, but only under stressful conditions" (Eysenck et al., 2007, p. 347). Many studies have measured anxiety as a trait (Dewaele, Petrides, & Furnham, 2008; Elkhafaifi, 2005; Johnson & Gronlund, 2009; Owens, Stevenson, Norgate, & Hadwin, 2008; Pacheco-Unguetti, Acosta, Callejas, & Lupianez, 2010; Sheen, 2008) or state (Owens et al., 2008; Pacheco-Unguetti et al., 2010), but a variety of different instruments have been used. Moreover, few have measured trait anxiety specific to reading (Saito, Garza, & Horwitz, 1999), which may be a more sensitive measure in this performance domain (Rai et al., 2011). In addition, some studies did not compare stressed versus unstressed conditions (Darke, 1988a, 1988b), and those that manipulated stress did so in very different ways. In some studies, experimenters have directly manipulated stress by telling participants that their public speaking performance would be evaluated (Darke, 1988a, 1988b), by limiting time (Chajut & Algom, 2003, Experiment 1), or by adding noise (Chajut & Algom, 2003, Experiment 2). Still others have used the presence of a video camera (Beilock & Carr, 2005; Calvo, Eysenck, Ramos, & Jimenez, 1994; MacIntyre & Gardner, 1994; Rai et al., 2011) or high- and low-reward contingencies (Chajut & Algom, 2003, Experiment 3).

In a recent study, investigators attempted to address all of these issues by measuring general state and trait anxiety, as well as foreign language reading anxiety, and comparing stressed and unstressed conditions, in which stress was manipulated both by telling the participants that they would be evaluated and by using a video camera (Rai et al., 2011). Results showed significant effects of stress and anxiety on foreign language reading comprehension efficiency (Rai et al., 2011). Nevertheless, those effects were only moderate and were not tested on native speakers. Doing so would be an important step in better understanding whether stress influences reading in general or is particular in affecting certain populations (such as poor readers only). Furthermore, it is possible that stronger effects might be found by including a more robust manipulation of social evaluative stress that has been shown to impair complex task performance, namely, having an unseen evaluative observer standing behind the participant (Aiello & Svec, 1993; Guerin, 1983; Innes & Gordon, 1985; Innes & Young, 1975; Markus, 1978).

Research Questions

Research Question 1: How do stressful conditions affect reading tasks involving the WM updating function in a native versus a second language? In the domain of L1 reading, there are mixed results. There is some evidence that L1 reading is affected by stress, at least among those with high trait anxiety, under conditions of high WM load, such as drawing pragmatic inferences (Calvo et al., 1992; Darke, 1988a). However, there is also evidence of L1 reading span being unaffected by stress, even among those high in trait anxiety (Santos & Eysenck 2005; Sorg & Whitney, 1992). In the domain of L2 reading, there is a paucity of experimental research on this topic; however, one recent study (Rai et al., 2011) showed significant effects of stress on reading efficiency in an L2, particularly for reading tasks involving WM updating (specifically, drawing pragmatic inferences). Thus, in the present study, we investigated whether stress and anxiety differentially affected L1 versus L2 reading. In looking at the effects of stress on reading, we necessarily took into account the effects of a number of other variables that have been shown to be important in mediating the effects of stress, which are addressed in our further research questions.

Research Question 2: How does trait reading anxiety (Saito et al., 1999) affect reading comprehension? Stress has previously been shown to more strongly affect those high in trait anxiety (Calvo et al., 1992; Darke, 1988a; Rai et al., 2011). Rai et al. (2011) found that standard state and trait measures of anxiety were highly intercorrelated and that a measure of foreign language reading anxiety explained more variance in reading comprehension than did stress alone. Thus, in the current study, we investigated the degree to which reading anxiety, in L1 and L2 explained reading comprehension.

Research Question 3: What role do central executive WM resources play in determining the effects of social evaluative stress on reading comprehension? According to attentional control theory, stress affects reading comprehension by reducing WM resources, specifically those of the central executive. In the current study therefore, we measured central executive WM capacity by the operation span (OSpan) task (Unsworth, Heitz, Schrock, & Engle, 2005). If limited central executive WM resources underlie the effects of stress on reading, then readers having fewer such resources to begin with should suffer most from anxiety caused by stress. Furthermore, if reading in an L2 puts greater strain on central executive WM resources than reading in L1, we may find an interaction between these factors.

Research Question4: How does reading task difficulty interact with stress, anxiety, and central executive WM resources in affecting reading comprehension? According to attentional control theory, effects of anxiety are greater when the task is more difficult. The current study examined the effects of reading difficulty more generally by measuring reading in both L1 and L2 and examined the effects of reading difficulty more specifically through different levels of inferential complexity. Previous research has shown the following difficulty hierarchy among reading comprehension question types: factual statements < bridging inferences (e.g., pronominal anaphora) < pragmatic inferences (Calvo, 2001; Horiba, 1996; Linderholm, 2002; Rai et al., 2011; Shimizu, 2005; St George et al., 1997). For example, items with higher levels of inferential complexity require more WM resources for L1 readers (Calvo, 2001; Linderholm, 2002; St George et al., 1997) and require greater proficiency for L2 readers (Horiba, 1996; Shimizu, 2005). In addition, Rai et al. (2011) found that for L2 readers, stress had its greatest negative impact on comprehension efficiency for pragmatic inferences. Thus, in the current study, we investigated the extent to which reading difficulty, operationalized in terms of reading fluency (i.e., L1 vs. L2) and inferential complexity, interacts with stress and central executive WM capacity in affecting reading comprehension.

Method

Participants

Eighty-six intermediate-level (fourth semester) Spanish foreign language (L2) students from a large midwestern U.S. university participated in this study for Spanish course extra credit. All were native English speakers. Five participants were eliminated from the study for being suspicious about the stress manipulation and one for being unable to complete the entire study. All participants self-reported their Spanish reading proficiency levels, which were quite homogeneous, with 88.4% of participants rating themselves as average, good, or excellent on a 5-point reading proficiency scale (none rated themselves as poor, 10 said fair, 33 average, 41 good, and 2 excellent). Numerous previous studies have shown high correlations between self-rated proficiency and objective measures of proficiency, thus validating our use of this measure of L2 proficiency (Dufour & Kroll, 1995; Kroll, Michael, Tokowicz, & Dufour, 2002; MacIntyre, Noels, & Clément, 1997; Rai et al., 2011). Additionally, through the Department of Modern Languages, these participants (typically sophomores, with some juniors and seniors) were administered a Spanish placement test in order to ensure homogeneity of their L2 Spanish proficiency within their respective classes. Students must have a score of 500–600 (on a 900-point total test) to be placed in the intermediate-level Spanish 4 class (with those scoring lower or higher placed in more beginning or advanced level Spanish classes). The Spanish placement test is a computerized, adaptive, multiple-choice measure in which students read a variety of passages (providing assessment of reading comprehension, vocabulary, and numbers), with harder questions provided as the participant gets more answers correct and easier ones if they get them wrong. Thus, based on both the students' self-rated and their objectively measured proficiency levels, it is clear that our L2 Spanish readers were a relatively homogeneous intermediate-level L2-proficiency group.

In addition, 76 native, monolingual English speakers (L1) from general psychology courses participated for class credit. Six participants were eliminated for being suspicious about the stress manipulation, leaving a usable sample size of 70. Of these, 48 students had minimal exposure to another language (i.e., French, German, Spanish, American Sign Language, or Czech) having taken one semester or less of any other foreign language course in high school only. The L1 students participated in the study in English only. All participants reported their English reading proficiency levels, which were quite homogeneous, with 96.1% of the participants rating themselves as average, good, or excellent on a 5-point reading proficiency scale (again, none rated themselves as poor, just 3 said fair, 16 average, 26 good, and 31 excellent). Thus, consistent with what one would expect, the modal self-rated reading proficiency rating for L1 readers was "excellent," whereas that for the intermediate level L2 readers was "good."

