The Effect of Working Memory Capacity on Multimedia Learning: Does Attentional Control Result in Improved Performance?

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Abstract
Do individual differences in working memory capacity (WMC) affect student learning within multimedia instructional environments? High and low WMC students, as measured by the operation span (OSPAN) task, engaged in a multimedia tutorial addressing lightning formation or car brake use. The results of two experiments indicated that students with high WMC recalled and transferred more information than students with low WMC after engaging in a multimedia tutorial. In addition, the multimedia principles of coherence (Exp 1) and signaling (Exp 2) were also assessed for validation. Each of the experiments failed to validate the previous multimedia learning principles. These results are consistent with a general individual differences WMC effect but inconsistent with previous finding regarding the coherence and signaling effects.

Key Words
Working memory capacity, multimedia learning, coherence principle, signaling principle

Introduction

The world has become saturated with multiple forms of media: television, radio, mp3 players, DVD players, and web-based audio and video. These multiple forms of media, or multimedia, have also infused themselves into both formal and informal instructional environments and have been demonstrated to have a significant impact, both negative and positive, on the nature of learning. For example, multimedia has been demonstrated to have a negative impact on learning and performance when a student's visual attention is split between an animation-based tutorial depicting the cause of lighting and a simultaneously presented text-based description of the lightning tutorial (Mayer & Moreno, 1998). In contrast, multimedia has been demonstrated to have a positive impact on learning and performance when a student's attention is guided toward specific goals for reading and viewing an illustrated, text-based tutorial of the cause of lighting, such as when students are told to focus on learning the steps involved in creating a stroke of lightning before engaging in the tutorial (Harp & Mayer, 1998).

If multimedia can both support and interfere with learning, might individual differences in attention influence learning and performance in multimedia instructional environments? In support of this question, there exists a body of literature demonstrating that attentional control affects learning and performance (Daneman & Carpenter, 1980; Oberauer, Süb, Schulze, Wilhelm, & Wittmann, 2000; Unsworth & Engle, 2007). Within this literature, "attentional control" has been defined as the ability to maintain information in working memory while effectively retrieving task relevant information from long-term memory (Feldman Barrett, Tugade, & Engle, 2004), and it has been measured by working memory capacity (WMC) (Kane, Bleckley, Conway, & Engle, 2001; Kane & Engle, 2003). Thus, the present study explored whether individual differences in WMC affect learning and performance in multimedia instructional environments.

Working Memory Capacity and Individual Differences

Individuals need to have the ability to dynamically retrieve, maintain, manipulate, and update information in order to successfully complete complex cognitive tasks (Baddeley & Hitch, 1974). While investigating this dynamic memory model, Daneman and Carpenter (1980) concluded that complex memory tasks and working memory capacity are positively correlated; in other words, they found that global and local measures for reading comprehension and working-memory span tasks that involve information processing and storage are positively correlated (Daneman & Carpenter, 1980). In this study, participants were asked to complete a task that involved reading a series of sentences (processing) while remembering the last word in each sentence (storage). Unlike previous storage-only working-memory span tasks (e.g., digit span, word span), this storage + processing working-memory span task included reading, an additional processing task that increased working-memory load complexity. In this sense, this type of complex storage + processing working-memory span task is thought to be more accurate at estimating the cognition needed to perform complex cognitive tasks than simpler span tasks that only involve storage and not processing of information (Daneman & Carpenter, 1980; Unsworth & Engle, 2007).

Over the past 25 years, researchers investigating the constitution of WMC and the effects of individual differences in WMC have used this type of complex storage + processing memory span tasks as a measure of WMC. It has been found that high WMC can be considered a good predictor of primary memory maintenance and secondary memory search (Unsworth & Engle, 2007), attentional control (Kane et al., 2001; Rosen & Engle, 1997), long-term memory activation (Cantor & Engle, 1993), general fluid intelligence (Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Kane et al., 2004), resistance to goal neglect (Kane & Engle, 2003; Roberts, Hager, & Heron, 1994), and resistance to proactive interference (Kane & Engle, 2000; Lustig, May, & Hasher, 2001). Therefore, it can be concluded that attentional control—being able to actively maintain information in working-memory, as well as being able to effectively and efficiently search for task-relevant information in long-term memory while completing a task, whether or not under conditions of interference or distraction—is the basis of WMC (Feldman Barrett et al., 2004; Unsworth & Engle, 2007).

This emphasis on attentional control as the basis of WMC has resulted in research focused on the effects of individual differences in WMC—that is to say, high and low WMC—on participants' performance in complex cognitive tasks. Researchers found that variations in WMC and in complex cognitive task performance were positively correlated. More specifically, it has been demonstrated that participants with high WMC perform better than those with low WMC on tasks involving Scholastic Aptitude Test performance (Turner & Engle, 1989), reasoning (Conway et al. 2002; Kyllonen & Christal, 1990; cf. Buehner, Krumm, & Pick, 2005), mnemonic strategy effectiveness (Gaultney, Kipp, & Kirk, 2005), lecture note taking (Kiewra & Benton, 1988), storytelling (Pratt, Boyes, Robins, & Manchester, 1989), reading comprehension (Daneman & Carpenter, 1980), computer language learning (Shute, 1991), language comprehension (Just & Carpenter, 1992), and vocabulary learning (Daneman & Green, 1986).

