EFFECT OF MULTIMEDIA DESIGN ON LEARNING AND PERCEPTION

THE EFFECT OF MULTIMEDIA DESIGN ON LEARNING AND PERCEPTION ACROSS THE LIFESPAN

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Lay Abstract

The goal of this dissertation was to examine the effect of multimedia design strategies on learning across the lifespan and across working memory capacities. The introduction outlines the main theoretical frameworks that constitute multimedia research, and the preliminary research that facilitated the articles represented in this sandwich thesis. The key contributions were 1) the replication of the negative effect of redundant text compared to complementary images on multimedia learning in younger adults, and an interesting reversal effect in older adults who benefited from redundant text and were impaired by images, 2) the finding that learners were unable to recognize ineffective presentations even when given direct exposure to both effective and ineffective designs, and 3) the demonstration that working memory capacity (WMC) predicted learning from various presentation designs—with poorly designed presentations selectively hindering low WMC learners, while pedagogically-sound presentation designs mediated differences in WMC and homologized performance.

Abstract

A significant contribution of this dissertation is that it highlights the importance of considering learner age and individual differences in working memory capacity (WMC) when designing multimedia instruction. I demonstrate that while younger adults benefit from multimedia presentations that combine relevant images and auditory narration (compared to presentations that combine verbatim on-screen text and auditory narration), older adults show the opposite pattern and learn best from presentation designs that combine on-screen text and narration. I provide several theoretical accounts to help explain this age dichotomy in design effectiveness, all of which posit fundamental differences in cognitive function between age groups as the driving factor in performance differences.

Similarly, within the younger adult population there is substantial variance in WMC among learners. I demonstrate that adhering to pedagogically-sound design strategies boosts performance for low WMC learners and allows them to perform similarly well as high WMC learners (who typically have higher performance on cognitively demanding tasks). Importantly, violating these design strategies, and making the multimedia learning environment more cognitively taxing, selectively impairs learning for low WMC individuals. Taken together, these studies highlight the need to consider variance in WMC across and within age groups to optimize design strategies for a wide range of learners.

Another important contribution of this dissertation is the finding that learners seem unable to recognize ineffective presentation designs even when given direct exposure to both effective and ineffective designs. This provides unique insight into learners' metacognitive abilities, and familiarity-driven learning preferences. Overall, this dissertation addresses important practical and theoretical issues in multimedia research, especially the role of individual differences in multimedia learning, and the state of learner awareness of effective and ineffective presentation designs.

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List of Abbreviations

WM: Working Memory

WMC: Working Memory Capacity

AIME: Amount of Invested Mental Effort

ATI: Aptitude by Treatment Interaction

CLT: Cognitive Load Theory

CTML: Cognitive Theory of Multimedia Learning

LTM: Long-Term Memory

Declaration of Academic Achievement

This sandwich thesis includes three manuscripts, one of which was published in Frontiers in Educational Psychology, and the other two submitted for publication in Frontiers in Developmental Psychology and the Journal of Applied Cognitive Psychology. I am the first author on all papers, and was involved in conceptualizing the theoretical and methodological frameworks, conducting the literature reviews, collecting and analyzing the data, and preparing the manuscripts for submission. Authors of the first article (published in Frontiers in Educational Psychology) retain copyright of the article, and my co-author (Dr. Joe Kim) has granted irrevocable, nonexclusive license to McMaster University [and to the National Library of Canada] to reproduce this material as a part of the thesis. Co-authors of the remaining submitted articles have also granted permission to reproduce the articles as part of the thesis. Upon acceptance of the articles for publication, full copyright will also be obtained from the respective journals (copyright has currently not been assigned).

1. **Fenesi, B., & Kim, J. A. Learners misperceive benefits of redundant text in multimedia learning. *Frontiers in Educational Psychology, 5*(710), 1–7.**

The second author provided valuable theoretical and methodological insight, and co-edited the manuscript prior to submission and during the review process. Previous versions of this manuscript were presented at McMaster University during the International Society for Teaching and Learning Conference (2012), and the Annual Women in Science and Engineering Conference (2012).

2. **Fenesi, B., Vandermorris, S., Kim, J. A., Shore, D. I., & Heisz, J. J. (revised and resubmitted).** ***One size does not fit all: Older adults benefit from redundant text in multimedia instruction*****. Paper submitted to the Frontiers in Developmental Psychology.**

All co-authors were involved in the theoretical and methodological conceptualization of the project, and provided constructive feedback on the manuscript. We recently received positive feedback from reviewers, and revised and resubmitted based on their comments and recommendations. Previous versions of this manuscript were presented at the Baycrest Excellence in Care and Education Poster Day in Toronto (2014), the Center for Integrative Research on Cognition, Learning and Education in St. Louis, Missouri (USA) (2014), and the Symposium on Cognition, Learning, & Education at McMaster University (2014).

3. **Fenesi, B**., **Kramer, E., & Kim, J. A. (submitted).** ***Split-Attention and Coherence Principles in Multimedia Instruction Can Rescue Performance for Learners with Lower Working Memory Capacity*****. Paper submitted to Journal of Applied Cognitive Psychology.**

The second and third authors provided valuable feedback and offered revisions on the manuscript structure and theoretical framework. The second author, Emily Kramer, was also involved in data collection and disseminating the findings through conference presentations. Previous versions of the manuscript were presented at the Second National Psychology Outside the Box Conference at the University of Ottawa (2013), and the Undergraduate Thesis Conference at McMaster University (2013).

Chapter 1: General Introduction

Instructional techniques should consider the limitations of the human mind to promote meaningful learning. Presenting excessive, disorganized or overly complex information interferes with a learner's ability to successfully acquire presented material (Mayer 2001, 2009; Sweller, 2005). The most salient cognitive factor involved in learning is working memory (WM)—a limited-capacity system that temporarily manipulates and stores a select amount of information at any given time (Dehn, 2008; Kane & Engle, 2000, 2002; Kyllonen, 1996). WM represents the bottleneck of learning as it processes all information before being sent for indefinite storage in long-term memory (LTM) (Alloway & Alloway, 2010). A classic example of WM in action is during mental arithmetic. For example, mentally multiplying 23 and 34 together requires holding those two numbers in WM, using previously learned multiplication rules to calculate the products of successive pairs of numbers and adding together the products as you proceed, and finally adding together the products held in WM (Dehn, 2008; Hitch, 1978). This complex mental activity would not be possible without WM to maintain some information in mind while simultaneously processing other material. During educational instruction, a central challenge is potentially overloading WM in which learners' intended cognitive processing exceeds their available working memory capacity (WMC). This challenge is multifaceted—not only is the *amount* of content presented a contributing factor in WM overload, but *how* that content is presented is also a key issue. The design of multimedia instruction represents a fundamental example of how WM limitations affect learning.

The goal of multimedia instruction is to use words and images to foster meaningful learning. Effective instructional design directly benefits from an understanding of WM limitations (Mayer 2001, 2009; Sweller, 2005). Multimedia research uses a theoretical understanding of WM limitations to generate applicable strategies that reduce WM load, and enhance mental processes that promote the learnability of presented material. Two dominant theories govern multimedia design in education: Cognitive Load Theory (CLT) proposed by John Sweller and colleagues (Sweller, 1999; Sweller Van Merriënboer, & Paas, 1998; Van Merriënboer and Sweller, 2005), and Cognitive Theory of Multimedia Learning (CTML) proposed by Richard Mayer (2001). Both CLT and CTML build on a cognitive architecture consisting of limited-capacity WM, an unlimited long-term store, and two subsystems for processing auditory and visual information (Baddeley, 1986; Chang, Tseng, & Tseng, 2011; Cowan, 2001). The following will provide an overview of how these two theories generate evidence-based instructional strategies by simultaneously considering the structure of information, and the cognitive architecture that allows learners to process information.

Cognitive Load Theory

CLT originated in the 1980s and became a popular theoretical framework for researchers in the 1990s to investigate cognitive processes and instructional design (de Jong, 2010; Paas, Renkl, & Sweller, 2003; Sweller & Chandler, 1994). CLT posits that learning mechanisms that contribute to intellectual skill have the primary function of circumventing limited WM and emphasizing LTM. Other than simple conditioning mechanisms, *schema acquisition* and transfer from controlled to *automatic processing* are major learning mechanisms that reduce the burden on WM (Sweller & Chandler, 1994). Schemas are sophisticated cognitive constructs that comprise LTM and represent information that has been organized according to how it will be later used. For example, a schema of a dog allows us to categorize it as a dog despite only briefly seeing some aspects (e.g., tail, head); a problem-solving schema categorizes problems according to solutions to help generate answers more efficiently. Importantly, schemas reduce cognitive load by permitting us to ignore most of the information overwhelming our senses. We have schemas that allow us to recognize each tree despite the fact that all trees differ. The infinite variety of trees can be ignored because of our schemas. We do not need to store the immense detail of information presented by a tree in WM, because we have formed a tree schema that resides in LTM (Sweller & Chandler, 1994).

In addition to schema formation, automation of those schemas allows cognitive processes to occur without conscious control. With time and practice, most cognitive processes can become automatic. For example, during initial acquisition of a schema for the problem *a/b = c, solve for a,* we need to consciously consider the problem before recognizing that it belongs to the category that requires initially multiplying out the denominator (Sweller, 1999; Sweller & Chandler, 1994; Sweller et al., 1998). Given enough practice, the schema will become automated, and we will instantly recognize the category of problem. Automation of schemas allows us to bypass WM and minimizes demands on our limited processing capacity. As a result, effective instructional design must promote both schema acquisition and schema automation to help learners take advantage of a powerful LTM and to reduce the burden on WM.

Beyond arguing for the importance of schema acquisition and automation during learning, CLT also outlined three categories of cognitive load: *intrinsic* cognitive load, *germane* cognitive load, and *extraneous* cognitive load (with germane and extraneous categories being the most salient for multimedia instructional design) (Chandler & Sweller, 1991; Sweller & Chandler, 1994). Importantly, CLT is based on the premise of element interactivity, which directly relates to intrinsic cognitive load. All information varies on a continuum from low to high element interactivity, and inherent to any learning task is the extent to which relevant elements interact. Information that has low-element interactivity can be learned without consideration of any other elements. For example, learning how the function keys on a computer affect a photo-editing program represents low interactivity because each item can be understood and learned without reference to any other items (Sweller, 1999; Sweller & Chandler, 1994). In contrast, learning how to edit a photo on a computer represents high interactivity because it requires an understanding of multiple elements and their interactions, such as how to change colour tones, darkness and contrast. Consequently, information that has high-element interactivity is more challenging to understand, and is the driving factor in intrinsic cognitive load. Demands on WMC imposed by element interactivity are intrinsic to the material being learned. For instructional design purposes, different materials vary in their levels of element interactivity, and thus intrinsic cognitive load, and cannot be directly altered by instructional manipulations. Simplifying learning tasks that omit some interacting elements is the only way to directly manipulate intrinsic load (Paas, Renkl, & Sweller, 2003; Sweller & Chandler, 1994). However, for successful learning to occur, all essential elements must be simultaneously processed despite the high intrinsic load of the task.

Unlike intrinsic cognitive load, instructional manipulations can directly influence germane cognitive load—that is, load devoted to the construction and automation of schemas. For example, encouraging learners to self-explain how they arrived at a particular solution fosters their ability to construct and organize their knowledge (Renkl, 2002). Example-based learning, also known as the *worked example effect* (van Gog & Rummel, 2010) also promotes germane processes by allowing learners to devote their limited WM resources to studying the worked-out solution procedure (i.e., the relation between problem states and operators). This instructional technique allows learners to construct a cognitive schema for solving such problems, and has been shown to transfer to novel problem domains as general rules can be abstracted from the worked examples. In the domain of multimedia design, it is critical to present information in a manner that streamlines WM resources towards germane processes. However, in order to maximize germane cognitive load, instructional design must simultaneously minimize extraneous cognitive load.

Extraneous cognitive load refers to load that is unnecessary and interferes with schema acquisition and automation (Sweller, 1999; Sweller & Chandler, 1994). This is typically the most infringed upon category of cognitive load as instructors often develop instruction without much consideration or knowledge of the structure of information or the cognitive architecture of the human mind (Mayer 2001, 2009; Sweller, 2005). For example, an instructional procedure that requires learners to search for referents in an explanation (i.e., Part A of an explanation refers to Part B without clearly indicating where Part B is to be found) imposes a heavy extraneous load because WM resources must be devoted to activities that are irrelevant to schema acquisition and automation (i.e., searching for referents). In multimedia instruction, the *split-attention effect* refers to a situation of enhanced extraneous load when the same modality (e.g., visual) is used for pictorial and verbal information within the same display (i.e., images and written text) (Florax & Ploetzner, 2010; Kalyuga et al., 1999; Mayer, 2001, 2009). Learners must engage in a process of splitting their attention between two visually disparate sources of information to understand the content. This split-attention effect is alleviated when the verbal information is transferred from visual text to auditory narration. As a result, learners only have to focus on one source of visual information (i.e., images), and can acquire the verbal information through narrative text. This allows greater WMC to be devoted to engaging in germane processes, which help promote schema acquisition and automation.

Importantly, the three categories of cognitive load are additive in that, together, the total load cannot exceed available WM resources if learning is to occur (Sweller & Chandler, 1994). Furthermore, the relations between the three types of cognitive load are asymmetric. Intrinsic cognitive load provides a base load that cannot be reduced other than by forming more schemas and automating schemas that have already been acquired. After sufficient WM resources have been devoted to dealing with intrinsic cognitive load, the remaining resources can be allocated to manage extraneous and germane load. These can work in tandem such that a reduction in extraneous load by using a more effective instructional design can free capacity for increased germane load. As a result of learning through schema acquisition and automation, intrinsic load is also reduced; this frees up more WMC for learners to use the newly learned material to acquire more advanced schemas. And a new learning cycle begins; over many cycles, learners can gain advanced knowledge and skills (Chandler & Sweller, 1991; Sweller, 1999; Sweller & Chandler, 1994).

Cognitive Theory of Multimedia Learning

Although CLT was developed to address a wide range of instructional issues, Mayer's Cognitive Theory of Multimedia Learning (CTML) was specifically developed to address issues related to multimedia instructional design (Mayer 2001, 2005; Mayer & Moreno, 2002). The theoretical foundation for CTML draws from several cognitive theories including Baddeley's multicomponent model of WM (Baddeley, 1986), Paivio's dual coding theory (Paivio, 1986), and Sweller's CLT (Sweller, 1991). The central premise of CTML is that during a multimedia presentation, learners attempt to build meaningful connections between words and pictures, and that learning from words and pictures fosters greater understanding compared to learning from words or pictures alone. The goal of multimedia instruction is to encourage learners to build a coherent mental representation from the presented material and to ultimately construct new knowledge (akin to schema formation).

CTML is based on three core assumptions: the *dual-channel assumption*, the *limited capacity assumption*, and the *active processing assumption*. The *dual-channel assumption* refers to WM having separate auditory and visual channels for processing auditory/verbal information and visual/pictorial information, respectively, and is based on Baddeley's (1986) theory of WM and Paivio's (1986; Clark and Paivio, 1991) dual coding theory. The *limited capacity assumption* refers to each channel having a limited (finite) capacity (similar to Sweller's notion of cognitive load). Learners can only hold a few images or words in WM at any one time, and these items reflect portions of presented information rather than exact copies. For example, when a narration is presented, learners are only able to hold a few words in WM; when an animation of a tire pump is presented, learners may only be able to focus on building mental images of the handle going down and air moving into the cylinder. The *active processing assumption* refers to learners actively engaging in cognitive processing to construct a coherent mental representation of their experiences. These active processes include filtering, selecting, organizing and integrating incoming information based upon prior knowledge. The outcome of active processing is the construction of a *mental model* (similar to Sweller's *schema*), which is a coherent mental representation of the key parts of the presented material and their relations. In essence, multimedia design can be conceptualized as an attempt to assist learners in their model-building efforts.

In addition to depicting the human mind as a dual-channel, limited-capacity, active processing system, CTML also accepts a memory model that includes three stores: sensory memory, WM, and LTM (Mayer, 2001, 2002, 2005). Sensory memory reflects a rapidly degrading system with a visual component that briefly holds pictures and printed text as visual images, and an auditory component that briefly holds spoken words and sounds as auditory images. WM attends to and selects information from sensory memory for processing and integration of information into mental models. While sensory memory holds an exact sensory copy of presented material for less than 250ms, WM holds a processed version of presented material for generally less than 30s and can process only a few items of information at any one time. LTM represents a repository of all prior knowledge that can be held for an indefinite amount of time. In order to actively think about material in LTM, it must be brought into WM. Importantly, the process of integrating prior knowledge from LTM with novel information in WM is fundamental to the construction of coherent mental representations. Successful multimedia learning therefore involves designing instruction that helps learners select relevant information, organize that information into a logical mental construct, and integrate this newly constructed schema with pre-existing knowledge from LTM to produce a long-lasting memory representation.

Although it is clear that WM plays a critical role in multimedia learning, surprisingly few alternative WM theories to CLT and CTML have been adopted to generate research questions in multimedia instruction. Two of these theories, the attentional control model (Engle, Kane, & Tuholski, 1999a; Kane et al., 2004) and embedded processes model (Cowan, 1988) have the potential to provide unique insight into multimedia design research. Proponents of the attentional control model argue that WMC primarily reflects domain-general executive attention (i.e., the ability to use attention to maintain task goals and inhibit information in the face of interference; Engle, 2002). Although aware of the domain-specific components of WM (i.e., short-term storage components that sub-serve a controlled executive; Brooks, 1968; Kane et al., 2004; Oberaurer, Sub, Schulze, Wilhelm, & Wittman, 2000), they argue that individual differences in executive attention are responsible for the correlations between WM and complex cognitive measures (Engle, Kane, & Tuholski, 1999; Kane et al., 2004). This processing limitation is qualitatively different from a capacity limitation (as is emphasized in CLT and CTML), which focuses on the number of items that can be stored (a representational limitation). Importantly, the attentional control model can inform multimedia design research by highlighting how learning is affected when the instructional design forces learners to allocate attention to disparate sources of visual information in a multimedia display, or to simultaneously attend to multiple sources of verbal information (e.g., on-screen text and auditory narration). This perspective moves beyond a limited-capacity framework that emphasizes a visual/verbal subsystem overload, and emphasizes the key role of attention during learning.

Similarly, the embedded processes model may also acknowledge the contributions of visual and verbal WM components in multimedia learning, but emphasizes that WM is a subset of LTM rather than a dedicated temporary storage system (Cowan, 1988). Essentially, there is just one memory repository with WM comprising the subset of information readily accessible by virtue of its activation. Importantly, long-term stores must be engaged to establish new information within a related context to achieve a stable mental model of the newly acquired information. With respect to multimedia instructional design, the embedded processes model could provide unique insight into how certain design strategies may make it more difficult to activate appropriate LTM representations, and may prevent adequate integration of prior knowledge and new incoming information. The General Discussion goes into more detail on how these two WM frameworks can be used to explain various multimedia learning outcomes.