Measures

Demographic Questionnaire for Hispanophones (DQH). This scale, developed by the experimenters, assessed participants' background in their Spanish usage, including 10 questions with multiple parts and 5-point Likert scale self-assessments of their reading, writing, listening, and speaking proficiency (Cronbach's $\alpha = .70$). As noted earlier, self-reported proficiency scales have been shown to be highly correlated with objective measures of proficiency (Dufour & Kroll, 1995; Kroll et al., 2002; MacIntyre et al., 1997) and are widely used in studies of bilingualism (Bialystok, Martin, & Viswanathan, 2005; Colzato et al., 2008; Dewaele et al., 2008; van den Noort, Bosch, & Hugdahl, 2006).

Foreign Language Reading Anxiety Scale (FLRAS). The results of Rai et al. (2011) showed that general measures of state and trait anxiety (State–Trait Anxiety Inventory; Spielberger, 1983) were significantly intercorrelated for our population of L2 learners. Furthermore, neither significantly explained variance in reaction times. However, the FLRAS (Saito et al., 1999) that specifically assesses self-reported trait anxiety regarding various aspects of reading and perceptions of reading difficulties in the foreign language did significantly explain reaction time variance for this population. Thus, in the current study, only the FLRAS scale was used. The FLRAS taps into foreign language *reading* anxiety rather than general FL anxiety, and the two have been shown to be distinct psychological constructs (Matsuda & Gobel, 2004; Saito et al., 1999). The FLRAS consisted of items such as "I get upset when I'm not sure I understand what I'm reading in Spanish" and "I would be happy just to learn to speak Spanish rather than having to learn to read as well." The FLRAS contains 20 items, each rated on a 5-point Likert scale. The range of possible scores was thus 20–100. The FLRAS was found to have good internal reliability (Cronbach's α = .83), consistent with other published norms for the scale (Matsuda & Gobel, 2004; Saito et al., 1999).

Participants in the English L1 condition completed a variation of the FLRAS adapted for general reading anxiety by the authors. This scale was found to have moderate internal reliability (Cronbach's α = .65). This reduction in Cronbach's alpha relative to that reported previously for the Spanish version was likely due to the fact that there were fewer questions on the English version of the FLRAS—only 12 versus 20 in the original—as it was adapted for general reading anxiety by removing items specific to foreign language reading (e.g., L2 orthography).

Automated Operation Span Task (OSpan). This computerized version of the OSpan task developed by Unsworth et al. (2005) is an established measure of executive WM (Broadway & Engle, 2010; Conway et al., 2005; Juffs & Harrington, 2011; Pardo-Vázquez & Fernandez-Rey, 2008). The OSpan task particularly taps into the central executive component of WM by asking participants to remember a string of letters while performing simple mathematical operations between the presentation of each letter. Because the OSpan measures the capacity of the central executive in WM, it predicts reading ability without measuring reading ability itself. For example, it is highly correlated with both reading span tasks (.88), which directly involve reading, as well as with mathematical operation span tasks (.77), which do not (Unsworth et al., 2005). More than other WM measures related to reading, the OSpan task is largely independent of either L1 or L2 language skill. This suggests that people possess an underlying language-independent WM span, as supported by correlations between WM spans across learners' L1, L2, and L3 (van den Noort, et al. 2006). However, we also predicted, consistent with van den Noort, et al. (2006), that reading in one's L2 would add a processing load that taxes executive WM resources. In sum, we used the "language-free" OSpan WM measure based on the assumption that central executive WM capacity and L2 proficiency are separable but that they interact, such that those lower in L2 proficiency experience a greater strain on their existing central executive WM resources when reading.

Reading comprehension task. We created a computerized reading comprehension task with both Spanish and English versions to measure readers' comprehension; the task consisted of 12 brief stories, all of similar length in number of sentences (M = 13.11, SD = 1.43), which were either of the children's fairy tale genre or a narrative of everyday events; thus, they did not depend on any specialized knowledge. Immediately following each passage were six questions about its content, two of each type presented in random order for each participant. Two questions were factual, requiring no inference processes to answer. Two other questions required the participant to draw a bridging inference to identify a pronominal referent mentioned one or two sentences earlier. The final two questions required the drawing of a pragmatic inference (for examples, see Appendix). These questions should require processing at the situation model level, while the factual questions and bridging inferences could be answered completely within the text-base level of representation (Kintsch, 1998), although the pronominal reference questions required connecting material across adjacent sentences. Thus, we predicted that cognitive complexity would increase from fact questions (which place few demands on the central executive WM updating function), to bridging inferences questions (which are slightly more demanding of the WM updating function), to pragmatic inference questions (which places the most demands on the central executive of WM), with comprehension accordingly becoming increasingly difficult across these three question types.

To ensure that word counts and character lengths of our questions did not explain differences in response times, we conducted several analyses of variance (ANOVAs). First, a one-way ANOVA was used to test for differences in the *number of words* per question among the three inference types for the L1 readers. The number of words did not significantly differ across the three inference types, $F(2, 71) = 1.76$, $p = .179$, *ns*. The same held for the *character length* per question for the three inference types for the L1 group, $F(2, 71) = 2.08$, $p = .133$, *ns*. We then conducted the same one-way ANOVAs for the L2 group and found that no significant differences in either the number of words per question across the three inference types, $F(2, 71) = 1.94$, $p = .152$, *ns*, or the character length per question for the three inference types, $F(2, 71) = 2.34$, $p = .104$, *ns*. Finally, we conducted a one-way ANOVA to test for the word count and character length per question for the two versions of the passages (English vs. Spanish). There was neither a significant difference in the number of words per question between the two language versions, $F(1, 143) = 0.075$, $p = .785$, *ns*, nor in the character length per question between the two language versions, $F(1, 143) = 3.83$, $p = .052$, *ns* (Table 1).

The passages were originally written in English by the experimenters, with an eye to translating them directly into Spanish. A native Spanish-speaking bilingual experimenter helped write the original English versions and then translated them into Spanish. These translations were then further evaluated and revised as necessary by (a) two Spanish faculty members from in the Modern

Table 1
Word and Character Lengths (Mean and SD) of Questions of Three Question Types for L1 and L2 Versions of the Reading Comprehension Task

Group/Inference type	Word count	Character length
L1 (English questions)		
Noninterference	7.21 (2.12)	30.83 (9.58)
Bridging	7.33 (2.14)	32.37 (9.79)
Pragmatic	8.25 (2.02)	36.13 (8.29)
Total	7.59 (2.12)	33.11 (9.38)
L2 (Spanish questions)		
Noninterference	6.83 (2.18)	33.38 (9.26)
Bridging	7.67 (2.18)	36.00 (9.31)
Pragmatic	8.00 (1.99)	39.21 (9.47)
Total	7.50 (2.14)	36.19 (9.52)

Note. L1 = first language; L2 = second language.

Languages department, one of whom was a native Spanish speaker and (b) another native Spanish speaker, who was a psychology doctoral student. In sum, the passages were forward-translated by a Spanish–English bilingual and then checked by three Spanish–English bilinguals, two of whom were native speakers of Spanish and two of whom were professors of Spanish as a foreign language. All of this was done to ensure the passages were equivalent and reasonable to have the two language groups read.