Domain-General and Domain-Specific Working Memory Capacity

A stable construct sensitive to individual variation has been identified through research on WMC and individual differences in WMC. However, a topic that has yet to be elucidated is whether WMC is influenced by task specificity or whether it has its basis in general underlying processes. Researchers studying the correlation between verbal and spatial measures of WMC, as well as verbal and spatial measures of ability, have found that these two types of measures are positively correlated, thus providing support to a domain-specific perspective on WMC; in contrast, researchers have found little or no correlation between spatial ability and verbal WMC, or between verbal ability and spatial WMC (Daneman & Tardif, 1987; Morrell & Park, 1993; Shah & Miyake, 1996). Additional support for the domain-specific perspective on WMC arises from explanatory and confirmatory factor analysis studies, whose results revealed that verbal ability and verbal WMC measures, as well as spatial ability and spatial WMC measures, have yielded separate independent factors (Friedman & Miyake, 2000; Handley, Capon, Copp, & Harper, 2002; Kane et al., 2004; Shah & Miyake, 1996).

Other research studies, however, support a domain-general WMC perspective. A study involving a latent-variable approach to verbal and spatial WMC that examined several measures of verbal and spatial WMC, short-term memory, and reasoning (Kane et al., 2004) found that, given the extensive shared variance (70%–85%) between verbal and spatial WMC tasks, WMC could be considered mainly domain-general, despite the fact that the researchers found a small domain-specific factor. The results of Kane et al. provided further support to previous latent-variable approaches to verbal and spatial WMC, in which it was concluded that verbal and spatial WMC constitute a single underlying factor (Ackerman, Beier, & Boyle, 2002; Oberauer et al., 2000, 2003). Other studies that confirm the domain-general perspective include those by Kane and Engle (2003), who found that maintenance of information (e.g., goals, representations) and avoidance of distraction (e.g., irrelevant stimuli, prepotent responses) depended on general controlled attention, as well as those of various other researchers, who found that, in tasks that demand attention-control for success (e.g. dichotic-listening task, antisaccade task, Stroop task), high WMC participants had better general performance than low WMC participants (Conway, Cowan, & Bunting, 2001; Kane & Engle, 2003; Unsworth, Schrock, & Engle, 2004; cf. Kane, Poole, Tuholski, & Engle, 2006). As Kane et al. (2004) pointed out, researchers have yet to reach consensus regarding the domain-specific or domain-general nature of WMC, and it is possible that this may never occur.

Working Memory Capacity in Multimedia Instructional Environments

Working memory capacity is a measure of an individual's ability to control attention in order to maintain representations in working memory and to search for and retrieve relevant information from long-term memory. WMC effects have been most consistent in tasks that require information maintenance, require long-term memory search, or involve interfering or distracting stimuli (Feldman Barrett, Tugade, & Engle, 2004; Unsworth & Engle, 2007). The previously reviewed WMC tasks (e.g., reading span, operation span, counting span) and the complex cognition tasks (e.g., antisaccade, dichotic listening, reading), however, are all single-media tasks, involving only visual *or* auditory information. Conversely, multimedia tasks generally include tasks with both a visual component (e.g., pictures, animation) and a verbal component (e.g., text, narration). Further, the multimedia learning literature, as with WMC, is based on the combination of attentional selection of stimuli, retrieval of relevant information from long-term memory, and active processing and integration of representations (see Mayer, 2001, 2005; Reed, 2006).

While it is evident that WMC and learning in multimedia instructional environments require similar processing (i.e., attention, retrieval, integration), the nature of individual difference effects of WMC on learning in multimedia instructional environments is unclear; thus, two experiments were designed to assess the individual differences effect for learning in multimedia environments. In Experiment 1, high and low WMC participants engaged in a tutorial on the cause of lightning in one of two conditions: visual animation with auditory narration (AN) or visual animation with auditory narration that includes irrelevant background graphics, sounds, and seductive details (ANSD). Previous research has indicated that participants in the AN condition tend to outperform participants in the ANSD condition, the coherence effect (Harp & Mayer, 1998; Mayer & Jackson, 2005; Moreno & Mayer, 2000). In Experiment 2, high and low WMC participants engaged in a tutorial on how car brakes work in one of two conditions, visual animation with auditory narration (AN) or visual animation with auditory narration that includes visual signaling (ANVS) in the form of key words located spatially contiguous to their referent and a spotlight effect to focus attention on the germane aspect of the animation. Previous research examining this signaling effect has been inconclusive, with some research supporting the cues to focus learner's attention and some research not supporting the inclusion of cues (Harp & Mayer, 1998; Mautone & Maher, 2001). Both of the present experiments were designed to assess whether a general individual differences effect of WMC for learning in a multimedia instructional environment exists and to verify previously supported principles of multimedia learning.

Experiment 1

The purposes of Experiment 1 were to test the general individual differences WMC hypothesis: that high WMC participants would outperform low WMC participants on measures of recall and transfer after engaging in a multimedia tutorial and, to validate the coherence principle, that students' recall and transfer of information is inhibited when a multimedia tutorial includes extraneous words, pictures, sounds or music (Moreno & Mayer, 2000). These extraneous items, termed "seductive details," may inhibit recall and transfer by activating inappropriate schemas or distracting the learner (Harp & Mayer, 1998; Mayer & Jackson, 2005; Sanchez & Wiley, 2006). In Experiment 1, extraneous graphics and sounds were added to a tutorial on how lightning forms.