Although both CLT and CTML have independently informed the domain of multimedia design research, CTML has been especially productive in generating a myriad of prescriptive multimedia design principles. Some of these principles include coherence, signaling, redundancy, spatial contiguity, temporal contiguity, segmenting, picture superiority, pre-training, modality, multimedia, personalization, voice and image (Mayer & Moreno, 2003; Mayer, 2001, 2002, 2005). These design principles were created based on the theoretical framework of CTML, and their efficacy has predominately been evaluated in highly controlled lab-based studies. Elements of two of these principles became a primary focus for my doctoral research: the verbal redundancy principle and the picture superiority principle.

The verbal redundancy principle refers to reduced learning when a presentation contains identical on-screen text and auditory narration compared to narration alone (Jamet & Le Bohec, 2007; Kalyuga et al., 1999; Leahy, Chandler, & Sweller, 2003; Mayer, Heiser, & Lonn, 2001; Moreno & Mayer, 2002). The reason for this detriment is often explained as due to the unnecessary and excessive load required of WM to integrate identical verbal information from both visual and auditory sources (Kalyuga et al., 2000). In contrast, the picture superiority principle refers to enhanced learning when a presentation contains images rather than the written word counterparts. One theoretical account for the benefit of images is perceptual superiority, in that images evoke richer stimulus encoding compared to words (Weldon & Roer, 1987). Paivio (1969, 1983,

1986) also suggested that images are more likely to arouse both the verbal and imaginal codes of the referent than are words, and such encoding redundancy improves the memorability of information represented by the images. Another theoretical account put forth by Nelson (1979) is that although images and words share identical semantic codes, images are more memorable because they have more distinctive sensory codes than do words. In general, the benefit of images over words has been localized in encoding processes, with richer encoding processes taking place when learning from images compared to words.

Overview of Dissertation

The basis for much of my doctoral research has focused on contrasting the effects of redundant text and images in multimedia instruction. Despite mixed findings on the effects of redundant text on learning, its use seems to permeate many educational contexts. For example, an examination of seventy–two PowerPoint presentations delivered by engineering instructors demonstrated that at least half contained redundant text and lead to reduced understanding and retention of key concepts (Gaudelli et al., 2009). Other studies have produced similar results showing reduced learning when presentations contained identical on-screen text and auditory narration compared to narration alone (Jamet & Le Bohec, 2007; Kalyuga et al., 1999; Leahy et al., 2003). However, others have demonstrated the opposite finding with enhanced learning when narration is paired with identical text compared to when narration is presented alone (Adesope and Nesbit, 2001; Moreno and Mayer, 2002), while others have demonstrated no improvement in learning under conditions of verbal redundancy (Kalyuga et al., 2004).

In contrast, the benefit of images in multimedia learning has been more consistent (Mayer 2002, 2009), as they are believed to help promote the construction of mental models.

In a recently published study (Fenesi, Heisz, Savage, Shore, & Kim, 2014), our goal was to further evaluate the effect of redundant text and images on multimedia learning. To do this, we contrasted a redundant text presentation style with a narration only presentation style, and directly compared the learning effects of a redundant text presentation versus a presentation containing relevant images. Up until that point, researchers had not directly compared a presentation style containing redundant text to a presentation style containing complementary images. A potential reason for the lack of empirical investigation into comparing these two presentation styles is that it did not fit conventional multimedia design research. In other words, by comparing a presentation with verbally redundant text to a presentation containing complementary images, we did not evaluate a specific design principle as outlined by Mayer and colleagues. However, these two design strategies (narration + on-screen text *vs*. narration + images) hold immense practical significance, as they are two common approaches to instructional design with often very different effects on learning.

In addition, the study by Fenesi et al. (2014) was motivated by a desire to incorporate more educationally relevant materials into multimedia design research. The vast majority of multimedia research has evaluated designs strategies using presentation content that is far removed from real educational contexts—using concepts that students do not typically learn in actual courses (e.g., simplified water cycle, how brakes and pumps work, lightning formation). In addition, these presentations are typically quite short in duration (e.g., one to two minutes). In real educational settings students learn complex, hierarchical concepts presented over longer durations. In such presentations, basic concepts are typically presented first to establish foundational knowledge, followed by more complex information, which builds on this foundation. Using short–duration presentations with content that is far-removed from real course material reduces the practical application of these results to inform teaching practice of actual educational material.

In our study, we presented complex introductory psychology course material over a relatively long duration (9 minutes). Critically, the presentation was a subset of a larger computer-based lecture from a first-year psychology course at McMaster University on the physiology, anatomy, evolution and biochemical mechanisms of hunger. The delivery of content through a computer-based presentation was identical to how students enrolled in the introductory psychology course learned their primary course content. This was a critical feature, because determining the most effective multimedia design would have direct implications on how to best present course material in the future. Participants viewed one of three computer-based presentations: Audio, Redundant (audio with redundant text), or Complementary (audio with images). We found that the Audio and Redundant conditions produced similar learning, while the Complementary condition produced greatest learning. Interestingly, although the Complementary condition produced the most learning, participants rated all three conditions as similarly interesting and able to promote understanding. This suggests that learners exposed to the Complementary condition were unable to recognize the benefit of the presentation style relative to participants exposed to the Redundant and Audio conditions. Overall, this study produced two critical findings: 1) presentations containing redundant text are less effective than presentations containing relevant images, and 2) learners may be unable to accurately gauge the effectiveness of different presentation styles and how they impact learning. These two findings were the catalysts for the first two articles (Chapters 2 and 3) in the current dissertation.

Overview of chapter 2: Learners misperceive benefits of redundant text in multimedia learning

Following from the work by Fenesi et al. (2014), this study aimed to 1) replicate the negative effect of redundant text compared to complementary images in multimedia learning, as well as to 2) disentangle whether learners falsely perceive redundant text as beneficial to their understanding compared to complementary images despite reductions in learning. Given that the work by Fenesi et al. (2014) was the first study to contrast a redundant text versus complementary image presentation style, replicating the negative effect of redundant text was crucial to establishing its reliability and educational significance. In addition, most previous work assessing the effects of redundant text presentations have typically relied on a between-subjects approach, exposing learners to only one of several possible multimedia presentations. For example, recent work by Yue et al. (2013) used a between-subjects approach to demonstrate that participants prefer identical full-text presentations and think they are best for learning, despite superior learning with presentations containing minimal or no text. However, participants only experienced one condition and simply indicated which presentation style they would prefer by selecting from a series of answer options (e.g., (a) images and narration only, (b) images, narration, and on-screen text identical to narration). Critically, this between-subjects approach might interfere with accurate metacognitive judgments about the quality of different presentation styles. Therefore, we used a unique within-subjects approach to examine the learning outcomes and accuracy judgments of participants exposed to both redundant and non-redundant presentation designs within the same experimental session.

In this study, a redundant text multimedia presentation containing narration paired with verbatim on–screen text (Redundant) was contrasted with two non-redundant text multimedia presentations: (1) narration paired with images and minimal text (Complementary) or (2) narration paired with minimal text (Sparse). Learners watched presentation pairs of either Redundant + Complementary, or Redundant + Sparse. Results demonstrate that Complementary and Sparse presentations produced highest overall performance on the final comprehension assessment, but that the Redundant presentation produced highest perceived understanding and engagement ratings. Overall, this study replicated the negative effect of redundant text compared to complementary images (as well as compared to a presentation style with sparse text), and highlighted how participants were unable to gauge how different presentation styles impacted their understanding despite juxtaposing an effective and ineffective presentation style within the same experimental session.

This research demonstrated a consistent trend that redundant text impairs learning compared to complementary images during multimedia instruction (Fenesi et al., 2014).

However, these findings may be specific to younger adult learners. In fact, most research examining the factors promoting optimal multimedia learning has focused on young adults, with little known about the factors promoting optimal multimedia learning in older adults. The second article in this dissertation was motivated by an empirical desire to determine if optimal design templates vary according to the different cognitive strengths and weaknesses of younger and older age groups.

Overview of chapter 3: One size does not fit all: Older adults benefit from redundant text in multimedia instruction.

The rapid rise of online courses in higher education, and an increasingly technology-oriented education system drives the need for practical research to address effective multimedia design across diverse age groups. Some researchers suggest that existing principles of instructional design can be used to accommodate the needs of older learners (Van Gerven et al., 2006), as existing instructional theories bear important benefits for older learners because they support an efficient use of available cognitive resources. However, age-related decline in WMC (Hedden and Gabrieli, 2004; Mattay et al., 2006) and processing resources (Pachman, 2007; Pachman and Ke, 2012) may mean that older adults require different design features than younger adults for optimal learning. This study examined younger and older adults with three different multimedia presentation designs to ask if design strategies vary as a function of different cognitive strengths and weaknesses across age groups. Following a similar methodology to Fenesi et al. (2014), the three presentation designs were: 1) Audio only (narration), 2) Redundant text (narration with redundant text), 3) Complementary images (narration with images).

Importantly, if instructional design strategies support an efficient use of available cognitive resources, older adults should show similar patterns of learning as younger adults, but might show overall reduced performance as a result of their age-related decline in WMC (Hedden and Gabrieli, 2004; Mattay et al., 2006; Pachman, 2007; Pachman and Ke, 2012; Wingfield et al., 1998). However, we found that while younger adults once again had superior comprehension when exposed to complementary images, older adults performed better with redundant text. We also found that both younger and older adults were poor at recognizing presentation styles that promoted or hindered their learning; both age groups rated the non-optimal condition for their age group as more effective for learning. The discussion section offers several theoretical accounts for age-related differences in performance including a multisensory integration perspective (Diaconescu, Hasher, & McIntosh, 2012), an attentional co-activation framework (Bucur, Madden, & Allen, 2005), and an environmental support hypothesis (Pachman, 2007; Pachman and Ke, 2012). This study suggests that one-size does not fit all, with older adults requiring unique multimedia design tailored to their cognitive abilities for effective learning.

Clearly, there are important differences in cognitive ability—especially WMC—between younger and older adults that influence the efficacy of multimedia design strategies. However, there are also differences in WMC *within* the younger adult population that can similarly impact the effectiveness of instructional treatments. The third article of this dissertation aimed to understand the role of individual differences in multimedia learning by examining the relation between WMC and several multimedia design principles.

Overview of chapter 4: Split-attention and coherence principles in multimedia instruction can rescue performance for learners with lower working memory capacity

Similar to the lack of empirical investigation into age-dependent multimedia design strategies, minimal attention has been directed towards understanding the role of individual differences in multimedia learning among younger adults. Importantly, WMC has been positively associated with higher-order cognitive tasks such as attentional control (Kane, Bleckley, Conway & Engle, 2001), general fluid intelligence (Engle, Tuholski, Laughlin & Conway, 1999) and mathematical performance (Ashcraft & Kirk, 2001). Individuals with high WMC perform better than individuals with low WMC in academic skills dependent on such higher-order cognitive tasks including reading comprehension (Daneman & Carpenter, 1980), language comprehension (Just & Carpenter, 1992), vocabulary learning (Daneman & Green, 1986), reasoning (Buehner, Krumm & Pick, 2005), lecture note-taking (Kiewra & Benton, 1988), and mnemonic strategy effectiveness (Gaultney, Kipp & Kirk, 2005). Although there is a strong link between individual differences in WMC and academic performance (Fenesi, Sana, Kim & Shore, 2014), only recently has greater empirical attention been directed towards examining the relation between WMC and multimedia learning.

Several studies reveal how WMC differences impact the efficacy of design principles, including the Modality (Seufert, Schutze & Brunken, 2008) and Segmentation (Lusk et al., 2008) principles in multimedia learning, and the Seductive Details effect in reading comprehension (Sanchez & Wiley, 2006). In these studies, learners with low

WMC performed significantly worse on measures of comprehension when design principles were violated, while high WMC learners were unaffected. However, when multimedia presentations adhered to effective design principles, both high and low WMC learners performed equally well. In particular, preventing learners from segmenting (i.e., pausing) their multimedia presentation, or presenting irrelevant images or text, selectively impaired comprehension for low WMC learners. The significance of these findings is not so much reflected in the individual differences in WMC, which has been empirically documented for many years (Daneman & Carpenter, 1980; Just & Carpenter, 1992; Kiewra & Benton, 1988), but rather that individual differences can directly impact the quality of learning from varying multimedia designs. The current paper extended this important body of literature by investigating the relation between WMC and the multimedia learning design principles of Split-Attention (i.e., presenting narration, images and on-screen text impairs learning compared to just presenting narration and images) in Experiment 1, and Coherence (i.e., presenting irrelevant images impairs learning compared to relevant images) in Experiment 2.

In Experiment 1, WMC predicted applied comprehension (i.e., ability to apply newly acquired information to novel problem scenarios) in the Split-Attention condition (audio + on-screen text + images), but not in the Complementary condition (audio + images). This means that learners with lower WMC performed significantly worse than learners with higher WMC on applied comprehension questions when exposed to a multimedia presentation that required them to split their attention between visual images and visual text. However, removing the split-attention component of a presentation (i.e., only presenting images and narration) allowed learners with lower WMC to perform equally well as learners with higher WMC.

Experiment 2 further emphasized the importance of considering individual differences in WMC when designing instruction, as WMC was a significant predictor of both recognition comprehension (i.e., basic fact retention) and applied comprehension when participants learned from an Incongruent presentation design (audio + irrelevant images) compared to a Congruent presentation design (audio + relevant images). Importantly, if multimedia design effectiveness were only assessed using comprehension performance, it would appear that image relevance did not impact learning, as there were no differences in comprehension performance between conditions. However, when WMC differences were considered, there was a clear detriment to using irrelevant images, specifically for low WMC learners.

Overall, it seems that high WMC learners were unaffected by poor presentation design, whereas low WMC learners were impaired when required to split their attention between images and text, or when required to learn from irrelevant images. However, adhering to pedagogically-sound design principles mediated individual differences in WMC and allowed both high and low WMC learners to perform equally well. These results add to a large body of literature demonstrating that individual differences in WMC influence performance on higher-order cognitive tasks and extend to multimedia learning. Importantly, these findings may be particularly relevant to first-year post-secondary courses, which typically encompass a diverse student body and substantial individual variance in WMC (Orzechowski, 2010).

The unifying goal of this dissertation was to examine the effect of multimedia design strategies on learning across the lifespan and across WM capacities. This body of work targets important and often overlooked domains of multimedia research by directly contrasting presentation designs that are not specifically outlined by CLT or CTML, and by including a more diverse range of learner both in terms of age-related variance as well as cognitive aptitude (i.e., WMC).

Content Overlap in Thesis

The main overlap between chapters relates to information about the two major theories in multimedia design research: Mayer's Cognitive Theory of Multimedia Learning, and Sweller's Cognitive Load Theory. Chapter 1 covers these two theories in-depth, and thus any mention of them in proceeding chapters may be redundant.

In addition, the first two articles contain the same multimedia presentation content as described in the methods sections (anatomy and physiology of hunger mechanisms). The comprehension quizzes and subjective perception measures were also similar.

Chapter 2: Fenesi, B., & Kim, J. A. (2014). Learners misperceive benefits of redundant text in multimedia learning. *Frontiers in Educational Psychology, 5*(710), 1–7.

Preface

The first article in this dissertation entitled "Learners misperceive the benefits of redundant text in multimedia learning" was published in Frontiers in Educational Psychology with Dr. Joseph Kim as co-author. The genesis of this study came from an earlier published paper by Fenesi et al. (2014) that showed that multimedia designs that pair images and narration produce superior learning compared to multimedia designs that pair redundant on-screen text and narration, or contain narration alone; however, presentations containing images and narration were not rated higher in terms of their ability to promote understanding. Since this was one of the few studies to directly compare presentation designs with complementary images versus redundant text, one of our goals was to replicate the observed benefit of complementary images over redundant text. The other goal was to unpack whether learners are indeed unaware of the detriment of redundant text and vice-versa, the benefit of complementary images on their multimedia learning. Unlike other studies that also aimed to disentangle this metacognitive issue by relying on a between-subjects approach and exposing learners to only one of several multimedia presentations (Yue et al., 2013), we used a unique within-subjects approach to examine the learning outcomes and accuracy judgments of participants exposed to both redundant and non-redundant presentation designs within the same experimental session. Overall, this study replicated the negative effect of redundant text compared to complementary images (as well as compared to a presentation style with sparse text) on learning, and highlighted how participants were unable to gauge how different presentation styles impacted their understanding despite juxtaposing an effective and ineffective presentation style within the same experimental session.

Learners misperceive the benefits of redundant text in multimedia learning

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Abstract

Research on metacognition has consistently demonstrated that learners fail to endorse instructional designs that produce benefits to memory, and often prefer designs that actually impair comprehension. Unlike previous studies in which learners were only exposed to a single multimedia design, the current study used a within–subjects approach to examine whether exposure to both redundant text and non-redundant text multimedia presentations improved learners' metacognitive judgments about presentation styles that promote better understanding. A redundant text multimedia presentation containing narration paired with verbatim on–screen text (Redundant) was contrasted with two non-redundant text multimedia presentations: (1) narration paired with images and minimal text (Complementary) or (2) narration paired with minimal text (Sparse). Learners watched presentation pairs of either Redundant + Complementary, or Redundant + Sparse. Results demonstrate that Complementary and Sparse presentations produced highest overall performance on the final comprehension assessment, but the Redundant presentation produced highest perceived understanding and engagement ratings. These findings suggest that learners misperceive the benefits of redundant text, even after direct exposure to a non-redundant, effective presentation.

1. Introduction

Lectures and presentations are dominated by the use of multimedia instruction tools such as PowerPoint or Keynote to presumably increase learner attention and engagement (Apperson et al., 2008; Mantei, 2000; Susskind, 2004; Szabo and Hastings, 2000). However, multimedia presentations are often designed ineffectively, leaving audiences disconnected from their learning experiences (Craig and Amernic, 2006; Parker, 2012). Indeed, the pervasive use of redundant text in presentations (i.e., aurally and visually presented verbal information are identical) has been shown to reduce learning (Chandler and Sweller, 1991; Fenesi et al., 2014; Kalyuga et al., 1998, 1999), yet it remains a principle practice. Recent work by Yue et al. (2013) showed that participants prefer identical-full text presentations (paired with images) and think they are best for learning, despite superior learning with presentations containing minimal or no text. However, participants only experienced one condition, and simply indicated which presentation style they would prefer by selecting from a series of answer options (e.g., (a) images and narration only, (b) images, narration, and on-screen text identical to narration). The current study expanded on prior work by using a within–subjects approach; participants were exposed to redundant and non-redundant text presentations within the same experimental session to determine whether exposure to both presentation styles influenced awareness of the negative effect of redundant text on learning.

There are two dominant instructional theories of multimedia design: Cognitive Load Theory (CLT) (Sweller, 1999; Sweller et al., 1998; Van Merrienboer and Sweller, 2005), and Cognitive Theory of Multimedia Learning (CTML) (Mayer, 2001), both of which propose principles of multimedia design based on the theoretical frameworks of limited working memory capacity (i.e., ability to attend to and process finite information at any given time). Importantly, instructional design that imposes high cognitive load (i.e., when required cognitive processing exceeds working memory capacity) reduces the working memory resources available for processing new information, thus preventing new learning. In addition to its limitations, working memory is comprised of two subsystems for processing information that is auditory/verbal and pictorial/non-verbal (Baddeley, 1986; Chang et al., 2011; Paivio, 1986). Instruction that engages both subsystems to include auditory/verbal information (e.g., narration) and pictorial/non-verbal information can help mitigate limited working memory capacity.