The level of reading difficulty for the Spanish passages was intended to be something that a typical fourth-semester undergraduate Spanish foreign language student would find neither overly difficult nor overly easy to comprehend, based on the judgments of three faculty members of the Modern Languages department (two of them native Spanish speakers), who read and suggested revisions of the Spanish texts.

Sample passages together with their questions appear in Appendix. We used a two-alternative forced-choice (2-AFC) procedure, having a possible range of between .5 (*chance*) and 1 (*perfect*; Ulrich & Miller, 2004). After reading each passage, participants answered six 2-AFC questions: two noninference (factual) questions, two bridging inference (pronoun-referent) questions, and two pragmatic inference questions, with the order of the six questions for each story randomized for each participant. For the bridging inference questions, the distance between pronouns and their referents varied from zero to two sentences, the typical range of distances found in natural texts (Hobbs, 1977). For the pragmatic inference questions, the choices were "yes" and "no"; for the other two types, the choices were various factual options. The reading task was self-paced, with one sentence shown per screen and participants pressing the space bar to proceed to the next sentence. Sentences were presented one at a time in order to require participants to use their WM to integrate their text-base representations across sentences. This reading comprehension measure was relatively reliable (Cronbach's αs = .64 for L1 readers and .74 for L2 readers). The L2 readers received the passages and questions in Spanish and all other materials in English, while the L1 readers received all materials in English.

Design and Procedure

Each participant was tested individually. Upon arrival, they first completed the self-rated proficiency questionnaire. Next, participants completed the Automated OSpan executive WM measure. These tasks were administered in English for all participants. Participants then read the L2 Spanish or English passages, presented on the computer by the E–Prime (Psychology Software Tools, Sharpsburg, PA) program. The passages were divided into two blocks of six passages each, with each block taking approximately 20 min to complete. Prior to reading the experimental passages, participants were given a practice passage to familiarize themselves with the task. As they began the experiment, participants were told that the computer would record how accurately and quickly they responded to the questions.

Stress was a within-participant factor, with every participant being in the no-stress condition for the first block of six passages and in the stress condition for the second block of six passages, with order of passages randomized within blocks across participants. The stress condition was blocked and always followed the no-stress condition in order to avoid any stress spillover effects that might otherwise occur with a counterbalanced design in which the stress condition sometimes occurred before the no-stress condition. Specifically, it was feared that such spillover from the stress condition to the nonstress condition could reduce differences between the two conditions. Consistent with this concern, research has shown that the physiological effects of social-evaluative stress, for example, cortisol levels, reach their peak levels between 10 and 30 min after the stressor is introduced (Kudielka, Hellhammer, & Kirschbaum, 2007). Thus, halfway through the reading task (i.e., after the sixth passage), participants were told that the previous trials had been for practice, and we would now begin the true experiment. At this point, the experiment introduced four separate manipulations of social-evaluative stress, which we defined as a situation in which individuals are publicly evaluated on their performance, consistent with the definitions of others who have used social evaluation as a stressor (Avero & Calvo, 1999; Dandeneau, Baldwin, Baccus, Sakellaropoulo, & Pruessner, 2007; Garner, Mogg, & Bradley, 2006; Mogg, Philippot, & Bradley, 2004; Viglione & Exner, 1983):

Manipulation 1: A video camera was brought out and set up to film the participant and the computer screen. This technique has been employed successfully by others to induce anxiety through social-evaluative stress (Beilock & Carr, 2005; Calvo et al., 1993; MacIntyre & Gardner, 1994; Rai et al., 2011).

Manipulation 2: Next, the participant read a tongue twister aloud into the camera, either in his or her L1 or L2 depending on the group; we devised this step on the supposition that the inherent difficulty of this task would cause performance anxiety.

Manipulation 3: Next, the participant was told that their teacher, either psychology or Spanish depending on the group, would be evaluating his or her videotaped performance on the reading task, because such statements alone have been shown to increase state anxiety (Darke, 1988a, 1988b).

Manipulation 4: Finally, the experimenter sat 1 foot (30.480 cm) behind the seated participant (as measured by the length of a clipboard held by the experimenter) while he or she completed the last six passages. Previous studies have consistently shown strong negative effects on a participant performing complex tasks when a known but unseen evaluative experimenter is present, particularly when the experimenter is behind the participant (Aiello & Svec, 1993; Guerin, 1983; Innes & Gordon, 1985; Innes & Young, 1975; Markus, 1978). Note that during the first block of six stories (no-stress condition), the experimenter sat across the room at a table, plainly visible, and kept busy doing unrelated work (reading or doing paper work) and largely ignored the participant. Previous research has shown that this is equivalent to the participant being alone and does not cause social-evaluative stress-related performance decrements (for review, see Guerin, 1986).

Based on the attentional control theory, the combination of the four social-evaluative stress manipulations was expected to be external, task-irrelevant, social-anxiety-provoking stimuli, which would divert executive attention from the reading comprehension task, thereby decreasing performance.

After completing all 12 passages, participants immediately completed the FLRAS questionnaire (Saito et al., 1999) and a suspiciousness questionnaire. After completing the experiment, all participants were debriefed, the deception of the stress manipulation was revealed, and a piece of candy was given for mood repair (Twenge et al., 2007).

Results

Analyses were conducted on both accuracy and reaction time (RT) data, with overall differences in Table 2.

Reaction Time (RT)

Overview and data preparation. All RT analyses were conducted on correct responses only and represent the time it took to both read and answer the questions. Furthermore, outliers (the top and bottom 1%) were trimmed based on *z* scores conditionalized on each combination of variables: 2 (L1 vs. L2) $\times$ 2 (stress) $\times$ 2 (WM: low vs. high) $\times$ 3 (inference type). This resulted in the removal of 2% of the data (138 of 6,748 cases), leaving 6,610 cases in the analysis. The RT data shown in Figure 1 will be discussed first. First, we conducted a 2 (L1 vs. L2) $\times$ 12 (*n*th passage read) mixed-design ANOVA on RT.

As expected, the mean RT per reading comprehension question for L2 readers ($M = 6{,}967$ msec, $SD = 1{,}821$) was significantly longer than for the L1 native English readers ($M = 3{,}490$ msec, $SD = 2{,}044$), $F(1, 151) = 252.75$, $p < .001$, Cohen's $f^2 = 0.90$,[1] showing a large difference between the two groups. Furthermore, as can be seen from Figure 1, the greatest jump in RT for L2 learners was just after the stress manipulation was introduced following the sixth passage. As shown in Table 2, for the L1 readers, there was no significant difference in RT from the no-stress (Passages 5 and 6) to the stress (Passages 7 and 8), $t(69) < 1$. However, for the L2 readers, there was a significant increase in RT from the no-stress to the stress condition, $t(85) = -2.28$, $p = .025$, Cohen's $d = 0.25$, showing a small, but clear drop in processing efficiency.

Therefore, for all further analyses, only the middle four passages, namely, the last two of the no-stress condition, and the first two of the stress condition (Passages 5, 6, 7, and 8) were included.

Effects of inference type and stress on RT for L1 and L2 readers. A 2 (L1 vs. L2; between-subjects) $\times$ 2 (no-stress vs. stress; within-subject) $\times$ 3 (inference: noninference vs. bridging vs. pragmatic; within-subject) mixed ANOVA on mean RT for the middle four passages was conducted. As expected and reported in Table 2, there was again a very large statistically significant main effect of group as L2 Spanish readers took significantly longer than the L1 English readers on the reading comprehension questions, $F(1, 154) = 260.94$, $p < .001$, Cohen's $f^2 = 0.91$. Furthermore, consistent with Rai et al. (2011), there was a medium-sized statistically significant main effect of inference type. This occurred across both L1 and L2 groups, $F(1, 308) = 38.41$, $p < .001$, Cohen's $f^2 = 0.23$, with RT increasing as the inferential complexity increased from noninference questions ($M = 4{,}620$ msec, $SD = 1{,}335$) to bridging inferences ($M = 5{,}489$ msec, $SD = 1{,}663$) to pragmatic inferences ($M = 5{,}591$ msec, $SD = 1{,}789$). Bonferroni pairwise comparisons revealed that there was a statistically significant difference between noninferences and bridging inferences and noninferences and pragmatic inferences ($p < .001$ in both cases).