Method

Participants and Design

The participants were 106 undergraduate students (74 men and 32 women) with a mean age of 19.7 years, including 6 freshmen, 34 sophomores, 48 juniors, and 18 seniors. They were enrolled in a non-major personal health class and received course credit for participation. Participants were taken from a larger pool of 201 students who were administered the OSPAN (Operation Span) working memory span test. Of these 201 students, only those that scored in the upper or lower quartiles were included as participants. The experimental design was a 2 × 2 factorial design with working memory capacity (high WMC, low WMC) and multimedia group (animation + narration [AN], animation + narration + seductive details [ANSD]) as between-subject variables. Participants were assigned to either the high (n = 54) or low (n = 52) WMC group based on their OSPAN performance. Participants were then randomly assigned to either the AN (n = 58) or ANSD (n = 48) multimedia group.

Materials and Apparatus

Working memory capacity OSPAN task. WMC was measured using the OSPAN operation-span task (La Point & Engle, 1990; Turner & Engle, 1989). The OSPAN requires participants to solve a series of basic math problems while attempting to remember a series of unrelated words. Specifically, participants were shown a series of math-word sentences in the form of "IS (3 + 7) – 4 = 5 ? Bird" or "IS (8 – 4) / 2 = 2 ? Grass." Participants were required to read the math statement aloud and respond aloud "yes" or "no" as to whether the math statement was true or false. After reading and solving the math statement, and without pausing, participants then read the unrelated word aloud. For example, given the second example above, the participant would say, "Is eight minus four divided by two equal to two? Yes. Grass." Participants viewed and read aloud one math-word sentence at a time on a computer screen and clicked a "Continue" button to advance to the next math-word sentence. Participants viewed and responded to a set of two to six math-word sentences before they were asked to recall the unrelated words from that set, in order, and type the words into a text box on the computer screen.

The OSPAN score was determined by counting the number of words recalled for those sets in which the participant recalled all words, in order, correctly; thus, if a participant recalled *all* four words from a four math-word sentence set, in the proper order, the participant would receive four points. Participants viewed 15 sets of math-word sentences, three sets each that contained two to six math-word sentences, for a total of 60 math-word sentences. The order of the math-word sets and the math-word sentences within each set were randomized for each participant. Potential scores ranged from 0 to 60. Participants were assigned to the high WMC group if they scored in the upper quartile and to the low WMC group if they scored in the lower quartile of the original 201 students' scores. The mean OPSAN scores for the high WMC and low WMC groups were 30.50 (SD = 4.72) and 5.00 (SD = 3.02), respectively.

Recall and transfer tests. The recall test included answering the following question on the computer: "Please provide an explanation of what causes lightning." The recall question was provided on its own screen with a response box located directly below it. The transfer test involved answering four questions used by Moreno and Mayer (2000, p. 119) and included "What could you do to decrease the intensity of lightning?"; "Suppose you see clouds in the sky, but no lightning. Why might this happen?"; "What does air temperature have to do with lightning?"; and "What do electrical charges have to do with lightning?" The four transfer questions were all provided on the same computer screen, and each question was followed by its own response box.

"What Causes Lightning?" tutorial. The multimedia tutorials consisted of Flash animations based on Mayer and Chandler's (2001) animation depicting how lightning forms. This depiction included drawings of cool air moving from an ocean to land; the air becoming heated, rising, and forming a cloud; the cloud rising above the freezing level and forming ice crystals; the ice

crystals rising and falling to create electrical charges in the cloud; the negative electrical charges dropping to the bottom of the cloud and then down toward the land; the positive electrical charges rising up from the land to meet the descending negative charge; and finally, the positive charges moving up this charged pathway to form lightning. The verbal accompaniment to this visualization is in Appendix A, and a screen shot of the animation is in Appendix B. The lightning tutorials were presented on iMac computers with 15-inch screens and Altec Lansing headphones. Two versions of the content were constructed based on the same lightning animation and verbal content: Tthe AN version contained the lightning animation and an auditory narration of the verbal content, while the ANSD version contained the same lighting animation and auditory narration but with extraneous sounds (i.e., wind, rain, electrical charges, thunder) and images (i.e., darkening skies, excessive clouds, lightning flashes). Each version lasted 145 seconds.

Procedure

All data collection and media presentations were completed on wireless laptop computers. Participants first completed the OSPAN task. Next, following a brief introduction, they pressed the Enter key and viewed the appropriate version of the "What causes lightning?" tutorial given their multimedia group assignment (AN or ANSD). Following the viewing of the tutorial, and after pressing the Enter key, participants were given 5 minutes to complete the recall test. Finally, after completin the recall test and after pressing the Enter key, participants were given 15 minutes to complete the transfer test.

Scoring

Recall test. Two trained raters evaluated each participant's recall response (inter-rater reliability, $r = .90$) and computed a recall score by counting the presence of 8 idea units. One point was given to participants for the inclusion of each of the following idea units, regardless of wording: "(a) air rises, (b) water condenses, (c) water and crystals fall, (d) wind is dragged downward, (e) negative charges fall to the bottom of the cloud, (f) the leaders meet, (g) negative charges rush down, and (h) positive charges rush up" (Mayer, Heiser, & Lonn, 2001, p. 191).