A critical finding shared between CLT and CTML is that information presented through the two subsystems should be complementary rather than identical. If narration is presented with identical written text, the extra verbal information does not provide additional content but merely duplicates the already presented information (Mayer, 2001; Sweller, 1999). The redundant verbal information overwhelms the auditory/verbal subsystem and reduces critical working memory resources needed to meaningfully understand and integrate incoming information. As a result, only simple facts and isolated concepts can be retained and integrated into memory.

However, pairing instructional images with simultaneous auditory narration allows both the pictorial/non-verbal and auditory/verbal subsystems to function in parallel, promoting optimal working memory resource allocation. Also, using images facilitates the construction of mental representations of information, which help integrate new information in working memory with existing long-term memory stores.

Despite clear demonstrations of the negative impact of redundant text on learning (Adesope and Nesbit, 2012; Chandler and Sweller, 1991; Kalyuga et al., 1998, 1999), its use permeates many contexts including education, business and training venues. For instance, among other factors, observers have speculated that poorly designed PowerPoint slides filled with abundant technical information and redundant text may have contributed to complications leading to the 2003 Columbia space shuttle disaster (Tufte, 2003). In addition, an examination of seventy–two PowerPoint presentations delivered by engineering instructors demonstrated that at least half contained redundant text leading to reduced understanding and retention of key concepts (Gaudelli et al., 2009). These findings are consistent with empirical studies that have compared presentations with redundant text to presentations with narration paired with images, narration paired with minimal text, and narration alone; findings from all studies clearly demonstrate that presentations with redundant text are detrimental to learning (Chandler and Sweller, 1991; Fenesi et al., 2014; Kalyuga et al., 1998, 1999).

Importantly, many studies have incorporated multiple measures of learning, including both comprehension tests and measures of perceived understanding and interest of lecture material (Fenesi et al., 2014; Kalyuga et al., 1998, 1999). Fenesi et al. (2014) recently replicated the negative impact of redundant text on comprehension in conjunction with learners' inability to accurately assess their poor understanding; learners in both the redundant and non–redundant text conditions produced similar perceptions of understanding and interest. These results suggest that learners exposed to redundant text failed to perceive a detriment to objective understanding relative to learners exposed to non–redundant text. Consistent with research in metacognition, these results are not surprising as studies demonstrate learners are typically poor evaluators of their own understanding (Glenberg and Epstein, 1987; Kornell and Bjork, 2008; Spellman and Bjork, 1992; Bjork et al., 1998).

Metacognitive research investigates learners' abilities to judge their own understanding or skill level (Benjamin and Bjork, 1996; Glenberg and Epstein, 1987). Learners with high metacognitive ability accurately judge their understanding and realize when additional information or practice is required for successful learning. In contrast, learners with low metacognitive ability tend to overestimate their understanding; they often perform poorly on assessments of learning yet perceive that they have successfully mastered the material (Jacoby et al., 1994). Most educational research demonstrates that learners have low metacognitive abilities and typically overestimate their understanding in the absence of actual learning (Benjamin and Bjork, 1996; Glenberg and Epstein, 1987; Jacoby et al., 1994; Kornell and Bjork, 2008; Spellman and Bjork, 1992). Importantly, low metacognitive ability often stems from a sense of familiarity with a particular topic or presentation style; this sense of familiarity is then misattributed to represent comprehension of material in the absence of actual understanding. Findings by Fenesi et al. (2014) that demonstrated a mismatch between perceived understanding and objective comprehension for learners exposed to redundant text presentations may therefore be expected within a metacognitive framework; learners exposed to redundant text were unable to recognize that their understanding was hampered compared to learners exposed to non–redundant text. Additionally, since learners may be more familiar with redundant text presentations due to repeated classroom exposure, they may have inaccurately perceived redundant text to be effective in promoting their understanding.

Previous research assessing the effects of redundant text presentations have typically relied on a between–subjects approach, exposing learners to only one of several possible multimedia presentations. Recent work used this between–subjects approach to demonstrate that participants indicate a preference for redundant text compared to minimal text and images when provided with a list of presentation style options (Yue et al., 2013). However, researchers noted that participants only experienced one condition, which might interfere with accurate metacognitive judgments about the quality of different presentation styles. Therefore, we used a within–subjects approach to examine if learners exposed to both redundant and non-redundant designs within the same experimental session can accurately gauge the differences in learning outcomes elicited between presentation designs.

Learners were presented with two computer–based presentations (one redundant and one non-redundant presentation). The redundant presentation consisted of narration paired with redundant on-screen text. There were two forms of non-redundant presentations; one consisted of narration paired with images and minimal text (Complementary), the other consisted of narration paired with minimal, non–redundant text (Sparse). Therefore, participants were exposed to a combination of either Redundant–Complementary, or Redundant–Sparse presentations, thereby creating experimental conditions: Redundant– Complementary and Redundant–Sparse. The same redundant presentation style was used in both the Redundant–Complementary, and Redundant–Sparse presentations. See Appendix A for visual examples of all three presentation styles. Prior research outlining principles of effective multimedia design demonstrate that Complementary presentations do not overwhelm learners with redundant on–screen text and promote understanding because they contain images that help learners construct mental representations of visual information (Chandler and Sweller, 1991; Fenesi et al., 2014; Kalyuga et al., 1998, 1999, 2000; Tangen et al., 2011). Similarly, Sparse presentations can promote learning because they help focus learner attention on relevant portions of the narration (Adesope and Nesbit, 2012; Mayer and Johnson, 2008; Yue et al., 2013), whereas verbatim redundant text displays all narrative content and overwhelms learners with excessive verbal information. Additionally, learners can engage in unobstructed mental imagery to create mental representations of visual information (Fleming and Hutton, 1983).

Since redundant text reduces learning, we predicted that the Redundant presentation would reduce comprehension performance compared to the Complementary and Sparse presentations. However, we predicted that learners would rate their perceived understanding of material and perceived engagement of the lecture as greater for information learned via the Redundant presentation than via the Complementary and Sparse presentations. These predictions were based on our hypothesis that learners' poor metacognitive judgments (both in terms of perceived understanding and engagement) would be driven by a misattributed sense of familiarity and comfort with redundant text presentations. We also predicted that lecture material interest would be rated equally among presentation styles because previous findings (e.g. Fenesi et al., 2014) found no differences in interest ratings across different presentation styles. Furthermore, we predicted that when learning via the Redundant presentation, learners would rate the perception of lecture difficulty as lower compared to both Complementary and Sparse presentations. This is because learners would equate their sense of familiarity and comfort with Redundant presentations as reduced lecture difficulty.

2. Materials and methods

2.1. Participants

Eighty undergraduate students from McMaster University enrolled in the Introductory Psychology course participated in the study in exchange for course credit. Forty participants were randomly assigned to each condition: Redundant–Sparse or Redundant–Complementary. The order of presentation exposure was counterbalanced (i.e., Complementary–Redundant, Sparse–Redundant), with twenty of the forty participants in each condition assigned to each counter-balanced condition. Participants were drawn from a class of 3000 students consisting of 46% males and 54% females, with a mean age of 19.21 (SD = 3.12). Only those without prior (or current) course enrollment in anatomy courses were eligible to participate in the experiment. All participants provided informed consent, and all procedures complied with the tri-council statement on ethics, as assessed by the McMaster Research Ethics Board.

2.2 Materials and procedure

The presentation was displayed on individual 17.5-inch Acer laptops and consisted of a 9-min, system-paced PowerPoint slide show (total of 18 slides) about the physiology, anatomy, evolution, and biochemical mechanisms of hunger. Each presentation style (i.e., Redundant, Complementary, Sparse) was split in half at the 4:30 mark. They were then combined to produce the conditions of interest: Redundant–Complementary, and Redundant–Sparse (counterbalanced: Complementary–Redundant, Sparse–Redundant). The Redundant, Complementary and Sparse presentations had identical audio tracks and only differed in the accompanying visuals. The Redundant presentation consisted of verbatim on–screen text and narration. The Complementary presentation consisted of relevant images (i.e., graphics of the intestinal track were presented during discussion of gastrointestinal chemicals) and minimal, complementary text (i.e., important points succinctly paraphrased). The Sparse presentation was identical to the Complementary presentation but excluded images. At the end of each four–and–a–half minute presentation, learners rated their perceived interest, difficulty, engagement and understanding specific to the preceding presentation. At the end of the experimental session, learners completed a comprehension quiz to assess objective understanding of the information presented. The comprehension quiz tested basic retention of facts (recognition), and deeper conceptual knowledge (applied).

Measures of perceived interest, difficulty engagement and understanding were assessed by a questionnaire following the first and second half of the presentation[1].

[1] Although some researchers encourage using multiple items to measure a single construct (e.g., perceived difficulty), there is extensive research demonstrating that single items (e.g., using one perception item to measure perceived difficulty) can adequately measure a given construct (Bergkvist and Rossiter, 2007;

Perceived interest was assessed through participants' response to the statement: (1) *I found the material presented in this lecture to be interesting*. Perceived difficulty was assessed through the participants' response to the statement: (2) *The lecture material has a high level of difficulty*. Perceived engagement was assessed through the participants' response to the statement: (3) *I found the multimedia presentation (use of images and/or words) engaging* (engagement). Perceived understanding was assessed through the participants' response to the statement: (4) *I found that I had a meaningful understanding of the material*. All perception responses were made on a 4–point Likert scale (1=absolutely disagree, 2=mostly disagree, 3=mostly agree, 4=absolutely agree).

Comprehension of the presented material was assessed using a multiple–choice quiz after both of the two presentations were viewed (see Appendix C for comprehension quiz). Principles from Bloom's Taxonomy were used to create distinct recognition and applied questions (Krathwohl, 2010). This allowed us to assess how retention of basic facts (recognition), and the ability to transfer newly learned concepts to novel problem scenarios (applied) were differentially affected by presentation style. A pilot study assessed the reliability of comprehension questions in evaluating recognition versus applied comprehension. Results showed acceptable internal consistency reliability scores using Kuder–Richardson 20 (Cronbach's alpha reported) for both question types (recognition: K–R 20 = .73; applied: K–R 20 = .71). In the current experiment twenty comprehension questions (10 recognition, 10 applied) were given, 10 of which tested information from the first half of the presentation, and 10 of which tested information

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Gardner et al., 1998). As a result, we adopted the approach of using single perception items to measure the subjective constructs of interest, difficulty, engagement and understanding.

from the second half of the presentation. The number of recognition and applied questions were evenly distributed across both presentations, so that there were 5 recognition questions and 5 applied questions for each half of the presentation. The presentations, comprehension questions and perception measures are all available upon request.

An online survey system (Limesurvey) was used to collect responses to the comprehension quiz and the four perception measures. Results were recorded on an anonymous and confidential basis by assigning individual identification numbers. An experimental session lasted one hour, during which the experimenter was always present.

2.3 Analysis

Comprehension scores were analyzed on SPSS 20 Macintosh using separate 2 (condition: redundant, non-redundant) × 2 (question type: recognition, applied) factorial ANOVAs on each of the non-redundant conditions: Complementary, and Sparse. Paired samples *t* tests were used to assess differences between specific presentation styles (i.e., Redundant vs. Complementary, Redundant vs. Sparse) on recognition and applied comprehension scores, as well as on ratings of the four perception measures (Norman, 2010), with all pairwise comparisons Bonferroni–corrected to the .05 level. Effect sizes were calculated for main effects, interactions and pairwise comparisons (partial eta squared—η_p^2—was used for ANOVA, and cohen's *d* was used for paired samples *t* tests). As results were consistent across counterbalanced conditions, data from the Redundant–Complementary condition were collapsed with data from the counterbalanced Complementary–Redundant condition. This was also true for the Redundant–Sparse and the Sparse–Redundant conditions. The complete data are represented as the Redundant–Complementary, and Redundant–Sparse condition (Appendix B provides supplementary material for those interested in the counterbalanced conditions and their respective data for comprehension performance and perception measures).

3. Results

Comprehension performance and perception measures' ratings are presented in Table 1 for the Redundant–Complementary condition, and in Table 2 for the Redundant–Sparse condition.

3.1. Comprehension performance

Analyses for the Redundant–Complementary condition yielded significant main effects of question type, $F(1, 19) = 16.89, p < .001, \eta_p^2 = .47$ (performance on recognition questions was greater than performance on applied questions), and condition, $F(1, 19) = 6.23, p = .022, \eta_p^2 = .25$ (the Complementary presentation produced greater comprehension than the Redundant presentation). The question type by condition interaction was also significant, $F(1, 19) = 11.71, p = .003, \eta_p^2 = .38$. Paired samples *t* tests yielded no difference in recognition comprehension scores between presentation styles, $t(19) = .68$, *p* = n.s., but significantly greater applied comprehension scores in the Complementary presentation compared to the Redundant presentation with a large magnitude–of–effect, $t(19) = 3.40, p < .001, d = 1.22$.

Analyses for the Redundant–Spare condition also yielded significant main effects of question type, $F(1, 19) = 15.82, p < .001, \eta_p^2 = .45$ (performance on recognition questions was greater than performance on applied questions) and condition, $F(1, 19) =$

9.63, $p = .006$, $\eta_p^2 = .34$ (the Sparse presentation produced greater comprehension than the Redundant presentation). The question type by condition interaction was significant, $F(1, 19) = 35.63$, $p < .001$, $\eta_p^2 = .65$. Paired samples *t* tests yielded significantly greater recognition comprehension scores for the Redundant presentation compared to the Sparse presentation with a large magnitude–of–effect, $t(19) = 2.65$, $p < .001$, $d = 0.81$, whereas applied comprehension scores was significantly greater for the Sparse presentation compared to the Redundant presentation with a large magnitude–of–effect $t(19) = 6.69$, $p < .001$, $d = 0.97$.

3.2. Perception measures (interest, difficulty, engagement, understanding)

Perception measures in the Redundant–Complementary condition demonstrate that lecture material was rated as equally interesting between presentations, suggesting that the quality of lecture material was unaffected by differences in multimedia presentation style, $t(19) = 1.56$, p = n.s. However, lecture material was rated as significantly less difficult when experienced in the Redundant presentation than in the Complementary presentation with a small to medium magnitude–of–effect, $t(19) = -5.11$, $p < .001$, $d = 0.41$. Presentation engagement was rated as significantly greater for the Redundant presentation with a large magnitude–of–effect, $t(19) = 4.29$, $p < .001$, $d = 1.51$. Interestingly, perceived understanding ratings were significantly higher for the Redundant presentation compared to the Complementary presentation with a large magnitude–of–effect, $t(19) = 5.67$, $p < .001$, $d = 1.60$, despite applied comprehension scores being higher for the Complementary presentation.

Comparisons in the Redundant–Sparse condition were similar to those reported above in the Redundant–Complementary condition. Lecture material was rated as equally interesting between Redundant and Sparse presentations, $t(19) = 2.10$, $p =$ n.s. Lecture material was rated as significantly less difficult when experienced in the Redundant presentation than in the Sparse presentation with a large magnitude–of–effect, $t(19) = 2.11$, $p = .003$, $d = 1.64$. Presentation engagement was rated as significantly greater for the Redundant presentation with a large magnitude–of–effect, $t(19) = 3.71$, $p < .001$, $d = 1.01$. Similar to the Redundant-Complementary condition, perceived understanding ratings were significantly higher for the Redundant presentation compared to the Sparse presentation with a large magnitude–of–effect, $t(19) = 4.68$, $p < .001$, $d = 0.90$, despite applied comprehension scores being higher for the Sparse presentation.

3.3. **Table 1.** Mean comprehension performance (recognition, applied) and mean perception measure ratings (interest, difficulty, engagement, understanding) for the Redundant–Complementary condition.

	Redundant *M (SD)*	**Complementary** *M (SD)*
Comprehension (%)		
Recognition	80.5 (7.59)	78.5 (10.89)
Applied	63 (11.28)	76 (9.94)
Perception (scale 1-4)		
Interest	3.15 (0.49)	2.9 (0.64)
Difficulty	2.15 (0.59)	3.05 (0.6)
Engagement	3.05 (0.6)	2.25 (0.44)
Understanding	3.15 (0.49)	2.3 (0.57)

Table 2. Mean comprehension performance (recognition, applied) and mean perception ratings (interest, difficulty, engagement, understanding) for the Redundant–Sparse condition.

	Redundant *M (SD)*	**Sparse** *M (SD)*
Comprehension (%)		
Recognition	79 (16.19)	69 (6.41)
Applied	51.5 (15.31)	76 (5.98)
Perception (scale 1-4)		
Interest	3.3 (0.66)	2.95 (0.51)
Difficulty	2.15 (0.67)	3.05 (0.39)
Engagement	3.15 (0.93)	2.2 (0.95)
Understanding	3.1 (0.72)	2.35 (0.93)

4. Discussion

The current study examined whether learners recognized the negative impact of a redundant text presentation on objective comprehension when provided with direct comparison to a non-redundant presentation. Results show that although applied comprehension performance was greatest for the non-redundant presentations (i.e., Complementary and Sparse), the Redundant presentation falsely produced greatest perceived understanding. Additionally, the Redundant presentation produced judgments of material difficulty and presentation engagement that did not match objective comprehension performance.

Importantly, this experiment demonstrates that non–redundant presentations produced superior applied comprehension compared to the Redundant presentation. However, the Redundant presentation did not differ in recognition understanding from the Complementary presentation, and produced greater recognition compared to the Sparse presentation. These results however, were not surprising. Redundant presentations may encourage superficial understanding of concepts, but interfere with deeper conceptual understanding due to competing visual–verbal information from on–screen text and narration. Given that recognition understanding evaluates superficial understanding of basic facts and isolated concepts (Jeffries and Maeder, 2006), it is not surprising that Redundant presentations produced similar, if not better, surface knowledge compared to non-redundant presentation styles. On the other hand, learners exposed to effective non-redundant presentations are able to direct greater mental effort to deep, meaningful learning because their attention is not consumed by redundant verbal information. As a result, although non-redundant designs such as the Complementary and Sparse presentations do not enhance recognition performance compared to Redundant presentations, they do promote the transfer of newly learned information to novel problem scenarios, which is vital to effective, long–term learning (Christina and Bjork, 1991).

Interestingly, applied performance of the Redundant presentation style within the Redundant–Sparse condition was significantly less than the applied performance of the Redundant presentation style within the Redundant–Complementary condition. This alludes to the possibility that the Complementary presentation style (but not the Sparse presentation style) influenced the way learners processed and consolidated application-based knowledge that was presented via the Redundant style. Learners may be better able to integrate information across presentation styles when one of the presentations includes helpful images rather than only minimal text. This hypothesis warrants further investigation, and can help contribute to our understanding of why images are highly effective instructional tools.