Although the main effect of stress on RT was nonsignificant, more important and consistent with results from Figure 1, there was a small but clear Group (L2 vs. L1 readers) $\times$ Stress (no-stress vs. stress) interaction, $F(1, 154) = 4.34$ $p = .039$, Cohen's $f^2 = 0.08$.

Specifically, as shown in Figure 2 and reported in Table 2, for the L1 readers there was no significant difference in RT from the no-stress to the stress condition, $t(69) < 1$. However, for the L2 readers, there was a significant increase in RT from the no-stress to the stress condition, $t(85) = -2.28$, $p = .025$, Cohen's $d = 0.25$, showing a small, but clear drop in efficiency.

In addition to the Stress $\times$ Group interaction, the main effect of inference type was qualified by a medium-size interaction between Group (L2 vs. L1 readers) $\times$ Inference Type (noninference vs. bridging vs. pragmatic), $F(2, 308) = 30.01$, $p < .001$, Cohen's $f^2 = 0.25$ (Figure 3).

Specifically, as reported in Table 2, the L1 readers showed little increase in their RT as inferential complexity increased from noninference to bridging inference to pragmatic inference. For the L2 readers, however, there was a significant increase in RT between noninference questions and bridging inference questions and between noninference questions and pragmatic inference questions. This interaction can be understood in terms of the two types of task difficulty, namely, L1 versus L2 and inferential complexity, such that only when linguistic processing was most difficult (in an L2), did inferential complexity significantly decrease processing efficiency.

Relationships Between WM, Reading Anxiety, and Reading Proficiency and Reading RTs and Accuracy for L1 and L2 Readers

In order to assess the relationships between the predictor variables of WM (OSpan), reading anxiety (FLRAS), and self-rated reading proficiency, on the one hand, and the outcome variables of RT and accuracy, on the other, we calculated the Pearson correlations shown in Table 3.

Simultaneous multiple regressions were conducted to further probe the degree to which WM, reading anxiety, and reading proficiency uniquely explained variance in the different outcome measures (RT, stress effect on RT, and accuracy) for L1 readers and L2 readers, respectively. Table 4 summarizes these regression analyses.

For L2 readers, as shown in Table 3, there was a significant negative correlation between WM (OSpan) and foreign language reading anxiety (FLRAS), $r = -.194$, $p = .037$, such that those L2 readers who had lower WM scores tended to have higher foreign language reading anxiety. Additionally, there was a significant negative correlation between self-reported reading skills and FLRAS, $r = -.319$, $p < .001$, such that those L2 readers who reported having lower reading skills also tended to have greater foreign language reading anxiety.

Additionally, as shown in Table 3, the only significant correlation with L2 readers' RTs was with self-reported foreign language reading skills, $r = -.183$, $p = .046$, such that those L2 readers who reported having lower reading skills also had longer reading times. We therefore carried out a standard simultaneous multiple regression analysis to evaluate if self-reported L2 reading proficiency uniquely predicted variance in RTs for the L2 readers. After controlling for WM and foreign language reading anxiety, self-

[1] The common convention for Cohen's f^2 effect sizes (that are appropriate for use in mixed-factorial ANOVAs) is small, medium and large, being .10, .25, and .40, respectively (Cohen, 1992).

Table 2
Descriptive Statistics (Mean and SD) of Reaction Time and Accuracy Measures Across Stress and Inference Type Conditions for Both L1 and L2 Readers

Measure/Inference type	L1 (English readers) $n = 70$		L2 (Spanish readers) $n = 86$	
	msec	%	msec	%
RT				
Overall	3,491 (879)		6,976 (2,668)	
No stress	3,506 (845)		6,708 (2,534)	
Stress	3,477 (914)		7,244 (2,766)	
Noninference	3,412 (941)		5,821 (2,048)	
Bridging inference	3,512 (839)		7,466 (2,747)	
Pragmatic inference	3,541 (857)		7,641 (2,774)	
Accuracy				
Overall		.888 (.169)		.746 (.242)
Noninference		.881 (.172)		.818 (.191)
Bridging inference		.911 (.143)		.753 (.248)
Pragmatic inference		.872 (.188)		.667 (.259)

Note. Reaction time (RT) measured in milliseconds. Accuracy measured by percentage correct. L1 = first language; L2 = second language; RT = reaction time.

rated L2 reading proficiency did not significantly uniquely predict RT variance but was approaching significance, $B = -327.84$, $t = -1.803$, $p = .075$.

We also explored the degree to which stress influenced the relationships between the continuous predictor variables and L2 readers' RTs, as shown in Table 3 under the heading of "Stress Effect on RT," that refers to each subject's difference in RT between stress conditions. As shown in Table 3, foreign language reading anxiety (FLRAS) was significantly positively correlated with the stress effect on RT for L2 readers, $r = .254$, $p < .009$, such that those L2 readers who reported having greater foreign language reading anxiety also showed a greater effect of stress on their reading times. In addition, self-rated L2 reading proficiency was significantly negatively correlated with the stress effect on RT for L2 readers, $r = -.184$, $p = .045$, such that those L2 readers who rated themselves as having lower foreign language reading proficiency showed a greater effect of stress on their reading times. We then carried out a simultaneous multiple regression to determine whether foreign language reading anxiety or self-rated L2 proficiency uniquely predicted variance in the stress effect on RT for L2 readers. As shown in Table 4, when entered into the regression simultaneously with each other and WM, neither foreign language reading anxiety nor self-rated L2 proficiency uniquely predicted variation in L2 readers' stress effect on RT. However, it is worth noting that foreign language reading anxiety was approaching significance, $B = 277.58$ $t = 1.82$, $p = .073$, suggesting that as trait foreign language reading anxiety increased, there was a trend toward an increased effect of stress on RT.

To further explore the above stress effect results for L2 readers, we carried out a median split on the foreign language reading anxiety scores (FLRAS) and carried out a 2 (stress vs. no stress) × 2 (high vs. low FLRAS) repeated-measures ANOVA on L2 readers' RTs. A significant Stress × FLRAS interaction, $F(1, 84) = 8.53$, $p = .004$, revealed that those L2 readers with high foreign language reading anxiety took significantly longer in responding in the stress condition ($M = 7{,}164$ msec, $SD = 314$) but not otherwise ($M = 5{,}941$ msec, $SD = 254$) (Figure 4). This is consistent with attentional control theory, which argues that anxiety only impairs performance under stressful conditions. It is important to note as well that those L2 readers low in foreign language reading anxiety seemed immune to the effects of the stress manipulation.

As with the L2 readers, we calculated correlations among the continuous predictor variables and RT for the L1 readers. As

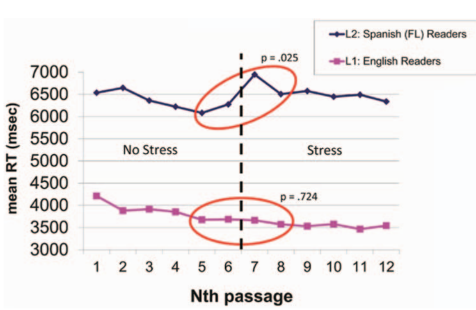

Figure 1. Reaction time (RT) as a function of *n*th passage for second-language (L2) and first-language (L1) readers. msec = milliseconds. See the online article for a color version of this figure.