Transfer test. Two trained raters evaluated each participant's transfer responses (inter-rater reliability, $r = .82$) and computed a transfer score by counting the total number of valid answers across the four transfer questions. Acceptable answers were determined by those established by Mayer et al. (2001). Acceptable answers to the first transfer question, "What could you do to decrease the intensity of lightning?" included decreasing the quantity of positively charged particles on land and increasing the quantity of positively charged particles next to the cloud; acceptable answers to the second transfer question, "Suppose you see clouds in the sky but no lightning, why not?" included the cloud not rising above the freezing level and ice crystals not forming; acceptable answers to the third transfer question, "What does air temperature have to do with lightning?" included the necessity of warm land and cool air, and the bottom part of the cloud being below the freezing level while the top of the cloud is above the freezing level; and finally, acceptable answers to the forth transfer question, "What causes lightning?" included differences in electrical charges within the cloud and differences in temperature within the cloud.

Results and Discussion

Experiment 1 was designed to (a) evaluate the general individual differences WMC hypothesis that students with high WMC will recall and transfer more from multimedia tutorials than students with low WMC, and (b) confirm previous results related to the coherence effect that student who receive multimedia messages embedded with irrelevant words, pictures, sounds or music will recall and transfer less from multimedia tutorials than students who receive multimedia messages without irrelevant elements. These two questions were analyzed using two 2 (high WMC, low WMC) × 2 (AN, ANSD) factorial designs based on the recall and transfer data.

Individual Differences WMC Effect

According to a general individual differences WMC approach, students with high WMC should recall and transfer more information from the multimedia tutorials than low WMC students as a result of high WMC students exhibiting better attentional control and resistance to distraction. This general individual differences WMC effect was confirmed for recall, as high WMC students recalled more idea units than low WMC students (see Table 1), resulting in a significant main effect for WMC, $F(1,102) = 6.57$, $MSe = 3.78$, Cohen's $d = 0.49$, $p = .01$. Similarly, for transfer, high WMC students generated more valid transfer responses than low WMC students, resulting in a significant main effect for working memory capacity, $F(1,102) = 10.97$, $MSe = 2.12$, Cohen's $d = .64$, $p = .00$. These results are consistent with the predications of the general individual differences WMC hypothesis; high WMC students outperformed low WMC students on recall and transfer after engaging in a multimedia tutorial.

Table 1
Means and Standard Deviations for Recall and Transfer Scores for High and Low Working Memory Capacity Students in Experiment 1

	Recall		Transfer	
	M	SD	M	SD
Low WMC	4.11	2.02	2.26	1.27
High WMC	5.08*	1.81	3.20*	1.61

Note: Max recall score = 8. Max transfer score = 8. * $p < .05$

Coherence Effect

According to the cognitive theory of multimedia learning (see Mayer, 2001), students' recall and transfer based on multimedia tutorials should be inhibited by the presence of extraneous words, pictures, sounds and music (seductive details), the coherence effect. The ANOVA for recall data resulted in no significant main effect between students who engaged in a narrated animation without seductive details and students who engaged in a narrated animation with seductive details (see Table 2), $F(1,102) = 0.73$, $MSe = 3.78$, Cohen's $d = 0.17$, $p = .39$. The ANOVA for transfer data also resulted in no significant main effect between students who engaged in a narrated animation without seductive details and students who engaged in a narrated animation with seductive details, $F(1,102) = 0.10$, $MSe =2.12$; Cohen's $d = 0.06$, $p = .74$. These results are inconsistent with prior research (see Harp & Mayer, 1998; Mayer & Jackson, 2005; Moreno &

Mayer, 2000; Sanchez & Wiley, 2006) and do not provide support for the coherence effect. The present experiment, however, may not have provided sufficient extraneous material to either activate inappropriate schemas (Harp & Mayer, 1998) or produce adequate distractions (Mayer & Jackson, 2005; Sanchez & Wiley, 2006). The present experiment used additional on-screen graphics and background sounds as seductive details; however, Moreno and Mayer (2000) found that the addition of background sounds did not consistently inhibit students' recall and transfer performance.

Table 2
Means and Standard Deviations for Recall and Transfer Scores for Students in Differing Multimedia Groups in Experiment 1

	Recall		Transfer	
	M	SD	M	SD
AN	4.76	2.02	2.77	1.48
ANSD	4.43	1.94	2.68	1.56

Note: Max recall score = 8. Max transfer score = 8. * $p < .05$

Differential Multimedia Group Effects on Individual Differences in WMC

There were no interactions between WMC and the multimedia groups (i.e., AN, ANSD) for recall, $F(2,102) = 0.37$, $MSe = 3.78$, Cohen's $d = 0.18$, $p = .53$, or transfer, $F(2,102) = 0.12$, $MSe = 2.12$, Cohen's $d = 0.24$, $p = .72$. Therefore, there was no indication that multimedia group affected high and low WMC students differentially.