Redundant text presentations are consistently viewed as positive instructional tools in the absence of meaningful learning. Even when learners were exposed to both redundant and non-redundant presentations within the same session, they were unable to gauge how different presentation styles impacted their objective comprehension. One possibility is that learners may have rated their perceived understanding on a superficial level (i.e., their understanding of basic facts). If this were the case, considering perceived understanding accurately matched recognition comprehension for Redundant presentation styles, it would be highly speculative to conclude that Redundant presentation styles produced poor judgments of understanding. However, learners were encouraged to judge their understanding beyond basic fact recognition by rating whether they had a meaningful understanding of the lecture. Another potential limitation of the current study is the exclusion of a presentation condition with both redundant text *and* images. However, extensive prior research comparing presentation styles containing images without redundant text (i.e., Complementary) to presentation styles containing images with redundant text, have demonstrated that the presence of redundant text significantly reduced comprehension (Kalyuga et al., 1999; Mayer et al., 2001; Mayer and Moreno, 2002). Overall, our results demonstrate that although Redundant presentations reduce meaningful learning, they are perceived as overwhelmingly positive. This supports our predictions that even when learners are exposed to both redundant and non-redundant presentations, they perceive redundant text as a superior instructional tool.

Our results also relate to the concept of *desirable difficulties*—where difficulty during initial learning yields better long–term retention than initial learning that is effortless (Bjork, 1994). Prior research on desirable difficulties has demonstrated that learners who are required to manipulate information in an initially complex, meaningful way (i.e., generating mnemonics, learning words inverted) compared to learners who simply memorize information, perform poorly on immediate comprehension tests; however, the same learners show superior retention on delayed comprehension tests (Bjork, 1994; Sungkhasettee et al., 2011). Our results also coincide with the concept of desirable difficulties, as perceptions of greater difficulty (as seen in the Complementary and Sparse presentations) corresponded with superior comprehension performance compared to lower ratings of difficulty (as seen in the Redundant presentation).

Our findings may also reflect the concept of *amount of invested mental effort* (AIME) (Salomon, 1983). AIME suggests that learners invest different amounts of mental effort depending on the situation. In situations when learning is perceived as fluid and easy (akin to Redundant presentations), less mental effort is expended to engage with the content. In contrast, when learning is perceived as more difficult, more mental effort is invested to understand content. Crucially, AIME posits that the amount of mental effort expended during learning has a direct impact on how well something is learned. As a result, since the Redundant presentation was perceived as less difficult, participants potentially exerted less mental effort during acquisition of presented information, consequently reducing meaningful learning. Since only minimal mental effort is required to understand basic facts (i.e., recognition knowledge), the Redundant presentation still encouraged recognition-based learning, but failed to evoke the necessary mental effort needed to produce high-level, application-based knowledge.

5. Conclusions

The results of the current study extend the metacognitive literature by demonstrating that learners are poor judges of their own understanding in an educational context. Repeated exposure to Redundant presentations in an educational context may instill a sense of familiarity that learners misinterpret as representing effective multimedia instruction. Importantly, inaccurate metacognitive judgments are so robust that exposure to effective and ineffective multimedia instruction could not produce appropriate assessments of perceived interest and understanding that were in–line with objective comprehension performance. As a result, Redundant presentations may pervade educational institutions because learners reinforce instructors to use redundant text (based on misguided perceptions of familiarity) and instructors correspondingly seek to appease student demands. Moreover, instructor evaluations, which rely heavily on student satisfaction (Greenwald, 1997; Marsh, 1980), may reinforce the use of redundant text in presentations to ensure students' sense of familiarity and comfort resulting in a debilitating cycle of ineffective instructional design. This cycle may lead learners to reject the use of more effective presentation designs with limited use of redundant text. It is also possible that students are accustomed to factual learning, which is often aided by rote-memorization of verbatim notes. Redundant presentations clearly promote factual knowledge (i.e., recognition knowledge), and are therefore well-matched to rote-memorization of fact-based information. It would be interesting if future work investigated whether there is a relationship between preference for Redundant presentations and the experience of classroom techniques employing rote-memorization.

There are several interventions that can be employed to avoid the learning pitfalls of redundant text presentations. First, instructors need access to appropriate multimedia training to avoid reliance on redundant text and promote the use of relevant images and minimal text. Making instructors aware of the cognitive detriments of redundant text may augment such practical training. Perhaps the overuse of redundant text in instructional design is in large part due to a lack of instructor awareness regarding effective and ineffective use of text and images during instruction. By educating instructors on appropriate multimedia design, they can in turn communicate to students why redundant text, although subjectively preferred, is an ineffective learning design. This flow of information is critical to diffusing the detrimental student–instructor cycle characterized by a sequence of student preference for redundant text, and instructor appeasement for student satisfaction. Second, as learners become regularly exposed to effective presentations in educational settings, they may develop an appropriate sense of familiarity with presentations that facilitate their understanding. It is critical that research continues to investigate ways to align objective, successful learning with subjective perceptions of understanding to maximize student achievement.

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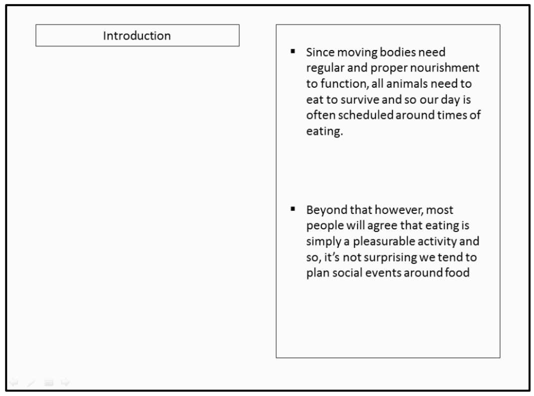
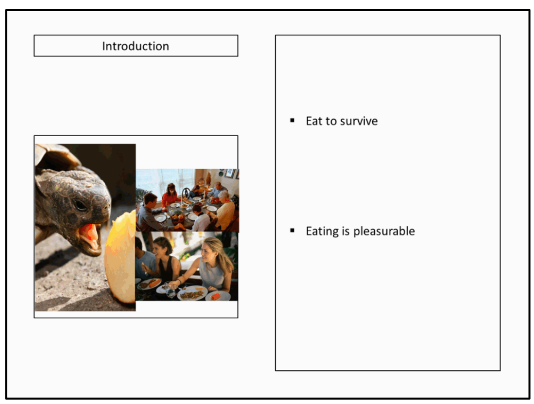
Appendix A

Examples of Presentation Styles

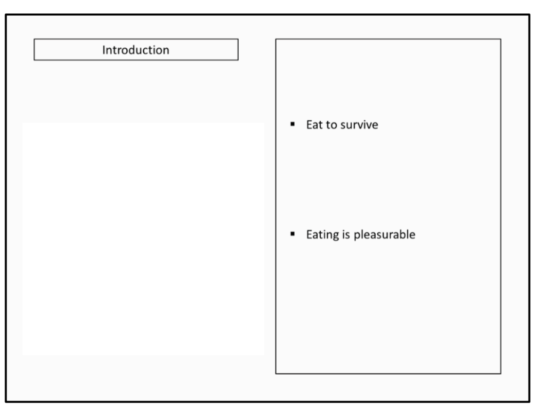
Redundant Condition



Complementary Condition



Sparse Condition



Appendix B
Counterbalanced data for comprehension scores and perception measures

Table 3. Comprehension scores for all counterbalanced presentations.

Comprehension Question (%)	Presentation style *M (SD)*	
	Redundant	**Complementary**
Recognition	80 (10.54)	76 (12.65)
Applied	66 (13.50	77 (11.60)
	Complementary	**Redundant**
Recognition	81 (8.76)	81 (3.16)
Applied	75 (8.50)	60 (8.16)
	Redundant	**Sparse**
Recognition	79 (15.24)	70 (6.67)
Applied	50 (6.67)	75 (5.27)
	Sparse	**Redundant**
Recognition	68 (6.32)	79 (17.92)
Applied	77 (6.75)	53 (21.11)

Table 4. Perception measures for all counterbalanced presentations.

Perception (scale 1-4)	Presentation style *M (SD)*	
	Redundant	**Complementary**
Interest	3.2 (0.42)	2.9 (0.57)
Difficulty	1.8 (0.42)	3 (0.47)
Engagement	3.1 (0.57)	2.3 (0.48)
Understanding	3.2 (0.42)	2.3 (0.68)
	Complementary	**Redundant**
Interest	2.9 (0.74)	3.1 (0.57)
Difficulty	3.1 (0.74)	2.5 (0.53)
Engagement	2.2 (0.42)	3 (0.67)
Understanding	2.3 (0.48)	3 (0.57)
	Redundant	**Sparse**
Interest	3.4 (0.52)	3.2 (0.42)
Difficulty	1.7 (0.48)	2.9 (0.32)
Engagement	3.1 (1.20)	2.2 (1.23)
Understanding	3.2 (0.79)	2.7 (1.06)
	Sparse	**Redundant**
Interest	2.7 (0.48)	3.2 (0.79)
Difficulty	3.2 (0.42)	2.6 (0.52)
Engagement	2.2 (0.63)	3.2 (0.63)
Understanding	2 (0.67)	3 (0.67)

Appendix C
Comprehension Questions

First half of presentation: Recognition questions (correct answers indicated in bold)

Cannon and Washburn (1992) proposed an interesting answer to why people feel hungry. What answer did they purpose?

a. You feel hungry when the walls of your intestine rub against each other
b. You feel hungry when the glucose in your stomach causes a sensation of emptiness
c. You feel hungry when the walls of your stomach rub against each other
d. You feel hungry when your small intestine contracts, and sends digestive enzymes up to your stomach

In 1944, Inglefinger studied cancer patients with their stomachs surgically removed. Describe what his study concluded about feelings of hunger?

a. You need a stomach in order to feel hungry
b. You do not need a stomach in order to feel hungry
c. Individuals without stomachs do not report feelings of hunger
d. You need only part of your stomach to feel hungry

As glucose levels drop:

a. You start feeling full
b. Remaining glucose is quickly converted into glycogen
c. Glycogen is broken down into glucose
d. Fat is stored

Which nutrient signals the need to replenish one's food intake?

a. glucose
b. fructose
c. adipose tissue
d. glycogen

According to the lecture, "our lives seem dominated by the consumption of food". What was the evolutionary rationale behind this statement?

a. In the past, humans had to expend more effort in order to find food than is typical for modern industrial societies today.
b. In the past, humans had to expend minimal effort in order to find than is typical for modern industrial societies today.
c. In the past and in present industrial societies, humans expend a great deal of energy seeking out scarcely available food.
d. In the past and in present industrial societies, humans expend less energy seeking out scarcely available food.

First half of presentation: Applied questions

You have discovered an animal that does not seem to employ glycogen stores (or an equivalent). Applying your knowledge about glycogen stores, you might expect this animal to:

a. **Eat frequently and have highly variable glucose levels**
b. Eat frequently and have consistently low glucose levels
c. Eat infrequently and have highly variable glucose levels
d. Eat infrequently and have consistently low glucose levels

Peter's liver is correctly identifying glucose levels in his blood. Frank's liver is incorrectly identifying glucose levels in his blood. What would be the difference between Peter and Frank's liver activity?

a. **Peter's but not Frank's liver would be breaking down glycogen into glucose when glucose levels are low**
b. Frank's but not Peter's liver would be breaking down glycogen into glucose when glucose levels are low
c. Peter's but not Frank's liver would be converting glucose into glycogen when glycogen levels are low
d. Frank's but not Peter's liver would be converting glucose into adipose tissue when glycogen levels are low

In a transporter malfunction, John's stomach was accidently removed. What effect will it have on his eating habits?

a. John will eat more
b. John will eat slightly less
c. John will now experience highly variable levels of hunger
d. **No effect**

Jim has a rare autoimmune disorder where his fat tissues attack his muscle cells. What kind of side effects would Jim experience as a result of his disorder?

a. **High blood glucose**
b. Low blood glucose
c. Fatty acids start breaking down glycogen
d. Fatty acids start breaking down glucose

Alex, Sam, and Amanda all eat the same amount of food for dinner. Alex eats a triple cheeseburger with fries. Sam eats a large turkey sandwich with a plate of steamed vegetables. Amanda eats a large plate of chicken thighs and wings. Who will feel full the longest?

a. Alex
b. Amanda
c. **Sam**
d. They will all feel full for the same amount of time

Second half of presentation: Recognition questions

Physiological evidence indicates that part of the _____ controls the cessation of feeding. It appears to do so by ______.

a. hypothalamus…monitoring stomach distension
b. thalamus…monitoring the rate of glucose use
c. hypothalamus…monitoring the rate of glucose use
d. limbic system…monitoring the rate of glucose use

According to the lecture, which part of the brain is the most important in the regulation of hunger and satiety?

a. olfactory bulb
b. prefrontal cortex
c. hippocampus
d. hypothalamus

Damage to the brain area important in regulating eating behaviour can affect hunger and satiety in two different ways. What are they?

a. overeating only
b. refusing to eat only
c. overeating, or refusing to eat
d. emotional overeating only

Stimulation of the ventromedial nucleus of the hypothalamus in rats might be expected to cause:

a. an increase in food intake and weight gain
b. a sharp decrease in food intake (or its complete cessation) and weight loss
c. a transition from waking to sleep, if the stimulation is of high frequency
d. permanent wakefulness

What is the role of adipose tissue?

a. stores energy for later use
b. signals the body to replenish its food intake
c. maintains the body at a healthy weight
d. carries glucose to different areas of the body

Second half of presentation: Applied questions

Dr. Smith discovers one of his patients (Mike) has been gaining weight. Upon closer inspection, Dr. Smith discovers Mike's leptin levels are abnormally low. What role does leptin play in long-term weight regulation?

a. When fat tissue increases, leptin production is halted, and daily food consumption is lowered
b. When an individual feels hungry, leptin levels rise, and signal the body to consume food
c. When an individual feels hungry, leptin levels rise, and signal the body to reduce food consumption
d. When fat tissue increases, leptin levels rise, and is involved in reducing daily food consumption.

A pharmaceutical company is trying to create a drug that will help obese clients lose weight. Taking advantage of what you have learned thus far, which of the following approaches would be best?

a. Create a drug that mimics the function of Leptin
b. Create a drug that stimulates the liver to break down glycogen to glucose
c. Create a drug that blocks the receptors of NPY
d. Create a drug that stimulates the overproduction of adipose tissues

Dr. Smith discovers the presence of a hormone in the small intestine, which he hypothesizes, causes feelings of fullness, and reduces eating. Which following observation (if found) would argue against his hypothesis?

a. When this hormone was injected into subjects, it resulted in feelings of nausea. Therefore, perhaps nausea, and not a feeling of fullness, reduced food consumption
b. When this hormone was injected into subjects, it caused stomach constriction and intense gastrointestinal pain. Therefore, perhaps pain, and not a feeling of fullness, reduced food consumption.
c. When this hormone was injected into subjects, it caused stomach the esophagus to constrict, consequently preventing food consumption. Therefore, perhaps esophagus constriction, and not a feeling of fullness, reduced food consumption.
d. When this hormone was injected into subjects, feelings of fatigue resulted. Therefore, perhaps fatigue, and not feelings of fullness, reduced food consumption.

John acquires a head injury during a car accident and over the subsequent weeks he gains over 80 pounds. What may have been the cause for his excessive weight gain?

a. Overproduction of CCK in the brain
b. Lateral hypothalamus damage
c. Ventromedial hypothalamus damage

d. Damage to hypothalamus inhibiting production and release of NPY

Dr. Burn has discovered a new hormone called DBH that he believes directly inhibits the actions of NPY. Which of the following experimental procedures would allow Dr. Burn to test his hypothesis?

a. Inject DBH into the hypothalamus; if eating increases, his hypothesis is correct
b. Inject DBH into the hypothalamus; if eating decreases, his hypothesis is correct
c. Inject DBH into the liver; if eating increases, his hypothesis is correct
d. Inject DBH into the liver, if eating decreases, his hypothesis is correct

Chapter 3: Fenesi, B., Vandermorris, S., Kim, J. A., Shore, D. I., & Heisz, J. J. (revised and resubmitted). ***One size does not fit all: Older adults benefit from redundant text in multimedia instruction*****. Paper submitted to the Frontiers in Developmental Psychology.**

Preface

The second article in this dissertation entitled "One Size Does Not Fit All: Older Adults Benefit From Redundant Text in Multimedia Instruction" was submitted to Frontiers in Developmental Psychology with co-authors Dr. Susan Vandermorris, Dr. Joseph Kim, Dr. David Shore, and Dr. Jennifer Heisz. The motivation behind this study was an empirical desire to determine if optimal design templates vary according to the different cognitive strengths and weaknesses of younger and older age groups. Age-related decline in WMC (Hedden and Gabrieli, 2004; Mattay et al., 2006) and processing resources (Pachman, 2007; Pachman and Ke, 2012) may mean that older adults require different design features than younger adults for optimal learning. This study examined younger and older adults with three different multimedia presentation designs to determine if design strategies vary as a function of different cognitive strengths and weaknesses across age groups. We found that while younger adults once again had superior comprehension when exposed to complementary images, older adults performed better with redundant text. We also found that both younger and older adults were poor at recognizing presentation styles that promoted or hindered their learning; both age groups rated the non-optimal condition for their age group as more effective for learning.

Importantly, this study suggests that one-size does not fit all, with older adults requiring unique multimedia design tailored to their cognitive abilities for effective learning.

One Size Does Not Fit All: Older Adults Benefit From Redundant Text in Multimedia Instruction

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Abstract

The multimedia design of presentations typically ignores that younger and older adults have varying cognitive strengths and weaknesses. We examined whether differential instructional design may enhance education. Younger and older participants viewed one of three computer-based presentations: Audio only (narration), Redundant (audio narration with redundant text), or Complementary (audio narration with non–redundant text and images). Younger participants learned better when audio narration was paired with relevant images compared to when audio narration was paired with redundant text. However, older participants learned best when audio narration was paired with redundant text. Younger adults, who presumably have a higher working memory capacity, appear to benefit more from complementary information that may drive deeper conceptual processing. In contrast, older adults learn better from presentations that support redundant coding across modalities, which may help mitigate the effects of age-related decline in working memory capacity. Additionally, several misconceptions of design quality appeared across age groups: both younger and older participants positively rated less effective designs. Findings suggest that one-size does not fit all, with older adults requiring unique multimedia design tailored to their cognitive abilities for effective learning.

1. Introduction

Optimal learning through multimedia design requires a careful combination of words and images. Most research examining the factors promoting optimal multimedia learning has focused on young adults, with little known about the factors promoting optimal multimedia learning in older adults. Previous work suggests that there may be age-dependent differences; for example, when considering the optimal presentation of news media, one study found that older adults retained most information when presented through narration alone whereas younger adults benefited the most when narration was paired with either written text or video imagery (Stine et al., 1990). Importantly, the rapid rise of online courses in higher education, and an increasingly technology-oriented education system drives the need for practical research to address effective multimedia design across diverse age groups. Some researchers suggest that existing principles of instructional design can be used to accommodate the needs of older learners (Van Gerven et al., 2006), as existing instructional theories bear important benefits for older learners because they support an efficient use of available cognitive resources. However, age-related decline in working memory capacity (WMC) (Hedden and Gabrieli, 2004; Mattay et al., 2006) and processing resources (Pachman, 2007; Pachman and Ke, 2012) may mean that older adults require different design features than younger adults for optimal learning. Indeed, some argue that design for older adults should involve understanding their unique capabilities and limitations, identifying their needs, preferences and desires for technology in their lives, and involving them in the design process (Rogers and Fisk, 2010). The present study examined younger and older adults with three different multimedia presentation designs to ask if optimal design templates vary according to the different cognitive strengths and weaknesses of each age group. The three presentation designs were: 1) Audio only (narration), 2) Redundant text (narration with redundant text), 3) Complementary images (narration with non–redundant text and images).