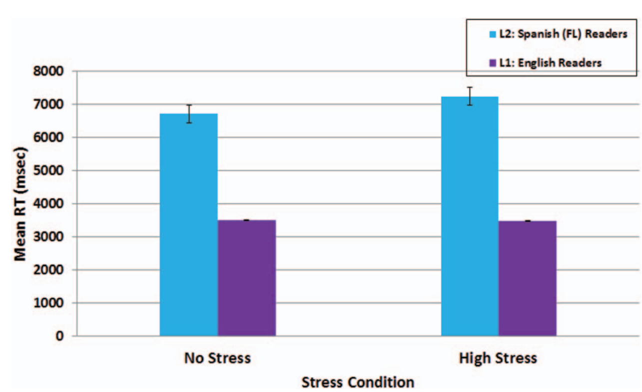

Figure 2. Reaction time (RT) as a function of stress for second-language (L2) and first-language (L1) readers (middle four passages only). msec = milliseconds. Error bars are standard error of the means. See the online article for a color version of this figure.

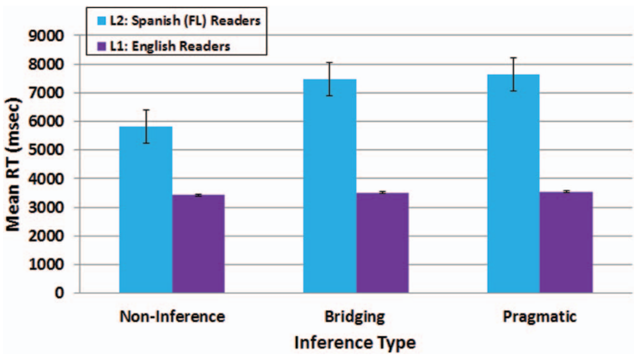

Figure 3. Reaction time (RT) as a function of inference type for second-language (L2) and first-language (L1) readers (middle four passages only). msec = milliseconds. Error bars are standard error of the means. See the online article for a color version of this figure.

shown in Table 3, similar to what we found for L2 readers, for L1 readers, there was a significant negative correlation between self-reported reading skills and L1 reading anxiety (adapted FLRAS), $r = -.226$, $p < .001$, such that L1 readers who rated themselves as having higher L1 reading proficiency also reported having less L1 reading anxiety. No other correlations among WM, L1 reading anxiety and self-rated L1 reading proficiency were significant.

Additionally, Table 3 shows that there was a significant negative correlation between L1 readers' reading RTs and their self-reported L1 reading skills, $r = -.412$, $p < .001$, in which L1 readers who rated themselves as having higher L1 reading skills tended to have lower (faster) RTs. We then performed a simultaneous multiple regression analysis to determine whether L1 readers' self-reported L1 reading skills uniquely predicted variance in their reading RTs after controlling for their WM and L1 reading anxiety levels. Table 4 shows the results of this regression, which revealed that the linear combination of these variables predicted 19.8% of the variance in RT, $R^2 = .198$, $F(2, 66) = 5.44$, $p = .002$, with self-reported reading skill significantly and uniquely predicting L1 readers' RTs, $B = -230.54$, $t = -3.56$ $p = .001$. These results corroborate that as self-reported reading skills increased, L1 reading RTs decreased. Neither WM nor L1 reading anxiety significantly predicted unique variance in L1 readers' RTs.

In terms of the stress effects on RT for L1 readers, Table 3 indicates that there was a significant negative correlation between WM (OSpan) and the stress effect on RT for L1 readers, $r = -.244$, $p = .021$, namely, those who had lower WM scores tended to show a greater effect of stress on their reading RTs. Neither L1 reading anxiety nor self-rated proficiency showed significant correlations with L1 readers' stress effect on their reading RTs. To investigate whether WM had a unique effect on L1 readers' stress effect on RT after accounting for these other two predictors, we carried out a simultaneous multiple regression of all three predictors on L1 readers' stress effect on their RTs. As can be seen in Table 4, WM did significantly and uniquely influence L1 readers' stress effect on RT, $B = -110.85$, $t = -2.07$, $p = .043$.

To further explore the role of WM in these stress effects L1 readers' RTs, we did a median split on L1 readers' WM scores, and carried out a 2 (stress vs. no stress) × 2 (high vs. low WM) repeated-measures ANOVA on RT. This produced a significant Stress × WM interaction, $F(1, 68) = 5.17$, $p = .026$, which Figure 5 shows to be a disordinal (cross-over) interaction. Specifically, those L1 readers with low executive WM took significantly longer to respond when under stress ($M = 3{,}614$ msec, $SD = 631$) but not otherwise ($M = 3{,}440$ msec, $SD = 721$). Conversely, and interestingly, those L1 readers high in WM showed the exact opposite result. Thus, for those L1 readers low in WM, stress apparently depleted cognitive resources, which in turn decreased processing efficiency. However, those L1 readers high in WM performed more efficiently under stress than without stress, perhaps due to a beneficial increase in arousal when carrying out a relatively easy task.

Accuracy

Effects of inference type and stress on accuracy for L1 and L2 readers. We also carried out a 2 (L1 vs. L2; between-subjects) × 2 (no stress vs. stress; within-subject) × 3 (inference: non vs. bridging vs. pragmatic; within-subject) mixed ANOVA on mean accuracy for questions in the middle four passages. As shown in Table 2, as expected, there was a statistically significant difference between groups as L2 readers had significantly lower accuracy than L1 readers, $F(1, 154) = 72.560$, $p < .001$, Cohen's $f^2 = 0.43$, reflecting a large difference between the two groups.

Table 3
Correlations of Measured Variables for L1 and L2 Readers

	1	2	3	4	5	6	7
1. Reaction time	1	*.029*	*.042*	*.001*	*−.081*	*−.006*	*−.183**
2. Stress effect on RT	.069	1	*−.194*	*−.052*	*−.106*	*.254***	*−.184**
3. Accuracy	−.129	−.040	1	*.121*	*.290***	*−.309***	*.049*
4. Stress effect on accuracy	.005	−.071	−.125	1	*−.003*	*−.093*	*−.017*
5. Working memory	−.163	−.244*	−.023	−.109	1	*−.194**	*.065*
6. Reading anxiety (FLRAS)	.135	−.120	−.237*	−.068	−.008	1	*−.319***
7. Reading proficiency	−.412***	.035	.286**	.095	.000	−.226*	1

Note. Coefficients above the main diagonal (in italics) represent values for the second-language (L2) readers, and the ones below are for the native English (L1) readers; the stress effect on reaction time (RT) is the difference in RT due to stress; the stress effect on accuracy is the difference in accuracy due to stress. FLRAS = Foreign Language Reading Anxiety Scale.
* $p < .05$. ** $p < .01$. *** $p < .001$ level.