Experiment 2

Experiment 1 provided evidence of a general individual differences WMC effect in which participants with high WMC recalled and transferred more information from a multimedia tutorial than participants with low WMC. The purpose of Experiment 2 was to provide an additional test of the individual differences WMC effect with different participants and different instructional materials. A second purpose of Experiment 2 was to validate the signaling effect. The signaling effect states that students' recall and transfer of information is facilitated by the presence of cues that guide the learners attention and highlight the structure of the information provided (Harp & Mayer, 1998; Mautone & Mayer, 2001). However, the findings regarding the signaling effect have been inconsistent. Harp and Mayer (1998) found that providing a learning objective prior to engaging in a multimedia tutorial increased students' recall and transfer (Exp 2); however, boldfacing and italicizing the main ideas within a written passage (Exp 1) and providing preview sentences and number signals (Exp 3) did not increase students' recall and transfer. Mautone and Mayer (2001) found that emphasizing key words or phrases in the narration by reading these key words more slowly and with a deep intonation increased students' recall and transfer (Exp 2); however, signaling the written text by providing section headers, a preview summary paragraph, transition or connecting words, and key words in boldface and italics (Exp 1), or providing colored arrows or summary icons (Exp 3) did not increase students' recall, but did increase students' transfer. Experiment 2 was designed to extend the research base on signaling by exploring the effects of signaling by (a) including key words within the animation spatially contiguous with their referent and (b) including a spotlight effect to focus the learner's attention on the aspect of the animation that was relevant to the narration (see Appendix B).

Method

Participants and Design

The participants were 105 undergraduate students (74 men and 31 women) with a mean age of 19.4 years, including 6 freshmen, 34 sophomores, 48 juniors, and 18 seniors. Participants were enrolled in a non-major personal health class and received course credit for participation. Participants were taken from a larger pool of 197 students who were administered the OSPAN working memory span test. Of these 197 students, only those that scored in the upper or lower quartiles were included as participants. The experimental design was a 2 × 2 factorial design with working memory capacity (high WMC, low WMC) and multimedia group (animation + narration [AN], animation + narration + visual signaling [ANVS]) as between-subject variables. Participants were assigned to either the high ($n = 53$) or low ($n = 52$) WMC group based on their OSPAN performance. Participants were then randomly assigned to either the AN ($n = 56$) or ANVS ($n = 49$) multimedia group.

Materials and Apparatus

Working memory capacity OSPAN task. WMC was measured using the OSPAN operation-span task (La Point & Engle, 1990; Turner & Engle, 1989) using the same materials used in Experiment 1. The mean OPSAN scores for the high WMC and low WMC groups were 29.32 ($SD = 5.62$) and 6.96 ($SD = 3.06$), respectively.

Recall and transfer tests. The recall test included answering the following question on the computer: "Please provide an explanation of how a brake works." The recall question was provided on its own screen with a response box located directly below it. The transfer test included answering four questions used by Mayer and Anderson (1992, p. 449) and included, "Why do brakes get hot?" "What could be done to make brakes more reliable, that is, to make sure they would not fail?" "What could be done to make brakes more effective, that is, to reduce the distance needed to bring a car to a stop?" and "Suppose you press on the brake pedal in your car but the brakes do not work. What could have gone wrong?" The four transfer questions were all provided on the same computer screen and each question was followed by its own response box.

"How Does a Car Brake Work?" tutorial. The multimedia tutorials consisted of Flash animations based on Mayer and Anderson's (1992) animation depicting how car brakes work. This depiction included drawings of a foot pressing a brake pedal, a piston moving inside a master cylinder, brake fluid being pushed out of the master cylinder and expanding smaller pistons in the wheel cylinder, and the smaller pistons pushing the brake shoes against the brake drum. The verbal accompaniment to this visualization is in Appendix A and a screen shot of the animation is in Appendix B. The car brake tutorials were presented on iMac computers with 15-inch screens and Altec Lansing headphones. Two versions of this content were constructed based

on the same car brake animation and verbal content: The AN version contained the car brake animation and an auditory narration of the verbal content, while the ANVS version contained the same car brake animation and auditory narration but with key words within the animation (i.e., piston, master cylinder, wheel cylinders, smaller pistons, brake shoes, drum) spatially contiguous with their referent and a spotlight effect focusing the learner's attention on the aspect of the animation that is relevant to the narration (see Appendix B). The spotlight effect mimicked a light being shown on the portion of the animation currently relevant to the narration. This effect resulted in the relevant portion of the animation being fully visible, while the remaining aspects of the animation were lightly shaded. The animation from the foot stepping on the brake to the brake shoes pressing against the brake drum lasted 30 seconds; however, this 30 second animation was played three times in order to accommodate the narration. Thus, each multimedia instructional episode lasted 90 seconds.

Procedure

All data collection and media presentations were completed on wireless laptop computers. Participants first completed the OSPAN task. Next, following a brief introduction, the participants pressed the Enter key and viewed the appropriate version of the "How does a car brake work?" tutorial based on their multimedia group assignment (AN or ANVS). Following the viewing of the tutorial, and after pressing the Enter key, participants were given 5 minutes to complete the recall test. Finally, after completing the recall test and after pressing the Enter key, participants were given 15 minutes to complete the transfer test.