Two dominant theories govern multimedia design in education: Cognitive Load Theory (CLT) proposed by John Sweller and colleagues (Sweller, 1999; Sweller et al., 1998; Van Merriënboer and Sweller, 2005), and Cognitive Theory of Multimedia Learning (CTML) proposed by Richard Mayer (2001). Both CLT and CTML build on a cognitive architecture consisting of limited capacity working memory (WM), an unlimited long-term store, and two subsystems for processing auditory and visual information (Baddeley, 1986; Chang et al., 2011; Cowan, 2001). The core features of this model include the limited capacity of WM and the independence of the subsystems (Brooks, 1968; cf. Paivio, 1986), which can simultaneously process their respective information. Purely unimodal instruction (e.g., audio narration only) does not engage these parallel processing streams, and is substantially less effective than instruction that takes advantage of both subsystems by simultaneously presenting auditory/verbal information (e.g., narration) and pictorial/non-verbal information. Critically, this multimodal presentation of information helps overcome limitations of WM.

The core features of WM models have been used to develop a myriad of multimedia design strategies to guide best practice (Mayer, 2009). For example, pairing instructional animation or images with auditory narration engages both verbal and visual processing subsystems; learners can effectively organize new information in WM and integrate this new knowledge into existing long-term memory stores, ultimately resulting in a richer memory representation. However, the impact of verbal redundancy (i.e., paring identical visual text with simultaneous narration) has been less clear. Several studies have shown that younger adults learn better when audio narration is paired with identical visual text compared to when audio narration is presented alone (Adesope and Nesbit, 2001; Moreno and Mayer, 2002). Yet others demonstrate no improvement in learning under conditions of verbal redundancy (Fenesi et al., 2014; Fenesi and Kim, 2014; Kalyuga et al., 2004). Several of these studies also show that on-screen text that is redundant with auditory narration produces substantially worse performance compared to when complementary images are paired with narration (Fenesi et al, 2014; Fenesi and Kim, 2014). Potential reasons for discrepant findings involving verbal redundancy might reflect methodological differences between studies, such as differences in material content. For example, Moreno and Mayer (2002) found a benefit of verbal redundancy for younger adults when presenting cause-effect explanations of a scientific system (e.g., lightning formation). Although this information is complex, work by Fenesi and colleagues (2014) presented hierarchically organized content from a subset of an actual online lecture from an introductory psychology course, where basic concepts are presented first, followed by more complex information, which builds on this foundational knowledge. Perhaps as multimedia content becomes increasingly complex and hierarchical, verbal redundancy impedes learning.

Importantly, if instructional design strategies support an efficient use of available cognitive resources, older adults should show similar patterns of learning, but might show overall reduced performance as a result of their age-related decline in WM capacity (Hedden and Gabrieli, 2004; Mattay et al., 2006; Pachman, 2007; Pachman and Ke, 2012; Wingfield et al., 1998). However, older adults may actually show enhanced performance under conditions of verbal redundancy. Indeed, older adults have demonstrated better learning with a verbally redundant presentation compared to an audio-only condition, whereas younger adults showed impaired learning under the same conditions (Pachman and Ke, 2012). In the context of driving, older adults benefited from a redundant text presentation (narration + text + map), which improved both comprehension of driving instructions and driving ability, as indexed by reduced number of lane deviations and inappropriately long glances (> 2.5s) (Dingus et al., 1997). These studies suggest that presenting redundant visual text has benefits for older adult comprehension, within both multimedia and driving navigation environments.

The differential effect of verbal redundancy for older and younger participants may reflect age-related differences in cognitive function that are not fully captured by existing multimedia learning frameworks. A key aspect of cognitive aging is decreased WMC (Pachman, 2007), which reflects reduced processing resources and slower processing of incoming information. Thus, optimal learning for older adults may be promoted by reducing the reliance on internal determinants of performance (e.g., WM) and instead, relying more on external components (e.g., contextual cues, visual text) to enhance encoding and processing of presented information (Craik and Rose, 2012). Importantly, older adults show enhanced multisensory integration, especially with respect to visual dominance and the integration of visual-verbal information with auditory-verbal information (Diaconescu et al., 2012). Consequently, a redundant presentation style may enhance their learning. Note, however, that this work used low-level visuo-verbal perceptual stimuli (e.g., image of bird and chirp sound for 400ms) to examine multisensory integration in older adults, and may not be considered scalable to high-level conceptual stimuli such as multimedia instruction. Additional evidence for the benefit of redundant presentation styles for older adults may come from attentional co-activation models (Bucur et al., 2005). According to a co-activation framework, older adults should benefit from verbal redundancy compared to younger adults, because they extract less information from the presentation of a single verbal target (e.g., narration or on-screen text alone), due to age-related reductions in WMC. Finally, narration alone or narration paired with images might lack necessary visuo-verbal support to counteract reduced auditory perception. Thus, it is possible that optimal design of multimedia for learning in older adults may be one that provides additional verbal cues in the form of redundant audio and visual text information.

The primary research objective of the current study was 1) to extend multimedia research to older adults and examine whether they show similar patterns of comprehension as younger adults, or whether they require unique multimedia design tailored to their cognitive abilities for effective learning, and 2) to replicate our prior research on younger adults that found verbal redundancy did not promote learning compared to narration alone and impaired learning compared to the use of complementary images. Unlike previous research that only examined the impact of verbally redundant text compared to audio alone (Pachman and Ke, 2012), we also examined the impact of verbally redundant text compared to complementary images; this is an important comparison as images are repeatedly shown to promote learning for younger adults, yet little is known about the impact on older adult learning. Younger and older participants were exposed to the same audio track under one of three conditions: 1) Audio only, 2) Redundant text (audio with redundant text), 3) Complementary images (audio with non–redundant text images). Both groups were then assessed for comprehension of presented material and subjective perceptions of multimedia quality and effectiveness.

According to prior research, (Fenesi et al., 2014; Fenesi and Kim, 2014; Kalyuga et al., 2004), younger participants were expected to have better comprehension performance when the audio track was presented with complementary images compared to redundant text or audio only. This is based on the theoretical assumption that redundant verbal information overwhelms the auditory/verbal subsystem and reduces critical working memory resources needed to meaningfully understand and integrate incoming information. Presenting narration and relevant images allows visual/pictorial and auditory/verbal subsystems to function in parallel, promoting optimal working memory resource allocation. For older participants, if we assume that existing instructional theories support an efficient use of available cognitive resources and are equally beneficial across age groups, we would predict a similar pattern of results for both younger and older adults, with both age groups performing best in the Complementary condition and worst in the Redundant text and Audio conditions. In contrast, if we assume that older adults cannot rely as effectively as younger adults on internal determinants of performance (i.e., WMC and processing resources), they may benefit from redundant text due to greater verbal ability, attentional co-activation or visual text functioning as an external contextual aid; in this case, we would predict older adults would show a different pattern of results from younger adults and perform best in the Redundant text condition compared to the Complementary and Audio conditions.

The secondary research objective was to examine how subjective perceptions of the multimedia presentation interacted with age group and presentation design, and if these subjective factors influenced comprehension. Prior work has demonstrated discrepancies between objective and subjective measures of comprehension, with younger adults believing ineffective presentations aid their understanding (Fenesi et al., 2014; Fenesi and Kim, 2014). Similarly, older adults also show limited accuracy in judging the effectiveness of learning strategies, rating rote memorization as an effective learning strategy, even though it is not (Hertzog and Dunlosky, 2004). We wanted to extend this research to judgments of multimedia design quality and effectiveness in older adults, and evaluate whether both younger and older adults have equally poor judgments of effective instructional design.

2 Materials and Methods

2.1 Participants

2.11 Young adults

Table 1 provides demographic information for both age groups. One hundred and one first year undergraduate students from McMaster University, 27 men and 64 women (*M* age = 18.75 , *SD* = 2.12) participated in the experiment and were randomly assigned to one of three conditions: Audio (*M* age = 18.86, *SD* = 2.5, *N* = 35), Redundant (*M* age =

18.33, *SD* =1.02, *N* = 33), and Complementary (*M* age = 19.06, *SD* =3.38, *N* = 33). All participants were enrolled in Introductory Psychology and received course credit. They were recruited using an online portal designed for psychology research. All participants provided informed consent, and all procedures complied with the tri-council statement on ethics, as assessed by the McMaster Research Ethics Board.

2.1.2 Older adults

Seventy-five older participants from the Baycrest Research Subject Pool, 25 men and 50 women (*M* age = 72.36, *SD* = 5.31) were recruited via telephone interview based on the following inclusion criteria: healthy volunteers, age over 65, fluent in English, functional hearing and vision, no major neurologic illness, no current untreated psychiatric or substance-related disorder, and no severe sensory impairment (normal or corrected to normal hearing and vision). Participants received $10 monetary compensation. They were randomly assigned to one of three conditions: Audio (*M* age = 71.63, *SD* =5.26, *N* = 27), Redundant (*M* age = 73.08, *SD* = 5.82, *N* = 24), and Complementary (*M* age = 72.04, *SD* = 5.2, *N* = 24). All participants provided informed consent, and all procedures complied with the Baycrest Human Subjects Research Ethics Board.

2.1.3 Table 1. Demographic information across both younger and older adults for age, sex, total years of education, number of hours spent on a computer per week, and total online courses taken in a lifetime.

	Younger			**Older**		
	Audio M *(SD)*	Redundant M *(SD)*	Complementary M *(SD)*	Audio M *(SD)*	Redundant M *(SD)*	Complementary M *(SD)*
N	34	33	33	27	24	24
Age	18.85 *(2.50)*	18.33 *(1.02)*	19.06 *(3.38)*	71.63 *(5.26)*	73.08 *(5.82)*	72.04 *(5.20)*
Sex	f = 22	f = 22	f = 29	f = 20	f = 20	f = 17
Education (yrs)	13.69 *(1.28)*	13.23 *(1.13)*	13.94 *(1.41)*	16.63 *(4.81)*	17.04 *(2.58)*	17.65 *(3.92)*
Computer use / week (hrs)						
0	0	0	0	2	2	1
< 1	0	0	0	3	1	0
1–3	0	1	0	4	1	3
4–6	3	2	1	11	3	4
7–10	2	7	5	2	2	8
11–15	6	8	4	1	7	3
16–20	12	4	10	1	1	3
20+	11	11	13	3	7	2
Total online courses	2.29 *(1.69)*	2.42 *(2.05)*	2.55 *(1.09)*	1.48 *(3.25)*	0.95 *(1.94)*	2.46 *(3.54)*

2.2 Stimuli and Procedure

Participants were randomly assigned to view one of three multimedia presentations: 1) Audio only, 2) Redundant text (audio narration paired with redundant on-screen text), or 3) Complementary (audio narration paired with images and minimal text). Appendix A (online-only supplemental file) provides example slides for the Redundant and Complementary conditions (Audio condition was a blank screen), along with web links to view the actual presentations. Each presentation consisted of a 9-min system-paced PowerPoint slide show (total of 23 slides) about the physiology, anatomy, evolution, and biochemical mechanisms of hunger. The narration was 1375 words (80 sentences), and was rated as requiring an 11.02 grade-school level of reading skill to effectively read the text (using Flesh-Kincaid Grade Level formula; Farr et al., 1951). The narration was also rated as having an average ease of readability using the Flesch Reading Ease inventory (scored 46.67 which falls within the range considered average of 6-70).

The Redundant condition consisted of 2-4 bullet points of text (Calibri font, size varied between 20-24) per slide (verbatim to the slide's narration). The location of the text was always within 1 inch left-right margins, and 0.5-1 inch top-bottom margins of the screen, with minor deviations due to slightly different amounts of text across slides. Text size and density varied slightly across slides to ensure both Redundant and Complementary conditions consisted of 23 slides total, and that each slide across both conditions presented the same amount of content. The loudness of the audio narration was adjusted for each participant, since they listened to the presentation narration via individual headsets. The experimenter presented a non-experimental video with sound prior to the beginning of the presentation, and allowed each participant to adjust the volume to a comfortable, audible level. Participants were also shown the volume control keys so that they could adjust the volume at any time during the experiment. At the end of the experiment, all participants were probed for audibility, with no participants reporting difficulty hearing. Additionally, all participants were prescreened for sufficient hearing; older adults that indicated hearing deficiencies had hearing aids, and indicated no hearing difficulties during the experiment.

Within the Complementary condition, the size of images varied depending on slide content (e.g., image of gastrointestinal tract was larger and more visually dense than an image of a balance beam with glycogen and glucose on opposite sides depicting the hunger process). The duration of each slide across conditions varied depending on the slide's content. Some slides were more content-heavy, requiring longer presentation durations of text and images (although slide duration was identical across conditions).

Younger participants individually viewed a multimedia presentation on a 15-inch Dell laptop with an attached headset. Older participants viewed the presentation on individual Dell desktop PCs with 19-inch displays and an attached headset. For both age groups, the experiment took 40-60 minutes to complete (5-min instructions, 9 min presentation, 30-40 mins comprehension quiz and questionnaire, 5-min debrief). There were 5-8 participants in each session, each on their own individual computer. Immediately after viewing the presentation, participants responded to the comprehension quiz, followed by a perception and technology use questionnaire.

Comprehension performance was determined by participants' mean score on 20 multiple-choice questions (4-option answers). Two different question types were used to diversify the questions: 10 questions evaluated basic retention and 10 questions evaluated problem-transfer (see Appendix B for the complete comprehension quiz—online-only supplemental file).

Perception measures were assessed by the participant's response to four statements: (1) I found the material presented in this lecture to be interesting (interest), (2) The lecture material has a high level of difficulty (difficulty), (3) I found the multimedia presentation to be engaging (engagement), and (4) I found that the presentation style helped me to understand the lecture material (understanding). Response options to all perception measures were reported on a 4-point scale (1=absolutely disagree, 2=mostly disagree, 3=mostly agree, 4=absolutely agree). Importantly, each perception measure was associated with a specific feature of the multimedia presentation. That is, perception measures of interest and difficulty required participants to reflect on the content of the presentation (i.e., lecture information), whereas perception measures of engagement and understanding required participants to reflect on the actual presentation design (i.e., use of words and images). Previous research has strongly encouraged the collection of both perception measures and performance indicators (i.e., comprehension) to better represent product quality (Moullin, 2004).

A computer-use measure was also included to determine whether time spent using a computer was related to comprehension performance or subjective perception measures. This was used to establish whether experimental conditions were equal with respect to computer-related technical prerequisites. Participants responded to the statement: What is the *total* number of hours a week that you spend on a computer? Response options were: 0, less than 1 hour, 1-3 hours, 4-6 hours, 7-10 hours, 11-15 hours, 16-20 hours, 20+ hours. Additionally, participants were asked to indicate how many online courses they had taken in their lifetime. An online survey system (Limesurvey) was used to collect data. All participants were debriefed following the experiment.

2.3 Analysis

Comprehension scores and perception measures were analyzed using a 2 (age group: young, old) × 3 (presentation condition: Audio, Redundant, Complementary) factorial ANOVA. Alpha was set to .05 for all main effects and interactions, and all pairwise comparisons using independent samples *t*-tests were Bonferroni corrected. Effect sizes were calculated for main effects, interactions, simple main effects and pairwise comparisons (cohen's *d* was used for independent *t* tests, and partial eta squared,η_p^2, was used for ANOVA). Two correlation matrixes (one for each age group) were also used to assess the relation between technology use and dependent measures of comprehension performance and subjective perception ratings. SPSS 20 for Macintosh was used to conduct data analyses.

3. Results

For both age groups, there were no significant correlations between technology use and comprehension, and no significant correlations between technology use and perception measures (all rs < .2). Therefore, the amount of computer-use across age groups was not related to comprehension performance or subjective perception measures. There were no significant differences in years of education or number of online courses taken within a lifetime across the three conditions for both age groups, as indicated by non-significant one-way ANOVAs (all Fs < 2.628, p > .07). These analyses indicate effective random assignment across conditions within both age groups; all conditions within an age group consisted of participants with similar years of education and online educational exposure. As expected, older adults also had significantly more years of education than younger adults, as indicated by an independent samples *t* test, $t(86) = 7.419$, $p < .001$, $d = 1.195$.

3.1 Comprehension performance

Comprehension scores are presented in Figure A. Preliminary analyses found no differences among conditions (across both age groups) in comprehension scores between basic retention and problem–transfer questions; we therefore collapsed across question type. Younger participants had higher comprehension scores than older participants, supported by a main effect of age, $F(1, 170) = 13.37$, $MSE = 0.19$, $p < .001$, $\eta_p^2 = .07$. Comprehension scores among the three conditions was similar when collapsing across the age groups, as indicated by a non-significant main effect of condition $F(2, 170) = 2.53$, $MSE = 0.19$, $p = .08$. , $\eta_p^2 = .03$. The presentation condition had differential effects on the two age groups, $F(2, 170) = 6.22$, $MSE = 0.19$, $p = .002$, $\eta_p^2 = .07$. For the younger participants, the Complementary condition had the best comprehension performance, which replicates previous findings (Fenesi et al., 2014). There was no difference between the Redundant and Audio conditions ($t(66) = 0.06$, $p = .95$.), which were both worse than the Complementary condition ($t(64) = -2.53$, $p = .01$, $d = 0.64$ and $t(66) = -2.87$, $p = .01$, $d = 0.35$, respectively). In contrast, for older participants the Redundant condition had the best performance. There was no difference between the Complementary and Audio conditions ($t(64) = -0.15$, $p = .89$), which were both worse than the Redundant condition ($t(46) = 2.51$, $p = .02$, $d = 0.76$ and $t(49) = -2.8$, $p = .01$, $d = 0.83$, respectively).