Table 4
Standard Simultaneous Multiple Regression Analyses for Working Memory, Reading Anxiety, and Reading

Variable	L1 readers			L2 readers		
	RT (msec): B (*SE*)	Stress effect on RT (msec): B (*SE*)	Accuracy (%): B (*SE*)	RT (msec): B (*SE*)	Stress effect on RT (msec): B (*SE*)	Accuracy (%): B (*SE*)
Intercept	3,601.519 (63.08)	−256.15 (53.57)	.890 (.007)	6,592.33 (172.309)	116.05 (142.31)	.752 (.009)
Working memory	−93.04 (63.13)	−110.85* (53.61)	−.001 (.007)	−135.38 (175.67)	−77.89 (145.09)	.022* (.009)
Reading anxiety (FLRAS)	24.61 (65.22)	−54.93 (55.39)	−.011 (.007)	−140.35 (184.94)	277.58 (152.74)	−.025* (.010)
Reading proficiency	−230.54* (64.80)	3.60 (55.04)	.015* (.007)	−327.84 (181.81)	−154.36 (150.15)	−.005 (.010)

Note. Stress effect on reaction time (RT) is the difference in RT due to stress. L1 = first language; 2 = second-language; FLRAS = Foreign Language Reading Anxiety Scale.
* $p < .05$.

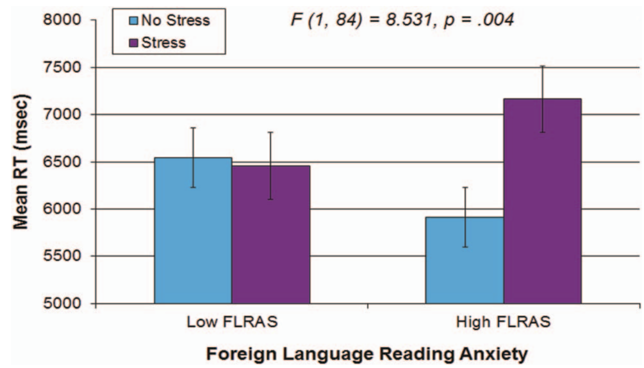

Figure 4. Reaction time (RT) as a function of Foreign Language Reading Anxiety Scale (FLRAS) and stress for second-language (L2) Spanish readers (middle four stories only). Error bars are standard error of the means. See the online article for a color version of this figure.

Furthermore, consistent with Rai et al. (2011), there was a small but statistically significant main effect of inference type, $F(2, 308) = 16.29$, $p < .001$, Cohen's $f^2 = .18$. Accuracy decreased as the inferential complexity increased from noninference questions ($M = 0.850$, $SD = 0.125$) to bridging inferences ($M = 0.830$, $SD = 0.150$) to pragmatic inferences ($M = 0.769$, $SD = 0.162$). Bonferroni pairwise comparisons revealed that there were statistically significant differences between noninferences and bridging inferences, noninferences and pragmatic inferences, and bridging and pragmatic inferences (all ts > 3.2, all ps $< .002$ in all three cases).

The main effects of group and inference type were qualified by a small but significant interaction between them, $F(2, 308) = 11.997$, $p < .001$, Cohen's $f^2 = 0.15$ (Figure 6). Specifically, for the L2 readers, there was a significant decrease in accuracy from noninferences to bridging inferences to pragmatic inferences However, for the L1 group, accuracy did not change as a function of inference complexity as seen in Table 2. These results are consistent with those reported earlier for RT and indicate that the RT results were not due to a speed–accuracy trade-off. Thus, the effects of processing difficulty caused by inferential complexity were only found when linguistic processing difficulty was greatest (i.e., in L2). Consistent with the results of Rai et al. (2011), there

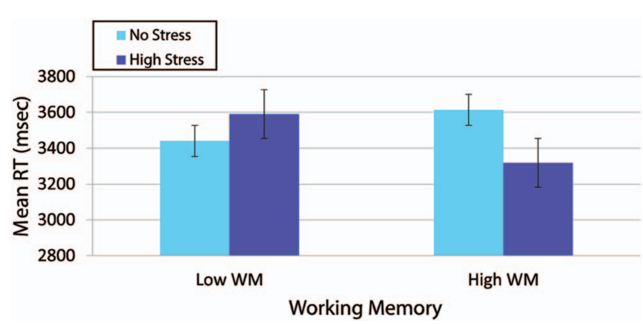

Figure 5. Reaction time (RT) as a function of working memory (WM) span and stress for first-language (L1) English readers (middle 4 stories only). msec = milliseconds. Error bars are standard error of the means. See the online article for a color version of this figure.

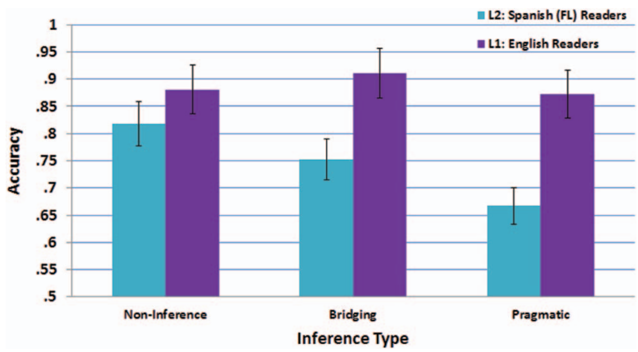

Figure 6. Reading comprehension accuracy as a function of inference type for second-language (L2) and first-language (L1) readers. Error bars are standard error of the means. See the online article for a color version of this figure.

were no significant effects or interactions on accuracy involving stress, all $ps > .05$.

To further explore the effects of WM, reading anxiety, and reading proficiency on accuracy for L2 readers, we calculated their correlations. As shown in Table 3, there was a significant positive correlation between WM (Ospan) and accuracy for L2 readers, $r = .290$, $p = .003$, with L2 readers who had higher WM scores tending to have a greater accuracy. Additionally, there was a significant negative correlation between foreign language reading anxiety (FLRAS) and accuracy, $r = -.309$, $p = .002$, with L2 readers who had greater reading anxiety having lower accuracy. We then carried out a standard simultaneous multiple regression to evaluate if WM and reading anxiety, after accounting for each other and self-rated L2 reading proficiency, uniquely accounted for variance in L2 readers' reading accuracy. As shown in Table 4, the linear combination of these predictor variables explained 15.3% of the variance in accuracy $R^2 = .153$, $F(3, 82) = 4.95$, $p = .003$. Specifically, both foreign language reading anxiety (FLRAS), $B = -.025$, $t = -2.57$, $p = .012$, and WM, $B = .022$, $t = 2.31$, $p = .024$, significantly and uniquely explained variance L2 readers' accuracy. The relationship between L2 reading accuracy and WM is a relatively standard result. However, the significant relationship between foreign language reading anxiety and L2 reading accuracy can be interpreted in at least three different ways: (a) foreign language reading anxiety disrupts L2 reading comprehension, (b) having generally poor L2 reading comprehension engenders foreign language reading anxiety, or (c) some third unmeasured variable influences both L2 reading comprehension and foreign language reading anxiety (e.g., foreign language learning aptitude).

As shown in Table 3, for L2 readers, there were no significant correlations involving the predictor variables of WM, foreign language reading anxiety, or self-rated L2 proficiency on stress effects on accuracy. This is consistent with the fact that the previously reported ANOVAs looking at the stress factor found no main effects or interactions involving L2 reading accuracy. We therefore did not carry out linear regressions looking at these relationships.

Similar to our findings for L2 readers, as shown in Table 3, we found a significant negative correlation between L1 reading anxiety (adapted FLRAS) and L1 reading accuracy $r = -.237$, $p = .024$, with L1 readers who had greater L1 reading anxiety tending to have lower L1 reading accuracy. Additionally, there was a significant positive correlation between self-reported L1 reading skills and L1 reading accuracy, $r = .286$, $p = .008$, such that those L1 readers who self-reported having greater L1 reading skills having greater L1 reading accuracy. We followed this with a standard simultaneous multiple regression analysis to determine whether L1 reading anxiety (adapted FLRAS) and self-rated L1 reading proficiency, when accounting for each other and WM, would uniquely explain variance in L1 reading accuracy. Considering the earlier mentioned fact that L1 reading anxiety and self-reported L1 reading proficiency were significantly negatively correlated (Table 3), one might predict that either one or the other of these two predictor variables would account for most of their shared relationship with L1 reading accuracy. Indeed, it was found that the linear combination of the continuous variables predicted 11.4% of the variance in L1 reading accuracy, $R^2 = .114$, $F(3, 66) = 2.83$, $p = .045$, with only self-reported L1 reading skills uniquely predicting L1 reading accuracy, $B = .015$, $t = 2.06$, $p = .043$. Thus, consistent with the L2 group, those L1 readers who reported having high reading proficiency were indeed more effective comprehenders.