Scoring

Recall test. Two trained raters evaluated each participant's recall response (inter-rater reliability, r = .92) and computed a recall score by counting the presence of 8 idea units. One point was given to participants for the inclusion of each of the following idea units, regardless of wording: "(a) driver steps on brake pedal, (b) piston moves forward inside master cylinder, (c) piston forces brake fluid out to the wheel cylinders, (d) fluid pressure increase in wheel cylinders, (e) small pistons move, (f) small pistons activate brake shoes, (g) brake shoes press against drum, and (h) drum and wheel stop or slow down" (Mayer & Anderson, 1992, p. 450).

Transfer test. Two trained raters evaluated each participant's transfer responses (inter-rater reliability, r = .89) and computed a transfer score by counting the total number of valid answers across the four transfer questions. The acceptable answer were determined by those established by Mayer and Anderson (1992). Acceptable answers to the first transfer question, "Why do brakes get hot?" included friction causes brakes to get hot; acceptable answers to the second transfer question, "What could be done to make brakes more reliable, that is, to make sure they would not fail?" included maintaining a backup system or using a system to cool the brakes; acceptable answers to the third transfer question, "What could be done to make brakes more effective, that is, to reduce the distance needed to bring a car to a stop?" included using a brake shoe that is more sensitive to friction or providing a smaller gap between the brake shoe and brake drum; and finally, acceptable answers to the forth transfer question, "Suppose you press on the brake pedal in your car but the brakes do not work. What could have gone wrong?" included that there may be a leak in the brake fluid line or that the brake pads are worn.

Results and Discussion

Experiment 2 was designed to (a) evaluate the general individual difference WMC hypothesis that students with high WMC will recall and transfer more from multimedia tutorials than students with low WMC, and (b) evaluate the visual signaling effect that students who receive visual signaling will recall and transfer more from multimedia tutorials than students who do not receive visual signaling. These two questions were analyzed using two 2 (high WMC, low WMC) × 2 (AN, ANVS) factorial designs based on the recall and transfer data.

Individual Differences WMC Effect

According to a general individual differences WMC approach, students with high WMC should recall and transfer more information from the multimedia tutorials than low WMC students as a result of high WMC students exhibiting better attentional control and resistance to distraction. This general individual differences WMC effect was confirmed for recall as high WMC students recalled more than low WMC students (see Table 3), resulting in a significant main effect for working memory capacity, $F(1,101) = 18.20$, $MSe = 2.53$, Cohen's $d = 0.83$, $p = .00$. Similarly, for transfer, high WMC students transferred more than low WMC students, resulting in a significant main effect for working memory capacity, $F(1,101) = 11.62$, $MSe = 1.92$, Cohen's $d = .66$, $p = .00$. These results are consistent with the predictions of the individual differences WMC hypothesis: high WMC students outperformed low WMC students on recall and transfer after engaging in a multimedia tutorial.

Table 3

Means and Standard Deviations for Recall and Transfer Scores for High and Low Working Memory Capacity Students in Experiment 2

	Recall		Transfer	
	M	SD	M	SD
Low WMC	4.80	1.64	2.87	1.52
High WMC	6.13*	1.51	3.80*	1.23

Note: Max recall score = 8. Max transfer score = 8. * $p < .05$

Signaling Effect

According to the cognitive theory of multimedia learning (Mayer, 2001), students' learning based on multimedia tutorials should be facilitated by the presence of cues that guide the learners' attention and highlight the structure of the information provided, the signaling effect (Mautone & Mayer, 2001). Specifically, the current experiment was designed to explore the effects of visual signaling by (a) including key words within the animation spatially contiguous with their referent, and (b) including a spotlight effect to focus the learner's attention on the aspect of the animation that is relevant to the narration. The ANOVA for recall data resulted in no significant main effect between students who engaged in a narrated animation with visual signaling and students who engaged in a narrated animation without visual signaling (see Table 4), $F(1,101) = 0.00$, $MSe = 2.53$, Cohen's $d = 0.02$, $p = .96$.

Table 4
Means and Standard Deviations for Recall and Transfer Scores for Students in Differing Multimedia Groups in Experiment 2

	Recall		Transfer	
	M	SD	M	SD
AN	5.47	1.79	3.36	1.39
ANSD	5.46	1.60	3.31	1.51

Note: Max recall score = 8. Max transfer score = 8. * p < .05

The ANOVA for transfer data also resulted in no significant main effect between students who engage in a narrated animation with visual signaling and students who engaged in a narrated animation without visual signaling, F(1,101) = 0.02, MSe = 3.01, Cohen's *d* = 0.04, p = .86. These results do not provide support for a visual signaling effect based on integrating keywords into an animation and spotlighting aspects of the animation that are relevant to the narration.

Differential Multimedia Group Effects on Individual Differences in WMC

There were no interactions between WMC and the multimedia groups (i.e., AN, ANVS) for recall, F(1,101) = 0.06, MSe = 2.53, Cohen's *d* = 0.27, p = .80, or transfer, F(1,101) = 1.00, MSe = 1.93, Cohen's *d* = 0.22, p = .31. Therefore, there was no indication that multimedia group affected high and low WMC students differently.

General Discussion

General Individual Differences WMC Effect in Multimedia Learning

Theoretically, the results of both experiments demonstrate that the ability to control attention and avoid distraction, as measured by WMC, positively affects cognitive performance in a multimedia environment. Specifically, in both experiments students with high WMC outperformed students with low WMC after engaging in various multimedia tutorials. These results are consistent with predictions from both the domain-general and individual differences perspectives of WMC—that is, variances in WMC are due to a general underlying attentional mechanism, and individual differences in WMC systematically affect cognitive performance.