Figure A. Comprehension performance scores across conditions for both age groups (±SE)

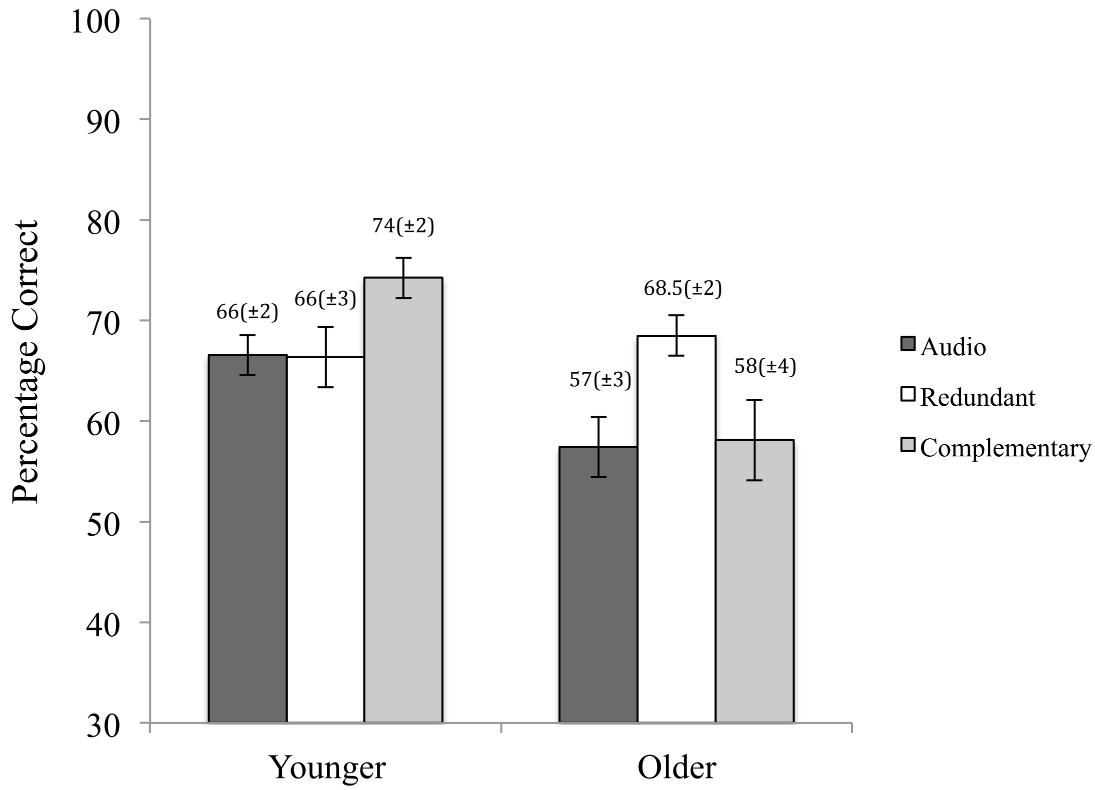

Figure A. Differences in comprehension performance between presentation conditions for both younger and older adults (±SE).

3.2 Subjective perception

3.2.1 Perceived understanding

Figure B shows perceived understanding ratings among conditions for both age groups. Older adults had higher perceived understanding ratings than younger adults, which was supported by a main effect of age for understanding $F(1, 170) = 11.08$, $MSE = 0.42$, $p = .001$, $\eta_p^2 = .06$. When collapsing across age groups, the three conditions also produced significantly different ratings of perceived understanding, which was supported by a main effect of condition $F(2, 170) = 36.62$, $MSE = 0.42$, $p < .001$, $\eta_p^2 = .30$. Furthermore, the presentation condition had differential effects on the two age groups, as indicated by a significant interaction $F(2, 170) = 3.61$, $MSE = 0.42$, $p = .03$, $\eta_p^2 = .04$. Younger adults believed the Complementary and Redundant conditions aided in their understanding more than the Audio condition (Redundant vs. Audio, $t(66) = -4.4$, $p < .001$, $d = 1.06$; Complementary vs. Audio, $t(66) = -6.69$, $p < .001$, $d = 1.61$). In contrast, older adults believed that the complementary condition aided in their understanding more than the redundant or the audio (Complementary vs. Redundant, $t(46) = -5.47$, $p < .001$, $d = 1.58$; Complementary vs. Audio, $t(49) = -5.57$, $p < .001$, $d = 1.66$). That is, the younger adults believed the redundant condition helped whereas the older adults did not. Spearman correlations revealed no significant relation between subjective and objective measures of understanding for both age groups ($r < .146$).

Figure B. Perceived understanding ratings across conditions for both age groups (±SE)

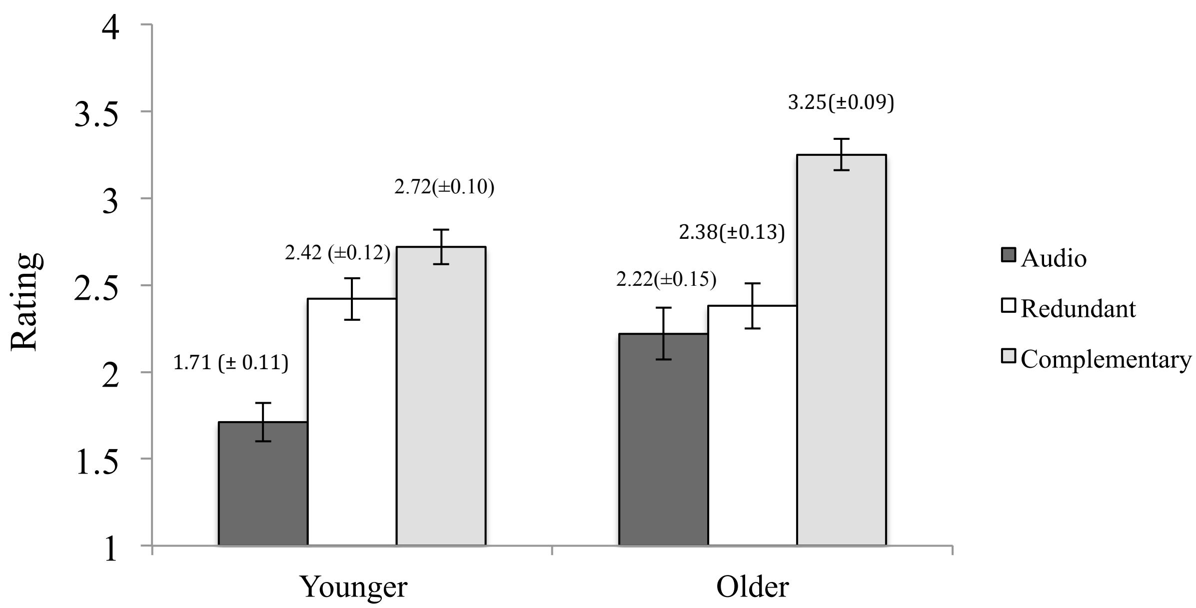

Figure B. Differences in perceived understanding ratings between presentation conditions for both younger and older adults (±SE)

3.2.2 Perceived interest, engagement and difficulty

Table 2 shows perception ratings among age groups and conditions. The three conditions were rated differently in terms of *interest* $F(2, 170) = 5.44$, $MSE = 0.49$, $p = .01$, $\eta_p^2 = .06$, and *engagement* $F(2, 170) = 26.22$, $MSE = 0.52$, $p < .001$, $\eta_p^2 = .24$, but not in terms of *difficulty* $F(2, 170) = 0.44$, $MSE = 0.44$, $p = .65$, $\eta_p^2 = .01$. Globally, older adults rated the presentations as more interesting, engaging, and difficult than younger adults (main effect of *interest* $F(1, 170) = 6.98$, $MSE = 0.49$, $p = .01$, $\eta_p^2 = .04$, *engagement* $F(1, 170) = 39.03$, $MSE = 0.52$, $p < .001$, $\eta_p^2 = .19$ and *difficulty* $F(1, 170) = 38.59$, $MSE = 0.44$, $p < .001$, $\eta_p^2 = .19$). Although younger adults found all conditions equally interesting (all *t*s < 1.44), the older adults found the Complementary condition more interesting than both the Redundant and Audio conditions as indicated by a significant interaction ($F(2, 170) = 5.49$, $MSE = 0.49$, $p = .01$, $\eta_p^2 = .06$), and pairwise comparisons (Complementary vs. Redundant, $t(46) = -2.67$, $p = .01$, $d = 0.78$; Complementary vs. Audio, $t(49) = -4.12$, $p < .001$, $d = 1.23$). With respect to engagement, the presentation condition did not have differential effects on the two age groups, as indicated by a non-significant interaction $F(2, 170) = 2.65$, $MSE = 0.19$, $p = .07$, $\eta_p^2 = .03$. Looking more closely, the younger adults rated the Redundant and Complementary conditions as more engaging than the Audio condition (Redundant vs. Audio, $t(66) = -2.84$, $p = .01$, $d = 0.69$; Complementary vs. Audio, $t(66) = -5.18$, $p < .001$, $d = 1.26$), while the older adults rated the Redundant condition as equally engaging as the Audio condition ($t(49) = -0.05$, $p = .96$), and the Complementary condition more engaging than the Redundant condition ($t(46) = -5.1$, $p < .001$, $d = 1.48$). Additionally, both younger and older adults rated the conditions as being of equal difficulty (all *t*s < 1.44, non-significant interaction $F(2, 170) = 1.41$, $MSE = 0.44$ $p = .06$, $\eta_p^2 = .02$)

3.2.3 Table 2. Mean ratings of perceived presentation material difficulty, engagement and interest for both age groups (± SE).

	Younger			Older		
	Audio	Redundant	Complementary	Audio	Redundant	Complementary
Difficulty	2.71 ± 0.12	2.42 ± 0.11	2.46 ± 0.11	3.11 ± 0.14	3.21 ± 0.10	3.17 ± 0.16
Engagement	1.57 ± 0.12	2.09 ± 0.14	3.38 ± 0.12	2.41 ± 0.13	2.42 ± 0.15	3.38 ± 0.12
Interest	1.71 ± 0.11	2.42 ± 0.12	2.73 ± 0.10	2.78 ± 0.17	3.21 ± 0.12	3.63 ± 0.10

4. Discussion

Two main results emerge from the data. First, the replication of superior comprehension for complementary images observed for younger learners was not seen in the older learners. Instead, older learners performed better with redundant text. Second, there was a lack of metacognitive awareness as indicated by a non-significant relation between subjective and objective measures of comprehension, with both groups rating a non-optimal condition for their age group as more effective in learning. These results highlight the importance of considering age-related differences in learning, and the poor awareness learners have of their respectively effective multimedia presentation design.

In line with previous findings (Fenesi et al., 2014; Fenesi and Kim, 2014), younger adults benefited most from a Complementary presentation, where pictorial and verbal information were simultaneously presented in separate processing streams; according to CLT and CTML, this may have helped younger adults maximize WM resource allocation by promoting visual/pictorial and auditory/verbal subsystems to function in parallel (Mayer, 2001; Sweller, 1999). This presentation is also believed to facilitate the construction of mental representations of information, which helps consolidate new information with pre-existing knowledge. However, presenting redundant on-screen text may have overwhelmed their auditory/verbal processing subsystem and reduced critical WM resources needed to meaningfully understand and integrate incoming information.

In contrast, older adults learned better with redundant text than images. These findings add to the existing research that demonstrates older adults have superior comprehension of information with redundant text compared to audio only (Dingus et al., 1997; Pachman and Ke, 2012). Pairing on-screen text with narration provides external contextual aid and may help reduce reliance on cognitive determinants of ability (i.e., WM), thereby enriching the perceptual detail of the presentation and enhancing older adult learning. Additionally, older adults might have difficulty attending to relevant words in the narration (known as selecting in CTML), so providing on-screen text helps compensate for insufficiently selected auditory-verbal input (Mayer, 2009).

These findings also suggest that older adults may have superior multisensory integration not only during exposure to low-level perceptual stimuli (Diaconescu et al., 2012), but also during exposure to high-level conceptual stimuli such as multimedia instruction; older adults are likely better able to integrate visual-verbal information with auditory-verbal information during multimedia learning, resulting in enhanced learning with redundant verbal information. These results also support an attentional co-activation framework, as older adults were likely less effective at extracting information from a single verbal target (e.g., narration alone), due to age-related reductions in WMC (Bucur et al., 2005). Thus, the presentation of an additional redundant target (i.e., on-screen text) promoted comprehension. Furthermore, given that older adults had significantly more years of education, which is strongly linked to greater verbal ability (Steffener et al., 2014), they may have been more efficient at encoding verbal information without overwhelming WMC, leading to superior performance when exposed to redundant verbal information (Lien et al., 2006).

Reduced performance in the Complementary condition for older adults might reflect their reduced capacity to engage in deep processing (known as integrating in CTML), which is required to effectively integrate words and images (Mayer, 2009). Another explanation could reflect age-related cognitive declines in the ability to coordinate complex information (Van Gerven et al., 2006). The Complementary condition could pose a coordination complexity, since it may have required processing and integrating multiple sources of information (i.e., verbal and pictorial). Therefore, although providing images should help externalize some of the instructional demand (by providing pictorial aid), the requirement to regulate and monitor information between processing steps may have created a learning task too high in complexity. Importantly, our conclusions are based on well-established theoretical frameworks of multimedia design (i.e., CLT and CTML), which are heavily entrenched in an understanding of WM processes and limitations. Also, there is extensive aging research demonstrating a robust pattern of reduced WMC as a function of increasing age (Hedden and Gabrieli, 2004; Paas et al., 2001; Van Gerven et al., 2006). Thus, our findings that older adults learn differently from multimedia instruction due to age-related reductions in WMC are well supported by extensive research in cognitive aging.

With respect to subjective perceptions, younger adults falsely perceived the Redundant condition as equally able to facilitate understanding and as equally engaging compared to their counterparts in the Complementary condition. These results replicate prior findings (Fenesi et al., 2014) and further highlight the inaccurate value young learners place on the use of redundant text. Students may view redundant text as a positive learning tool due to its common use within classrooms (Pina and Savenye, 1992). Instructors often use redundant text to conveniently organize and execute required lesson plans, but may not realize that such presentations do not improve comprehension. As a result of repeated educational exposure, learners may develop a sense of familiarity and comfort with such presentations (Hansen and Wanke, 2009), driving the belief that redundant text promotes learning.

Older adults showed an even greater lack of awareness for multimedia presentations that helped or hindered their learning; they rated the Complementary condition as more interesting, engaging, and better able to facilitate understanding compared to the Redundant condition. Perhaps older learners are less exposed to the text-heavy PowerPoint culture that accompanies many university lectures. They therefore do not have a sense of familiarity and comfort with such presentations, which may reduce any familiarity-driven preference for redundant text. Older adults may also fail to recognize on-screen text as an external contextual aid, even though their cognitive processing mechanisms rely on the additional environmental support to enhance comprehension. Importantly, these findings demonstrate poor metacognitive awareness across the lifespan.

This study reinforces the need for multimedia design research to continue investigating differential advantages of prescribed multimedia design strategies across younger and older adults. Effective multimedia design for older adults is especially important considering they typically have lower technology-related self-efficacy and higher computer anxiety than younger adults (Czaja et al., 2006; Czaja and Sharit, 1998). Well-designed multimedia has the potential to not only promote learning, but also to help older adults become more comfortable with instructional technology. Although there may be many design principles that benefit both age groups, this study demonstrates that effective multimedia design can vary depending on learner age. With an educational culture that is increasingly technology-based, it is important for instructional design research to be inclusive of diverse age groups.

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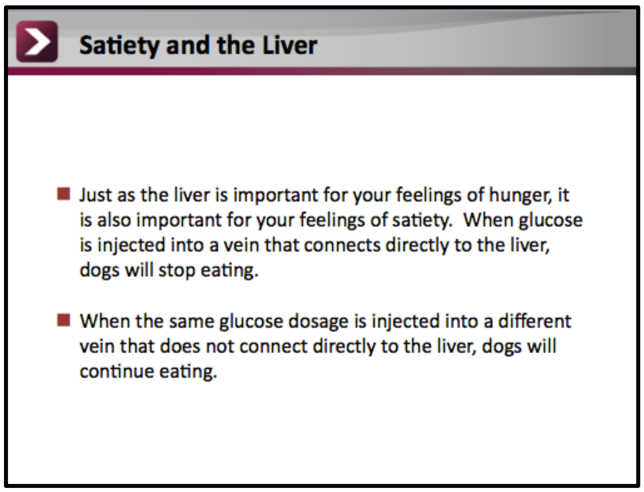
Appendix A

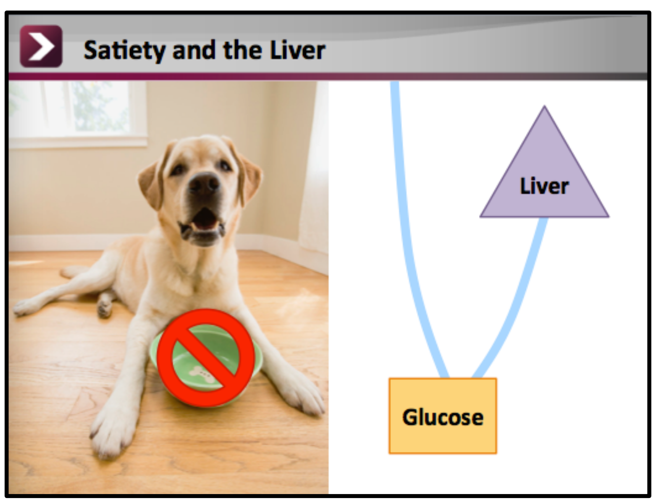
Example slide from Redundant and Complementary presentation conditions

Audio only (*http://bit.ly/1rJJMvG)*

Redundant Presentation (*http://bit.ly/1pjYJN8)*



Complementary Condition (*http://bit.ly/1A0Mewc)*



Appendix B
Comprehension quiz (answers are bolded)

Recognition Comprehension Questions

In 1944, Inglefinger studied cancer patients with their stomachs surgically removed. Describe what his study concluded about feelings of hunger?

a. You need a stomach in order to feel hungry
b. You do not need a stomach in order to feel hungry
c. Individuals without stomachs do not report feelings of hunger
d. You need only part of your stomach to feel hungry

Physiological evidence indicates that part of the _____ controls the cessation of feeding. It appears to do so by ______.

e. hypothalamus…monitoring stomach distension
f. thalamus…monitoring the rate of glucose use
g. hypothalamus…monitoring the rate of glucose use
h. limbic system…monitoring the rate of glucose use

As glucose levels drop:

e. You start feeling full
f. Remaining glucose is quickly converted into glycogen
g. Glycogen is broken down into glucose
h. Fat is stored

Which nutrient signals the need to replenish one's food intake?

e. glucose
f. fructose
g. adipose tissue
h. glycogen

What hormone, produced in the small intestine, is hypothesized to be related to feelings of fullness?

a. PYY
b. CCK
c. Leptin
d. Glucose

According to the lecture, which part of the brain is the most important in the regulation of hunger and satiety?

e. olfactory bulb
f. prefrontal cortex
g. hippocampus

h. hypothalamus

According to the lecture, "our lives seem dominated by the consumption of food". What was the evolutionary rationale behind this statement?

e. In the past, humans had to expend more effort in order to find food than is typical for modern industrial societies today.
f. In the past, humans had to expend minimal effort in order to find than is typical for modern industrial societies today.
g. In the past and in present industrial societies, humans expend a great deal of energy seeking out scarcely available food.
h. In the past and in present industrial societies, humans expend less energy seeking out scarcely available food.