As noted previously for the L2 readers, stress did significantly affect L1 reading accuracy in the earlier reported ANOVA, and as shown in Table 3, L1 readers stress effects on accuracy were not significantly correlated with any of the predictor variables. Additionally, for both L1 and L2 readers, there were no significant correlations between RT, accuracy, and the stress effects of RT and accuracy. Thus, we did not carry out linear regressions looking at these potential relationships.

Relationship Between RT (Processing Efficiency) and Accuracy (Processing Effectiveness)

We further graphically illustrated the relationship between processing effectiveness and efficiency by plotting reading RT versus accuracy as a function of stress and WM capacity, for both L1 and L2 readers separately (see Figures 7 and 8).[2] We did this to explore whether readers traded efficiency for effectiveness (speed–accuracy trade-offs) as predicted by attentional control theory. As shown in Figures 7 and 8, the L1 readers low in WM and the L2 readers high in WM were able to maintain or increase their reading effectiveness (i.e., accuracy) when under stress by trading off reading efficiency (i.e., increasing RT). However, the L2 readers with low WM capacity were unable to trade efficiency for effectiveness when under stress (i.e., no speed–accuracy trade-off). Instead, they showed both a decrease in accuracy and an increase in RT when under stress. This is consistent with a hypothesis generated from our third research question, which suggested that if limited central executive WM resources underlie the effects of stress on reading, then readers with fewer resources to begin with should suffer most from anxiety caused by stress. We can explain this based on the attentional control theory, in the following way: L2 readers with low WM capacity had a combination of the fewest

[2] The multivariate relationship between the two dependent variables of RT and accuracy was not reported in any previous univariate analyses. The current plots are exploratory and graphical in nature, not the result of multivariate analyses.

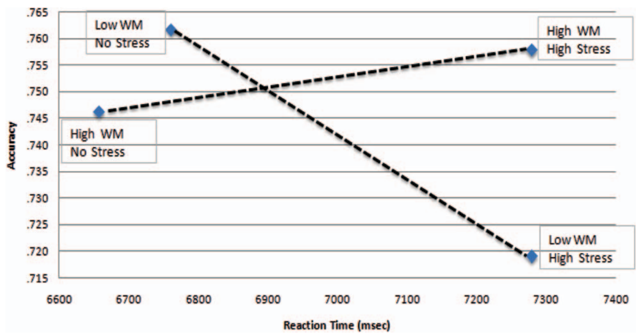

Figure 7. Speed–accuracy trade-off as a function of working memory (WM) capacity and stress for second-language (L2) Spanish readers only. msec = milliseconds. See the online article for a color version of this figure.

executive resources and the most difficult task (L2 reading). Thus, consistent with Rai et al. (2011), when stress depleted low WM L2 readers' limited executive resources, even a decrease in processing efficiency (longer RTs) was not enough to maintain their reading effectiveness. Finally, the L1 readers high in WM actually increased their efficiency when under stress (i.e., they read faster), but this slightly decreased their effectiveness (i.e., they were a bit less accurate), namely, the "flip side" of a speed–accuracy trade-off. This difference in accuracy, however, was not significant, $t(31) = 1.26$, $p = .22$. Presumably, for these readers, the task was easy enough and their WM resources were plentiful enough that social-evaluative stress simply spurred them to perform more quickly, if slightly less accurately.

Discussion

The chief question addressed in the current study was how social-evaluative stress affects reading. We first noted that consistent with attentional control theory, such stress should have negative effects only on reading efficiency, so long as the readers control their own reading time, and those negative effects should only occur for those readers prone to anxiety. However, there have been inconsistent results in the literature about the effects of stress and anxiety on the central executive updating function (Eysenck et al., 2007), a process critical for constructing situation models in reading. We hypothesized that such complex results may have been due to the fact that, as attentional control theory argues, anxiety only impairs performance when task difficulty is high and when anxious thoughts compete for limited central executive resources. Yet, for most educated adult L1 readers, reading is a highly automatized task. Thus, such readers may show weak or variable effects of anxiety and stress on their reading performance. Conversely, the task of reading is less automatized in an L2 for which the reader's proficiency is less than native-like. Thus, based on the attentional control theory, we predicted greater effects of situational stress and trait anxiety on L2 than L1 reading efficiency. The results of the current study are consistent with this hypothesis, thus answering our first research question by showing that stress differentially affects L1 versus L2 reading. We found reduced processing efficiency (longer RTs) in the short term due to social-evaluative stress for those high in reading anxiety in L2 reading (Figure 4). However, for L1 reading, although there was no overall difference between stress and no stress on RT, this was due to a cross-over interaction producing opposite effects of stress and WM capacity on L1 reading speed (Figure 5). Specifically, L1 readers who were low in WM capacity read more slowly (less efficiently) when under stress, while L1 readers high in WM capacity read faster (more efficiently) when under stress. However, consistent with our predictions from attentional control theory and previous results (Rai et al., 2011), we found no effects of social-evaluative stress on reading effectiveness (accuracy).

Our third research question was regarding how reading anxiety affects reading comprehension. Consistent with attentional control theory, we only found decreases in processing efficiency due to social-evaluative stress among those participants who were higher in trait reading anxiety (Figure 4). For L2 readers, only those who were high in foreign language reading anxiety showed negative effects of stress on reading efficiency. Furthermore, foreign language reading trait anxiety explained 15.3% of L2 readers' variance in comprehension accuracy. Finally, for both L1 and L2 readers, trait reading anxiety was negatively correlated with self-rated reading proficiency. Thus, an important question for further research is the direction of causality behind this correlation.

These results have both theoretical and applied implications. From a theoretical perspective, it suggests that it is important to consider both L1 and L2 reading in order to fully understand the effects of stress on reading, because L1 and L2 reading differ in their inherent task difficulty (which was the topic of our fourth research question). From an applied perspective, these results suggest that compared with L1 students, intermediate (i.e., non-fluent) L2 students may be more likely to suffer reading comprehension impairments due to social-evaluative stress, which educators should be bear in mind.

The current study also speaks to more general issues regarding the scope and intensity of stress effects on reading comprehension. Consistent with attentional control theory (Eysenck et al., 2007) and related previous studies of stress and reading (Calvo et al., 1992, 1994; Darke, 1988b; Rai et al., 2011), we found that social-evaluative stress primarily affected processing efficiency, not effectiveness, though it interacted with several other factors (i.e., reading anxiety, WM capacity, and L1 vs. L2). The fact that social-evaluative stress primarily affected reading efficiency can be explained by the fact that

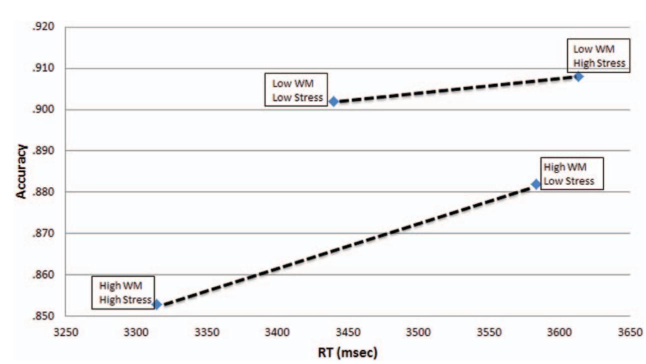

Figure 8. Speed–accuracy trade-off as a function of working memory (WM) capacity and stress for first-language (L1) English readers only. RT = reaction time; msec = milliseconds. See the online article for a color version of this figure.

our reading task was self-paced, and thus readers could trade processing efficiency to maintain their effectiveness when necessary (and when they had sufficient WM resources to do so). However, previous research has shown that if reading time is strictly limited, then the effects of stress (more specifically, resultant anxiety) indeed reduce accuracy (Calvo & Eysenck, 1996). Outside the laboratory, strict time limitations and social-evaluative stress often are both present in timed reading comprehension tests.