The present study extends the WMC literature by addressing WMC in a multimedia instructional environment. The previous WMC research focused on complex cognitive tasks that involved only single-media instructional environments, such as reading and vocabulary learning (Daneman & Carpenter, 1980, 1983; Daneman & Green, 1986), aural comprehension (Just & Carpenter, 1992), standardized test performance (Turner & Engle, 1989), and storytelling (Pratt, Boyes, Robins, & Manchester, 1989), as well as the dichotomous listening task (Conway, Cowan, & Bunting, 2001), antisaccade task (Unsworth, Schrock, & Engle, 2004), associative list task (Watson, Bunting, Poole, & Conway, 2005), baseball task (Hambrick & Oswald, 2005) and Stroop task (Kane & Engle, 2003). In each of these instructional environments, perceptual attention is focused on only a single modality, visual *or* auditory, while in a multimedia instructional environment attention must be focused on two modalities, visual *and* auditory.

The present study also extends the multimedia learning literature by identifying a specific individual difference variable of interest: working memory capacity. Previous research has identified spatial ability (Moreno & Mayer, 1999) and prior knowledge (Cooper, Tindall-Ford, Chandler, & Sweller, 2001; Mayer & Sims, 1994; Ollerenshaw, Aidman, & Kidd, 1997) as individual difference variables that affect multimedia learning performance, to which WMC is now added. This general finding that high and low WMC systematically affect individuals differently leads to the question of how WMC differences may interact with specific multimedia learning principles. In addition, it is important that future research address which aspects of WMC (e.g., attention control, distraction avoidance, goal neglect, representation activation, knowledge search, knowledge updating) affect learning in multimedia instructional environments, and how.

The practical application of the general individual differences WMC effect relates to the generality of the benefits of learning in multimedia instructional environments. While there is significant research indicating the benefits of learning in multimedia instructional environments (see Mayer, 2005), there is emerging evidence that multimedia instructional environments may benefit some learners (e.g., high spatial ability, high prior knowledge, high WMC) more than others.

Coherence and Signaling Multimedia Learning Effects

The current experiments failed to validate previous findings regarding the coherence and signaling effects. In Experiment 1, there was no appreciable decrement in performance due to the addition of seductive details, background sounds, and irrelevant, graphics. In Experiment 2, there was no appreciable increase in performance due to the addition of visual signals, key words spatially contiguous with their referents, and a spotlight effect.

The lack of a coherence effect was somewhat surprising, although not all coherence effect research has been positive. Harp and Mayer (1998) and Mayer and Jackson (2005) did find a reduction of recall and transfer when additional but irrelevant text and pictures were added to an illustrated booklet describing the cause of lightning and waves, respectively. Mayer, Heiser, and Lonn (2001), however, found a reduction of recall and transfer when interesting but irrelevant text was added to an animation addressing the cause of lightning (Exp 1), but found only a reduction in transfer, not recall, when video clips were added (Exp 3). In addition, Moreno and Mayer (2000) found a reduction of recall and transfer when an interesting, but irrelevant, instrumental music loop was added to the background of an animation addressing the cause of lighting or function of car brakes (Exps 1 and 2) and when interesting but irrelevant mechanical sounds were added to the background of an animation addressing the function of car brakes (Exp 2). However, no reduction in recall or transfer was found when environmental sounds were added to the background of an animation addressing the cause of lighting (Exp 1). The current lack of a coherence effect may have been due to the use of background environmental sounds, as found in Moreno and Mayer (2000), along with the on-screen graphics.

Finally, Experiment 2 adds to the inconsistent literature findings regarding the signaling effect. Studies by Harp and Mayer (1998) and Mautone and Mayer (2001) have determined that providing a learning objective prior to students engaging in a multimedia tutorial and emphasizing key words or phrases in the narration by reading these key words more slowly and with a deep intonation increased students' recall and transfer; however, boldfacing and italicizing the main ideas within a written passage and providing preview sentences, number signals, section headers, preview summary paragraphs, transition or connecting words, colored arrows or summary icons did not increase students' recall, but doing so did increase students' transfer. In the current Experiment 2 there was no signaling effect for recall or transfer, based on the inclusion of key words within the animation spatially contiguous with their referent, nor of a spotlight effect to focus the learner's attention on the aspect of the animation that was relevant to the narration.

Differential Effects of WMC on Multimedia Learning Principles

The current study clearly finds no interactions between WMC and the coherence and signaling principles; that is, high and low WMC student were not differentially affected by the multimedia principles. These findings are in contrast to Sanchez and Wiley (2006), who found that low WMC students were more affected by seductive details (coherence effect) than high WMC. The lack of a differential effect in the current study across both multimedia principles—coherence and signaling—supports the conclusion that there exists a "general" individual differences WMC effect and that the generalizability of the multimedia learning principles is in question. Specifically, the current results indicate that high WMC positively affected all groups of students in similar and general ways and that the lack of findings related to the multimedia principles held for both the treatment groups as a whole and the high and low WMC subgroups.