Stimulation of the ventromedial nucleus of the hypothalamus in rats might be expected to cause:

e. an increase in food intake and weight gain
f. a sharp decrease in food intake (or its complete cessation) and weight loss
g. a transition from waking to sleep, if the stimulation is of high frequency
h. permanent wakefulness

Damage to the brain area important in regulating eating behaviour can affect hunger and satiety in two different ways. What are they?

e. overeating only
f. refusing to eat only
g. overeating, or refusing to eat
h. emotional overeating only

What is the role of adipose tissue?

e. stores energy for later use
f. signals the body to replenish its food intake
g. maintains the body at a healthy weight
h. carries glucose to different areas of the body

Problem–Transfer Comprehension Questions

A recent visit to the doctor reveals your large intestine is not secreting the PYY hormone. Choose the most likely consequence you would encounter?

a. You may not be able to feel full
b. You may not be able to feel hungry
c. Your liver will be unable to convert glycogen to glucose
d. You may feel constantly full

Dr. Burn is testing the role of the liver in monitoring glucose levels to control feeding behaviour. Although he injects two similar dogs with a sufficient load of glucose, one stops eating while the other continues to eat. Solve what is most likely to have happened?

a. The dog that continues to eat is extremely hungry and the glucose had no impact
b. The dog that continues to eat is low on glycogen levels
c. The dog that continues to eat had the glucose injected into a vein that <u>does not</u> reach the liver
d. The dog that continues to eat had the glucose injected into a vein that <u>does</u> reach the liver

You have discovered an animal that does not seem to employ glycogen stores (or an equivalent). Applying your knowledge about glycogen stores, you might expect this animal to:

e. Eat frequently and have highly variable glucose levels
f. Eat frequently and have consistently low glucose levels
g. Eat infrequently and have highly variable glucose levels
h. Eat infrequently and have consistently low glucose levels

Dr. Smith discovers one of his patients (Mike) has been gaining weight. Upon closer inspection, Dr. Smith discovers Mike's leptin levels are abnormally low. What role does leptin play in long-term weight regulation?

e. When fat tissue increases, leptin production is halted, and daily food consumption is lowered
f. When an individual feels hungry, leptin levels rise, and signal the body to consume food
g. When an individual feels hungry, leptin levels rise, and signal the body to reduce food consumption
h. When fat tissue increases, leptin levels rise, and is involved in reducing daily food consumption.

Peter's liver is correctly identifying glucose levels in his blood. Frank's liver is incorrectly identifying glucose levels in his blood. What would be the difference between Peter and Frank's liver activity?

e. Peter's but not Frank's liver would be breaking down glycogen into glucose when glucose levels are low
f. Frank's but not Peter's liver would be breaking down glycogen into glucose when glucose levels are low
g. Peter's but not Frank's liver would be converting glucose into glycogen when glycogen levels are low
h. Frank's but not Peter's liver would be converting glucose into adipose tissue when glycogen levels are low

A pharmaceutical company is trying to create a drug that will help obese clients lose weight. Taking advantage of what you have learned thus far, which of the following approaches would be best?

e. **Create a drug that mimics the function of Leptin**
f. Create a drug that stimulates the liver to break down glycogen to glucose
g. Create a drug that blocks the receptors of NPY
h. Create a drug that stimulates the overproduction of adipose tissues

Dr. Smith discovers the presence of a hormone in the small intestine, which he hypothesizes, causes feelings of fullness, and reduces eating. Which following observation (if found) would argue against his hypothesis?

a. **When this hormone was injected into subjects, it resulted in feelings of nausea. Therefore, perhaps nausea, and not a feeling of fullness, reduced food consumption.**
b. When this hormone was injected into subjects, it caused stomach constriction and intense gastrointestinal pain. Therefore, perhaps pain, and not a feeling of fullness, reduced food consumption.
c. When this hormone was injected into subjects, it caused the esophagus to constrict, consequently preventing food consumption. Therefore, perhaps esophagus constriction, and not a feeling of fullness, reduced food consumption
d. When this hormone was injected into subjects, feelings of fatigue resulted. Therefore, perhaps fatigue, and not feelings of fullness, reduced food consumption.

In a transporter malfunction, John's stomach was accidently removed. What effect will it have on his eating habits?

a. John will eat more
b. John will eat slightly less
c. John will now experience highly variable levels of hunger
d. **No effect**

John acquires a head injury during a car accident and over the subsequent weeks he gains over 80 pounds. What may have been the cause for his excessive weight gain?

3 Overproduction of CCK in the brain
4 Lateral hypothalamus damage
5 Ventromedial hypothalamus damage
6 Damage to hypothalamus inhibiting production and release of NPY

Dr. Burn has discovered a new hormone called DBH that he believes directly inhibits the actions of NPY. Which of the following experimental procedures would allow Dr. Burn to test his hypothesis?

e. Inject DBH into the hypothalamus; if eating increases, his hypothesis is correct

f. **Inject DBH into the hypothalamus; if eating decreases, his hypothesis is correct**
g. Inject DBH into the liver; if eating increases, his hypothesis is correct
h. Inject DBH into the liver, if eating decreases, his hypothesis is correct

Chapter 4: Fenesi, B., Kramer, E., & Kim, J. A. (submitted). ***Split-Attention and Coherence Principles in Multimedia Instruction Can Rescue Performance for Learners with Lower Working Memory Capacity*. Paper submitted to Journal of Applied Cognitive Psychology.**

Preface

The third article in this dissertation entitled "Split-Attention and Coherence Principles in Multimedia Instruction Can Rescue Performance for Learners with Lower Working Memory Capacity" was submitted to the Journal of Applied Cognitive Psychology with co-authors Emily Kramer and Dr. Joseph Kim. The motivation behind this study was similar to the second article in that not only is there a lack of empirical investigation into age-dependent multimedia design strategies, but there has also been minimal attention directed towards understanding the role of individual differences in multimedia learning among younger adults.

Recently greater empirical attention been directed towards examining the relation between WMC and multimedia learning, and have demonstrated that learners with lower WMC performed significantly worse on measures of comprehension when design principles were violated, while higher WMC learners were unaffected. However, when multimedia presentations adhered to effective design principles, both high and low WMC learners performed equally well. The current paper extended this important body of literature by investigating the relation between WMC and the multimedia learning design principles of Split-Attention (i.e., presenting narration, images and on-screen text impairs learning compared to just presenting narration and images) in Experiment 1, and Coherence (i.e., presenting irrelevant images impairs learning compared to relevant images) in Experiment 2.

Overall, it seems that high WMC learners were unaffected by poor presentation design, whereas low WMC learners were impaired when required to split their attention between images and text, or when required to learn from irrelevant images. However, adhering to pedagogically-sound design principles mediated individual differences in WMC and allowed both high and low WMC learners to perform equally well. These results add to a large body of literature demonstrating that individual differences in WMC influence performance on higher-order cognitive tasks and extend to multimedia learning

Split-Attention and Coherence Principles in Multimedia Instruction Can Rescue Performance for Learners with Lower Working Memory Capacity

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Abstract

This study examined the relation between WMC and the principles of Split-Attention (Experiment 1) and Coherence (Experiment 2) in multimedia learning. In Experiment 1, WMC predicted applied comprehension in the Split-Attention condition (audio + on-screen text + images), but not in the Complementary condition (audio + images). In Experiment 2, WMC predicted recognition and applied comprehension in the Incongruent condition (audio + irrelevant images), but not in the Congruent condition (audio + relevant images). Whereas high WMC learners were unaffected, low WMC learners were impaired when required to split their attention between images and text, or when required to learn from irrelevant images. Additionally, Experiment 2 demonstrated that perceived understanding was predicted by WMC, with low WMC learners accurately rating their understanding as significantly lower when exposed to irrelevant images. These findings reinforce the importance of pedagogically-sound instructional design, as they may help rescue low WMC learners from reduced comprehension.

Introduction

The widespread use of slideware (e.g., PowerPoint, Keynote) in education underscores the need for pedagogical research on the efficacy of instructional design in multimedia learning. However, successful learning depends not only on effective instructional design, but also on individual learners actively engaging in constructing understanding (Lusk et al., 2008). While an extensive body of research has focused on investigating effective multimedia design principles (Mayer, 2005), minimal attention has been directed towards understanding the role of individual differences in multimedia learning. Our primary goal was to address this important gap in the literature by examining the relation between working memory capacity and the multimedia learning design principles of Split-Attention (Experiment 1) and Coherence (Experiment 2).

Working memory capacity (WMC) is a limited capacity cognitive construct that varies among individuals and plays a critical role in learning. WMC reflects individual differences in the ability to actively maintain task-relevant information and access related information from long-term memory (LTM) in the face of distraction (Cowan, 2005; Engle & Kane, 2004). WMC has been positively associated with higher-order cognitive tasks such as attentional control (Kane, Bleckley, Conway & Engle, 2001), general fluid intelligence (Engle, Tuholski, Laughlin & Conway, 1999) and mathematical performance (Ashcraft & Kirk, 2001). Individuals with high WMC perform better than individuals with low WMC in academic skills dependent on such higher-order cognitive tasks including reading comprehension (Daneman & Carpenter, 1980), language comprehension (Just & Carpenter, 1992), vocabulary learning (Daneman & Green, 1986), reasoning (Buehner, Krumm & Pick, 2005), computer language learning (Shute, 1991), lecture note-taking (Kiewra & Benton, 1988), and mnemonic strategy effectiveness (Gaultney, Kipp & Kirk, 2005). Although there is a strong link between individual differences in WMC and academic performance (Fenesi, Sana, Kim & Shore, 2014), only recently has greater empirical attention been directed towards examining the relationship between WMC and multimedia learning.

Several studies reveal how WMC differences impact the efficacy of design principles, including the Modality (Seufert, Schutze & Brunken, 2008) and Segmentation (Lusk et al., 2008) principles in multimedia learning, and the Seductive Details effect in reading comprehension (Sanchez & Wiley, 2006). Learners with low WMC performed significantly worse on measures of comprehension when design principles were violated, while high WMC learners were unaffected. However, when multimedia presentations adhered to effective design principles, both high and low WMC learners performed equally well. In particular, preventing learners from segmenting (i.e., pausing) their multimedia presentation, or presenting irrelevant images or text, selectively impaired comprehension for low WMC learners. The significance of these findings is not so much reflected in the individual differences in WMC, which has been empirically documented for many years (Daneman & Carpenter, 1980; Just & Carpenter, 1992; Kiewra & Benton, 1988), but rather that individual differences can directly impact the quality of learning from varying multimedia designs. The current paper extends this important body of literature by investigating the relation between WMC and the multimedia learning design principles of Split-Attention (i.e., presenting narration, images and on-screen text impairs learning compared to just presenting narration and images) in Experiment 1, and Coherence (i.e., presenting irrelevant images impairs learning compared to relevant images) in Experiment 2.

Experiment 1

In the first experiment, we examined how WMC differences among learners impacted the effectiveness of the Split-Attention design principle. This principle states that multimedia instruction should be designed so that learners do not have to mentally integrate multiple sources of information leading to split-attention (Mayer & Moreno, 1998; Mayer, 2001). Issues related to split-attention have plagued educational domains such as mathematics and physics (Tarmizi & Sweller, 1988; Ward & Sweller, 1990); students are often required to mentally integrate physically disparate diagrams and written explanations, as well as to encode auditory information (i.e., speech from the instructor). The Split-Attention principle suggests that geometric and mechanical diagrams should be paired with auditory speech to minimize the need for learners to engage in mental integration of visually disparate items; however, in cases where diagrams and written text must be paired together, they should be paired in close physical and temporal proximity. This principle has also been extended to non-mathematical domains such as the design of multimedia presentations, which include two sources of information (e.g., words and images) (Mayer, 2001).

According to the cognitive theory of multimedia learning (CTML) by Mayer (2009), learners process visual and verbal information in two separate, orthogonal channels: the visual/pictorial channel processes visual information (e.g., images, animations), while the auditory/verbal channel processes verbal information (written text, narration). Importantly, both channels are limited in processing capacity; when learners are presented with a split-attention condition, they must simultaneously process two items of verbal information (written text and narration) while engaging in a divided attention task because visual attention is split between images and written text. Removing the written text component allows learners to focus their visual attention on a single source of visual input (i.e., the images), and reduces the processing demands on the auditory/verbal channel (since verbal information is only presented aurally). This allows learners to efficiently recruit separate channels of processing and maximize their comprehension. Accordingly, learners presented with images and narration have been shown to outperform learners presented with a combination of images, narration, and written text (Mayer & Moreno, 1998).

According to CTML, learners must engage in three key processes for successful multimedia learning: (1) selecting relevant information, (2) organizing relevant information, and (3) integrating relevant information (Mayer, 2009). The cognitive processes needed for successful learning may be disrupted with the presentation of multiple sources of verbal information and disparate sources of visual information. Importantly, low WMC learners may have greater impairments than high WMC learners in these essential processing demands, leading to greater difficulty selecting, organizing, and integrating information. Thus, the goal of Experiment 1 was to address whether removing the split-attention component of a presentation (i.e., only presenting images and narration) would help learners with low WMC to more effectively process information and perform equally well as learners with higher WMC. We used a between-groups design and exposed both low and high WMC learners to a multimedia presentation that either paired relevant images with narration (Complementary condition), or to a presentation that paired relevant images with narration and verbatim on-screen text (Split-Attention condition).

Method

Participants

Seventy-four first year undergraduate students from McMaster University, 24 men (M = 19.63; SD = 2.22) and 50 women (M = 19.2; SD = 3.84), participated in the experiment and were randomly assigned to one of two conditions: Complementary (N = 36) or Split-Attention (N = 38). All participants were enrolled in an Introductory Psychology class and received course credit. They were recruited using an online portal designed for psychology research. All participants provided informed consent, and all procedures complied with the tri-council statement on ethics, as assessed by the McMaster Research Ethics Board.

Stimuli and Procedure

Participants individually completed a working memory task, after which they watched either a Complementary or Split-Attention multimedia presentation on a 15-inch Dell laptop with an attached headset (5–8 participants per session on individual computers). Following the presentation, participants completed a comprehension quiz. The experiment took approximately 50-min to complete: 5-min instructions, 20-min working memory task, 8 min presentation, 20-min comprehension quiz, and 5-min debrief.

Working Memory Task (Backwards Digit Span)

This task required participants to temporarily store and manipulate target information (e.g., digits) and recall them in reverse order (Yuan et al., 2006; Hester, Kinsella & Ong, 2004; Oberauer, Süß, Schulze, Wilhelm, & Wittmann, 2000). Participants watched a string of single digit numbers appear sequentially on the computer screen (digits were black and centered on a white background). Each digit was presented for 1 second, followed by 1 second of blank white screen before the next digit appeared. Since digits 0 and 7 were disyllabic (e.g., ze-ro, se-ven) they were omitted to prevent different encoding requirements than monosyllabic words (e.g., one, three). After the presentation of digits for a single trial was completed, a text prompt appeared indicting where participants should write their answer. They then wrote down the list of digits in reverse order on an answer sheet provided.

Before the start of a new trial, a black fixation cross and an auditory beep were presented to draw participants' attention to the screen and alert them to the start of a new trial. Participants began with three practice rounds, the first round with 3 digits, and the second and third rounds with 4 digits. Participants were then asked if they had any questions before proceeding to the full backwards digit span task. Trials began with sets of three digits, with a set of five trials completing a block. At the start of a new block, one more digit would be added to each trial, increasing the difficulty of the task. As the number of digits increased over blocks, participants were given more time after each trial to record their answers. Participants completed 7 blocks, with the final trials consisting of 9-digit long strings.

The backwards digit span was scored in blocks. Blocks were successfully completed if participants correctly answered 3 or more of the 5 trials. If participants answered less than 3 out of 5 in a block, the following block was still scored. If participants successfully completed the following block, then the previously failed block was ignored. WMC was defined as the number of digits recalled in the last full block that participants successfully completed. Participants were assigned WMC scores ranging from 3 (low) to 9 (high).

Multimedia presentation

Each presentation consisted of an 8-min system-paced PowerPoint slide show (total of 48 slides) on the topic of visual memory. Both presentations had identical audio tracks, but differed in the accompanying images. The Complementary presentation augmented the narration with relevant images; the Split-Attention presentation augmented the narration with relevant images and identical on-screen text. Appendix A provides an example of a slide from each presentation style.

Comprehension Quiz

Immediately after viewing the presentation, participants responded to a multiple-choice quiz (see Appendix B for examples of quiz questions). Comprehension performance was determined by participants' mean score on 16 multiple-choice questions (4-option answers). Two different question types were created and guided by Principles from Bloom's Taxonomy (Krathwohl, 2010): eight questions evaluated basic retention (i.e., recognition) of facts, and eight questions evaluated inferential reasoning (i.e., applied). These two question types were used to determine how recognition and applied knowledge were differentially affected by presentation style.

Analyses

Analyses were conducted in SPSS Version 22. First, a 2 (condition: Complementary, Split-Attention) x 2 (question type: recognition, applied) factorial ANOVA was used to assess basic group differences in comprehension performance. Alpha was set to .05 for all main effects and interactions (effect sizes were calculated using partial eta squared, η_p^2). Second, there were two simple linear regressions conducted for each multimedia condition (i.e., Complementary, Split-Attention) to determine if WMC predicted comprehension performance (unstandardized beta coefficients reported). The two linear regressions were conducted to assess whether WMC was a good predictor of recognition comprehension, and applied comprehension as a function of presentation style (i.e., Complementary vs. Split-Attention). These analyses highlight the effects of each unit increase in WMC on comprehension performance and subjective perception ratings.

Results

Table 1 provides descriptive statistics for comprehension performance. Recognition questions produced higher comprehension scores than applied questions, as indicated by a significant main effect of question type $F(1, 144) = 7.157$, $MSE = 0.027$, $p = .008$, $\eta_p^2 = .047$. The Complementary condition also produced higher overall comprehension performance, as indicated by a significant main effect of condition *F*(1,

144) = 17.37, *MSE* = 0.027, $p < .001$, $\eta_p^2 = .108$, and there was a significant interaction between condition and question type $F(1, 144) = 7.751$, *MSE* = 0.027, $p = .006$. , $\eta_p^2 =$ .051.

Table 1. *Mean comprehension performance (recognition, applied) for Complementary and Split-Attention conditions (± SD).*

	Complementary *M (SD)*	**Split-Attention** *M (SD)*
Comprehension (%)		
Recognition	76.74 (16.94)	73.03 (16.83)
Applied	77.01 (16.64)	58.39 (14.44)

Linear Regressions

WMC did not significantly predict recognition or applied performance in the Complementary condition (recognition: β = -.015, $t(34) = -0.945$, $p = .351$; applied: β = -0.15, $t(34) = -0.936$, $p = .356$). WMC also did not significantly predict recognition performance in the Split-Attention condition (β = .005, $t(36) = 0.303$, $p = .764$), but it did significantly predict applied performance (β = .035, $t(36) = 2.834$, $p = .007$). WMC also explained a significant portion of variance in applied performance ($R^2 = .182$, $F(1, 36) = 8.031$, $p = .007$). All regression analyses met assumptions of homoscedasticity, as evaluated using the Breush-Pagan test for heteroscedasticity (all $\chi^2 < 2.008$, $p > .157$).

Discussion

Experiment 1 emphasizes the importance of considering individual differences in WMC when designing instruction, as WMC was a significant predictor of applied comprehension performance when participants learned from a Split-Attention presentation design. This means that learners with lower WMC performed significantly worse than learners with higher WMC on applied comprehension questions when exposed to a multimedia presentation that required them to split their attention between visual images and visual text. However, removing the split-attention component of a presentation (i.e., only presenting images and narration) allowed learners with lower WMC to perform equally well as learners with higher WMC on questions testing applied comprehension. These results highlight the importance of removing split-attention from multimedia presentations to help mediate the effect of individual differences in WMC among learners.