High stakes reading comprehension tests are perhaps the prime real-world example of a social-evaluative stressor that occurs while reading. Thus, in our study, the entire reading comprehension task (reading passages and questions) were in the target language, simulating real-world tests.[3] Although our study manipulated social-evaluative stress in the form of a reading test, our tasks were relatively easy for the L1 group (whose overall mean accuracy was 89%). This was because it was important to hold the complexity of the reading materials constant across L1 and L2 groups, while at the same time not making the reading task impossibly difficult for the L2 group. Thus, it is possible that using more difficult reading materials and tasks (e.g., reading comprehension tasks at the level of the Graduate Record Examination) would produce stronger effects of stress on L1 reading efficiency and effectiveness.[4] More generally, we would predict that as standardized measures of reading level of the reading materials used to test reading comprehension increase (e.g., from Grade 6 to Grade 12), the effects of stress on educated adult L1 readers should become more apparent. In addition, in the future, researchers may want to investigate the effects of varying L2 language proficiency (e.g., second-year vs. fourth-year foreign language students) in determining the effects of stress on L2 reading.

We should note that these effects of social-evaluative stress were relatively short-lived, dissipating after reading two passages and answering their associated reading comprehension questions. However, within the bounds of a laboratory study meeting ethical standards of doing no harm to participants, it seems unlikely that we could have caused much greater social-evaluative stress. Thus, our results suggest that the negative effects of such moderate levels of social-evaluative stress on reading comprehension are relatively modest and short-lived, and, in the absence of time pressure, only affect processing efficiency.

The current study also investigated how reading task difficulty, as manipulated by inferential complexity, interacts with stress and anxiety to affect reading comprehension. Consistent with Rai et al. (2011), L2 readers' processing effectiveness and efficiency were both affected by inferential complexity. Thus, foreign language reading teachers should know that tasks requiring the learner to use his or her prior knowledge to build situation models of text (e.g., drawing pragmatic inferences) may require more time and effort (and perhaps higher fluency) than simpler factual memory or bridging inference questions. Although the current study found no effect of inferential complexity on the processing efficiency or effectiveness of the L1 readers, there was a trend in that direction for the pragmatic (most complex) inferences. This suggests that only when the reading task was made more difficult, due to lesser linguistic competency in the L2, was inferential complexity an important factor.

The finding of WM span differentially affecting inference comprehension for L1 versus L2 readers is consistent with the results of Alptekin and Ercetin (2010), who showed that WM processing was slower for L2 readers than for L1 readers, even when WM storage capacity was the same. Specifically, Alptekin and Ercetin (2010) showed that compared with L1 readers, L2 readers are more limited in their processing capacities than their storage capacities. Further research on the effects of stress on reading could also examine the effects of stress and anxiety on the processing versus storage capacities of L2 and L1 learners.

The present study has highlighted the importance of interactive effects (moderating variables) in examining the effects of stress and WM capacity on reading. Stress does not have the same effect, in either kind or degree, on all reading tasks and situations. More difficult tasks, such as reading in a second language or reading to construct situation models and draw pragmatic inferences, make far greater demands on the central executive resources than do simpler reading tasks. These more complex reading tasks and situations are much more vulnerable to disruption by external stress. In addition, stress may impact some measures (e.g., time–efficiency) while leaving others (e.g., accuracy–effectiveness) untouched. Stress effects may simply speed up reading in one's native language, while slowing down reading in a second language, but only for those higher in dispositional reading anxiety. Such complexities must be kept in mind when constructing theories of the effects of stress on reading comprehension or when developing pedagogical strategies for dealing with stress.

[3] Some studies of second-language acquisition assess L2 reading comprehension though the L1 in order to decouple the comprehension of the reading passages from comprehension of the test questions. Investigators conducting follow-up research to the current study may want to do likewise. However, the current study reflects the context in which L2 readers' reading comprehension is most commonly assessed, namely, the context in which both the reading passages and reading test questions are in the L2. In addition, research on the effects of "language-mode" induction in bilinguals (Grosjean, 1998) has shown that language switching sometimes produces carry-over effects, so we intentionally kept students in only one language mode at a time.

[4] It could be argued that people who take foreign language courses may be more linguistically adept than the general population. However, because these potentially more linguistically adept subjects in our L2 group also were lower in L2 proficiency than our L1 subjects were in L1 proficiency, self-selection in the L2 group did not affect the results given the difficulty level of the text. It is possible that our L2 subjects, however, might have performed even better in their L1 than our L1 subjects did.

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Appendix

Sample Passages and Questions

The following are two examples of reading comprehension text passages and their accompanying questions. The passages are in English but were presented in Spanish for the L2 Spanish learners in the study and were presented in English for the L1 group. Neither the question-type labels (“Bridging inference,” “Noninference,” and “Pragmatic inference”) nor the asterisks indicating the correct answer were seen by the participants in the experiment.

Sample Passage 1 and Questions

> Since we are thinking of adopting a new pet, yesterday my family and I visited the animal shelter. It is a sad yet hopeful place. There is a room filled with puppies only. Unfortunately, most people want young dogs, so the old dogs don’t get much attention. One room was completely filled with breeds of larger dogs. My father spent most of his time looking at these larger breeds. My mother and I walked around, trying to find where the cats were located. We were surprised to note that the shelter also had rare animals. My mother thought the pig and chicken were disgusting. We saw both a small lizard and a hen waiting to be adopted! Vicente, my brother, saw a pot-bellied pig. As my mother was explaining how dirty farm animals are, the pig suddenly snorted at him!

Bridging inference: At whom did the pig snort? a. father *b. Vicente

Noninference: What type of dogs weren’t getting much attention? *a. older dogs b. puppies

Pragmatic inference: Did the narrator’s father want to get a small dog? a. yes *b. no

Sample Passage 2 and Questions

> There are 50 students in young Santino’s economics class. Unfortunately, the four most annoying people in the class happen to sit nearby. The student who sits to his right, Ricardo, props his book up on his desk and sleeps through the class. Sebastian, who sits to Santino’s left, fidgets a lot. He spends the class period practicing tricks he can do with his pen. About every half minute, he drops it and has to look for it. Manuel, who sits in front of Santino, reads the newspaper all through class. There just can’t be that much interesting news to fill the whole hour! And the red-haired kid who sits behind him constantly kicks his chair. It’s as if the red-haired kid and his friends are trying to make Santino fail his class! Every time he kicks Santino’s chair, Santino remembers how much he can’t stand economics.

Bridging inference: Who kicks Santino’s chair? *a. the red-haired kid b. Manuel

Noninference: What is Santino studying? a. current events *b. economics

Pragmatic inference: Does Santino like the people sitting near him? a. yes *b. no

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