Overall, the current study provides support for a general individual difference WMC effect related to learning in multimedia instructional environments. This effect adds to the list of identified multimedia learning individual difference variables: prior knowledge, spatial ability, and working memory capacity. The same studies, however, found no support either for the specific coherence and signaling effects tested, or for differential effects of WMC on multimedia learning principles.

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Appendix A
Verbal Content for Each Experiment

Experiment 1: What causes lightning?

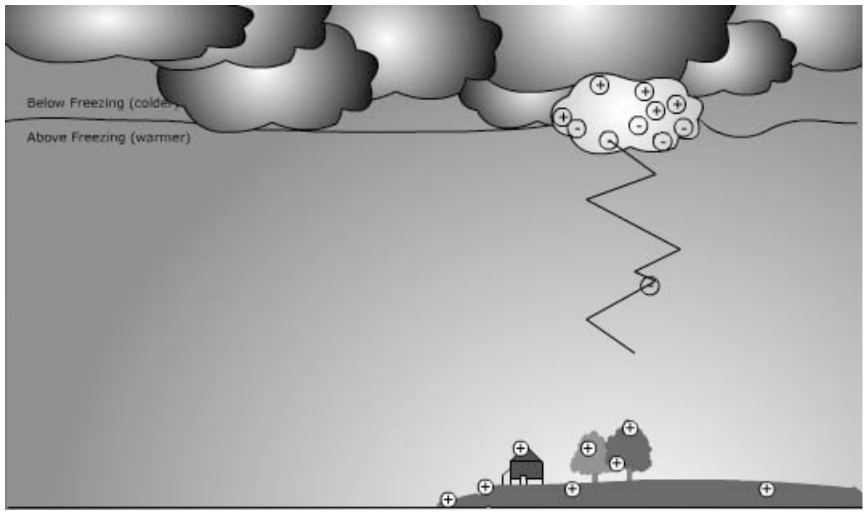
Cool moist air moves over a warmer surface and becomes heated. Warmed moist air near the earth's surface rises rapidly. As the air in this updraft cools, water vapor condenses into water droplets and forms a cloud. The cloud's top extends above the freezing level, so the upper portion of the cloud is composed of tiny ice crystals. Within the cloud, the rising and falling air currents cause electrical charges to build. The charge results from the collision of the cloud's rising water droplets against heavier, falling pieces of ice. The negatively charged particles fall to the bottom of the cloud, and most of the positively charged particles rise to the top. Eventually, the water droplets and ice crystals become too large to be suspended by updrafts. As raindrops and ice crystals fall through the cloud, they drag some of the air in the cloud downward, producing downdrafts. When downdrafts strike the ground, they spread out in all directions, producing the gusts of cool wind people feel just before the start of the rain. A stepped leader of negative charges moves downward in a series of steps. It nears the ground. A positively charged leader travels up from such objects as trees and buildings. The two leaders generally meet about 165 feet above the ground. Negatively charged particles then rush from the cloud to the ground along the path created by the leaders. It is not very bright. As the leader stroke nears the ground, it induces an opposite charge, so positively charged particles from the ground rush upward along the same path. This upward motion of the current is the return stroke. It produces the bright light that people notice as a flash of lightning. (Moreno & Mayer, 1999, p. 368)

Experiment 2: How does a car brake work?

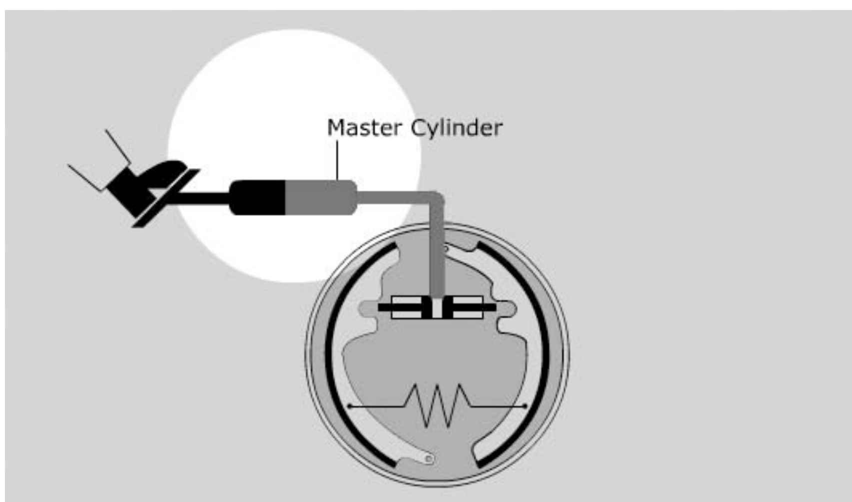
When the driver steps on the car’s brake pedal, a piston moves forward inside the master cylinder. The piston forces brake fluid out of the masters cylinder and through the tubes of the wheel cylinders. In the wheel cylinders, the increase in fluid pressure, makes a set of smaller pistons move. These smaller pistons activate the brake shoes. When the brake shoes press against the drum, both the drum and the wheel stop or slow down. (Mayer & Anderson, 1992, p. 446)

Appendix B
Sample Animation Screen Capture for Each Experiment

Experiment 1: What causes lightning?



Experiment 2: How does a car brake work?



(Screen capture includes the spotlight effect and spatially contiguous keywords.)