Experiment 2 aimed to expand these findings to investigate the impact of WMC differences on the Coherence Principle (i.e., presenting irrelevant visuals or sounds impairs learning). Our goals also included incorporating a more standardized measure of WMC (Operation Span Task), and determining whether WMC differences influence subjective perception of multimedia quality.

Experiment 2

The use of irrelevant information—whether sounds or visuals—is a common, albeit inadvertent, practice in multimedia instruction. Shallcross and Harrison (2007) conducted a large-scale survey of undergraduate Chemistry lectures from years 1–4 during 2004–2005 and found that students overwhelming reported that multimedia presentations often contained seemingly irrelevant images and diagrams. Despite robust findings that students prefer PowerPoint presentations compared to transparencies and overhead projections during lectures, students often report being distracted by irrelevant information (Bartsch & Cobern, 2003). A desire to include engaging images or sounds, even if they do not they support the content, may come from an assumption that appealing items promote interest and ultimately comprehension. In fact, *Arousal Theory* suggests exactly this; introducing entertaining features will make the learning task more interesting, which increases overall arousal and promotes a greater level of attention so that more material is processed, ultimately enhancing comprehension (Moreno & Mayer, 2002; Renninger, Hidi, & Krapp, 1992). However, extensive research in the domain of multimedia learning suggests the opposite conclusion—introducing irrelevant sounds or images actually distracts learners and impairs comprehension (Mayer, 2009).

There are several theoretical explanations as to why irrelevant images impair learning. The CTML (Mayer, 2005) suggests that presenting irrelevant images forces learners to process extraneous material, consequently overloading WMC and interfering with cognitive processes necessary for meaningful understanding. Another proposition is that irrelevant images prime inappropriate schemas around which learners organize information and later store in LTM (Harp & Mayer, 1998; Lehman, Schraw, McCrudden, & Hartley, 2007). Furthermore, a *controlled attention* framework posits that irrelevant images impair performance only for a select group of learners. Many researchers (e.g., Conway & Engle, 1994; Kane, Bleckley, Conway, & Engle, 2001) argue that controlled attention is a direct reflection of WMC. Evidence for this view comes from several studies using attention paradigms; for instance, in dichotic-listening tasks low WMC participants were more likely than high WMC participants to hear their name in the unattended channel while processing information in the attended channel (Conway, Cowan, & Bunting, 2001), suggesting that low WMC participants were less able to inhibit distractions. Moreover, under increased cognitive load (i.e., performing a secondary task), recall performance for high WMC participants diminished, suggesting that under normal conditions high WMC participants use attentional control to combat interference; in contrast, performance for low WMC participants remained the same, suggesting that they do not normally allocated attention to resist interference.

Based on a controlled attention framework, we predicted that learners with low WMC are more easily distracted because of poor attentional control and selectively impaired by the presentation of irrelevant images. In contrast, high WMC learners are better at controlling attention and inhibiting interference from distraction, and should perform similarly when presented with relevant or irrelevant images. We also predicted that a multimedia presentation containing relevant images would elevate low WMC learners to perform equally well as high WMC learners (as they did when removing split-attention elements from multimedia instruction in Experiment 1). We used a between-groups design and exposed both low and high WMC learners to a multimedia presentation that either paired narration with relevant images (Congruent condition), or to a presentation that paired narration with irrelevant images (Incongruent condition). We also included two subjective measures: perceived interest and perceived understanding of presentation content (Fenesi, Heisz, Savage, Shore, & Kim, 2014; Fenesi & Kim, 2014). These measures were used to explore whether WMC differences influence subjective perception when learning via Congruent vs. Incongruent presentation styles.

Method

Participants

Seventy-one first year undergraduate students from McMaster University, 26 men (*M* age = 18.35, *SD* =0.81) and 45 women (*M* age = 18.46, *SD* = 1.52), participated in the experiment and were randomly assigned to one of two conditions: Congruent (*M* age = 18.41, *SD* = 1.08, *N* = 34), and Incongruent (*M* age = 18.39, *SD* =1.25, *N* = 37). All participants were enrolled in Introductory Psychology and received course credit. They were recruited using an online portal designed for psychology research. All participants provided informed consent, and all procedures complied with the tri-council statement on ethics, as assessed by the McMaster Research Ethics Board.

Stimuli and Procedure

Participants individually completed a computer-based working memory task, after which they watched either a Congruent or Incongruent multimedia presentation on a 15-inch Dell laptop with an attached headset (5–8 participants per session on individual computers). Following the presentation, participants completed a comprehension quiz and responded to the perception measures. The experiment took approximately 60-min to complete: 5-min instructions, 15-min working memory task, 8 min presentation, 20-min comprehension quiz and perception measures, and 5-min debrief.

Working memory task: Automated Operation Span (OSPAN)

Participants completed an automated operation span task (OSPAN; see Unsworth, Heitz, Schrock, & Engle, 2005 for a detailed explanation) via Inquisit by Millisecond software prior to viewing their multimedia presentation. The task was mouse-driven, and the program recorded and calculated all WM data. A mathematical operation was presented on the screen (e.g., 'Does (4/2) + 1 = 6?"), and participants indicated whether the equation was correct or incorrect by clicking on a "true" or "false" box. All responses and response latencies were recorded. Following this answer selection, a letter was presented for 800 msec (e.g., 'F'). After a series of two to six operation-letter pairs, participants were asked to recall the list of two to six letters in the order that they were presented. Each participant was presented with three sets of each length. A response was counted as correct only if the letter was in the correct serial order, and the letter itself was correctly recalled. An 85% criterion for math accuracy was imposed to ensure only data were recorded for those attempting to solve both math operations and remember letters. At the end of the task, the program assigned participants an OSPAN score, which reflected the sum of correctly recalled letters across all sets (completely and in order of presentation). For a more comprehensive overview of the automated OSPAN task, please see Unsworth, Heitz, Schrock, & Engle (2005).

Multimedia presentation

Each presentation consisted of an 8-min system-paced PowerPoint slide show (total of 48 slides) on visual memory. Both presentations had identical audio tracks, but differed in the relevance of accompanying images. The Congruent condition paired relevant images that supported the narration, and the Incongruent condition paired images that did not support the narration. Appendix A provides an example of a slide from each presentation style. In the example slide provided, the visual incongruence is manifested by a mismatch between the item that is shown as *stored* in visual working memory, and the item that is shown as *retrieved* in visual working memory. While many visual components across congruent and incongruent slides are identical (i.e., same man with a thought bubble), the critical visual components (i.e., items being stored and retrieved) were manipulated to either be congruent or incongruent with the narration (i.e., storage of a landscape vs. storage of a dog). A pilot study ensured each slide's accompanying images were operationally relevant vs. irrelevant. For all slides, raters scored the relevance of images to the accompanying narration on a 1–7 scale (1=totally irrelevant, 2=mostly irrelevant, 3=somewhat irrelevant, 4=neutral, 5=somewhat relevant, 6=mostly relevant, 7=totally relevant). The average rating for relevant images was 5.55 (SD = 0.73), and the average rating for irrelevant images was 3.25 (SD = 1.04). Image relevance was statistically different between conditions, as indicated by an independent samples t test, $t(94) = 12.52$, $p < .001$, $d = 2.56$.

Comprehension quiz

Immediately after viewing the presentation, participants responded to a multiple-choice quiz (see Appendix B for examples of quiz questions). Comprehension performance was determined by participants' mean score on 16 multiple-choice questions (4-option answers). Two different question types were created and guided by Principles from Bloom's Taxonomy (Krathwohl, 2010): eight questions evaluated basic retention (i.e., recognition) of facts and eight questions evaluated inferential reasoning (i.e., applied). These two question types were used to determine how recognition and applied knowledge were differentially affected by presentation style.

Perception measures

Subjective perception of presentation content interest and understanding were assessed by participant's response to two statements: (1) I found the material presented in this lecture to be interesting (interest), and (2) I found that the presentation style helped me to understand the lecture material (understanding). Response options were reported on a 7-point scale (1=absolutely disagree, 2=mostly disagree, 3=somewhat disagree, 4=neutral, 5=somewhat agree, 6=mostly agree, 7=absolutely agree). Previous research has strongly encouraged the collection of both perception measures and performance indicators (i.e., comprehension) to better represent multimedia quality (Moullin, 2004).

Analyses

Analyses were conducted in SPSS Version 22. First, a 2 (condition: Congruent, Incongruent) x 2 (question type: recognition, applied) factorial ANOVA was used to assess basic group differences in comprehension performance. Two independent samples *t* tests were also used to assess group differences in perceived interest and perceived understanding ratings. Alpha was set to .05 for all main effects and interactions, and all pairwise comparisons were Bonferroni corrected. Effect sizes were calculated for main effects, interactions and pairwise comparisons (partial eta squared, η_p^2, was used for ANOVA, and cohen's *d* was used for independent *t* tests).

Second, a total of four simple linear regressions were conducted for each multimedia condition (i.e., Congruent, Incongruent) to determine if WMC predicted comprehension performance and perception ratings (unstandardized beta coefficients reported). The predictor variable was WMC, and the dependent variables were recognition scores, applied scores, perceived interest ratings, and perceived understanding ratings. Two linear regressions were conducted to assess whether WMC was a good predictor of recognition comprehension, and applied comprehension as a function of presentation style (i.e., Congruent vs. Incongruent). Additionally, two linear regressions were conducted to assess whether WMC was a good predictor of perceived interest, and perceived understanding as a function of presentation style. These analyses highlight the effects of each unit increase in WMC on comprehension performance and subjective perception ratings.

Results

Table 2 provides descriptive statistics for comprehension performance and perception ratings. Recognition questions produced higher comprehension scores than applied questions, as indicated by a significant main effect of question type $F(1, 138) = 27.486$, $MSE = 0.047$, $p < .001$. , $\eta_p^2 = .166$. However, there was no difference in comprehension scores between the two conditions, as indicated by a non-significant main effect of condition $F(1, 138) = .217$, $MSE = 0.047$, $p = .642$, $\eta_p^2 = .002$, and there was no significant interaction $F(1, 138) = .165$, $MSE = 0.047$, $p = .686$. , $\eta_p^2 = .001$. Perceived interest was also rated equally between conditions ($t(69) = 1.314$, $p = .195$), whereas perceived understanding was rated as greater in the Congruent condition ($t(69) = 2.573$, $p = .013$, $d = 0.608$.

Table 2. *Mean comprehension performance (recognition, applied) and mean perceived interest and understanding ratings for Congruent and Incongruent conditions (± SD).*

	Congruent *M (SD)*	**Incongruent** *M (SD)*
Comprehension (%)		
Recognition	69.12 (20.47)	72.30 (21.48)
Applied	51.47 (20.36)	51.69 (24.15)
Perception (scale 1-7)		
Interest	5.06 (1.28)	4.68 (1.18)
Understanding	4.97 (1.22)	4.11 (1.59)

Linear Regressions

Congruent.

WMC did not significantly predict recognition or applied performance in the Congruent condition (recognition: β = -.003, $t(32) = -1.877$, $p = .07$; applied: β = -4.749E-5, $t(32) = -.005$, $p = .98$). WMC also did not significantly predict ratings of perceived interest or understanding (interest: β = -.008, $t(32) = -.685$, $p = .498$; understanding: β = .014, $t(32) = 1.278$, $p = .211$). All regression analyses met assumptions of homoscedasticity, as evaluated using the Breush-Pagan test for heteroscedasticity (all $\chi^2 < 1.623$, $p > .203$).

Incongruent.

WMC significantly predicted recognition and applied performance in the Incongruent condition (recognition: β = .004, $t(35) = 2.578$, $p = .014$; applied: β = -.004, $t(35) = 2.136$, $p = .04$). WMC also explained a significant portion of variance in recognition and applied performance (recognition: $R^2 = .16$, $F(1, 35) = 6.648$, $p = .014$; applied: $R^2 = .12$, $F(1, 35) = 4.562$, $p = .04$). Additionally, WMC marginally predicted perceived interest ratings (β = .018, $t(35) = 1.833$, $p = .075$), and significantly predicted perceived understanding ratings (β = .027, $t(35) = 2.073$, $p = .046$). WMC explained a moderate portion of variance in perceived interest ratings ($R^2 = .09$, $F(1, 35) = 3.359$, $p = .075$), and a significant portion of variance in perceived understanding ratings ($R^2 = .11$, $F(1, 35) = 4.295$, $p = .046$). All regression analyses met assumptions of homoscedasticity, as evaluated using the Breush-Pagan test for heteroscedasticity (all $\chi^2 < 2.452$, $p > .117$).

Discussion

Experiment 2 further emphasized the importance of considering individual differences in WMC when designing instruction, as WMC was a significant predictor of both recognition and applied comprehension performance when participants learned from an Incongruent presentation design. Importantly, if multimedia design effectiveness were only assessed using comprehension performance, it would appear that image relevance did not impact learning, as there were no differences in comprehension performance between conditions. However, when WMC differences were considered, there was a clear detriment to using irrelevant images, specifically for low WMC learners.

According to the controlled attention framework, learners with low WMC were selectively impaired by irrelevant images because they were unable to effectively engage in attentional control mechanisms to inhibit distraction from irrelevant images, and thus were less efficient at engaging in cognitive processes needed to understand information. High WMC learners however, were better at sustaining attention on relevant task goals (i.e., understanding content) while inhibiting interference from distracting images. Unlike previous research on the Coherence principle, we did not observe group differences in comprehension performance; rather, learning outcomes were only evident when WMC differences were considered. Previous research suggests that even high WMC learners are negatively affected by irrelevant images, as the group mean is significantly lower in Incongruent conditions compared to Congruent conditions (Mayer, 2005; Mayer & Moreno, 2002). We can only speculate as to why we did not observe group differences whereas other studies did, but perhaps part of the answer has to do with differences in presentation duration across studies, with most previous studies using presentation durations of approximately 2mins. Perhaps high WMC learners require longer presentation durations to acclimate to their multimedia environment and apply inhibitory mechanisms to prevent distraction from irrelevant images, and consequently boost the group mean and wash out any condition differences. In contrast, when presentations are relatively shorter in duration, both high and low WMC learners are equally burdened by irrelevant images, thus reducing the group mean and promoting condition differences when compared to congruent presentations. Further research is needed to determine whether presentation duration can be used to explain non-significant differences in our presentation conditions compared to other findings.

Interestingly, when WMC differences were considered, learners accurately judged their understanding, and were aware of how well they understood information when exposed to a presentation containing irrelevant images. The lack of relation between WMC and perceived understanding in the Congruent condition also reflects accurate learner awareness when WMC is considered, as both low and high WMC learners had similar performance outcomes. These findings contrast research on metacognitive ability, which propose that regardless of WMC, learners are poor judges of their understanding (Jacoby et al., 1994; Kornell and Bjork, 2008; Spellman and Bjork, 1992). Perhaps metacognitive research would benefit from considering WMC differences, as these results suggest that there may be greater accuracy in metacognitive awareness as a function of WMC.

General Discussion

The current set of experiments emphasizes the importance of considering individual differences in WMC when designing instruction. In both experiments, learners were exposed to presentations that did or did not follow established design principles for multimedia learning. Learners with low WMC were selectively impaired when exposed to presentations containing disparate sources of visual information (Experiment 1) and irrelevant images (Experiment 2). Removing visually disparate or irrelevant information allowed low WMC learners to perform equally well as high WMC learners. Although recognition performance was not predicted by WMC under conditions of split-attention, we suggest that the presence of redundant on-screen text in the Split-Attention Condition may be conducive to the acquisition of low-level knowledge, which is a pattern we previously found with redundant text (Fenesi & Kim, 2014). Thus, low WMC learners are able to perform equally well as high WMC learners on recognition comprehension questions when exposed to redundant text.

Overall, our results add to a large body of literature demonstrating that individual differences in WMC influence performance on higher-order cognitive tasks and extend to multimedia learning. From a CTML perspective, successful multimedia learning requires selecting, organizing, and integrating relevant information, and our results suggest that these processes may be more easily disrupted in learners with low WMC. In other words, the capacity threshold may be lower for these processes to become dysfunctional in learners with low WMC. As a result, presenting low WMC learners with multiple sources of visual information or irrelevant information may impair one or more of these essential processes. Further research is needed to tease apart the most vulnerable processing stage (i.e., selection, organization, or integration) for learners with varying working memory capacities. From a controlled attention perspective, learners with low WMC were selectively impaired by irrelevant images because they were unable to effectively engage in attentional control mechanisms to inhibit distraction from irrelevant images, and thus were less efficient at engaging in cognitive processes needed to understand content. High WMC learners however, were better at sustaining attention on relevant task goals (i.e., understanding content) while inhibiting interference from distracting images. Although high and low WMC learners in the Incongruent condition may have both recognized that the images did not support the narration, there is still clearly a dichotomy in their ability to inhibit distraction from incongruent images. However, further research is needed to verify whether both low and high WMC learners *recognize* image congruence, and selectively differ in their ability to inhibit distraction from irrelevant images.

Taken together, it is clear that removing split-attention components from presentations and removing irrelevant images selectively improves multimedia learning for low WMC learners. Some learners may be especially responsive to effective instructional manipulations, because such manipulations help compensate for limitations in WMC. For example, using relevant images reduces the amount of WM resources required during the learning process; low WMC learners do not have to allocate resources to inhibit interference from irrelevant images and thus can more effectively engage in cognitive processes needed to understand information. In contrast, high WMC learners do not experience an added benefit from the use of relevant images, because they already capitalize on controlled processes; high WMC learners may also have a higher threshold for disruption to the essential processes of selection, organization, and integration and may be better able to integrate across multiple sources of information during split-attention presentations.

The present findings may be particularly relevant to first-year post-secondary courses, which typically encompass a diverse student body and substantial individual variance in WMC (Orzechowski, 2010). The literature remains much less clear regarding whether deficits in WMC itself can be remediated through interventions such as working memory training. Although some studies show improvements in WMC through training (Jaeggi, Buschkuehl, Jonides, & Perrig, 2008; Kinberg, 2000), others demonstrate only targeted improvements in certain WM tasks, but a lack of transfer to general application and tasks different from training materials (Harrison et al., 2013; Moody, 2009). Therefore, it seems that the most effective and efficient way to promote equal learning outcomes for learners with varying WMCs is to adhere to pedagogically sound principles of multimedia instruction.

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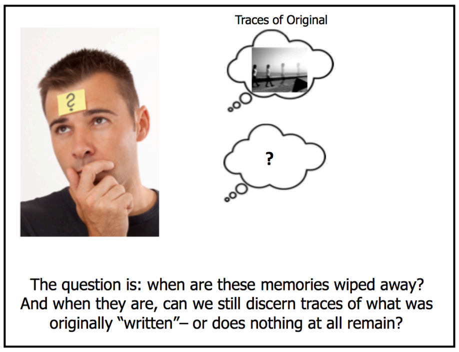
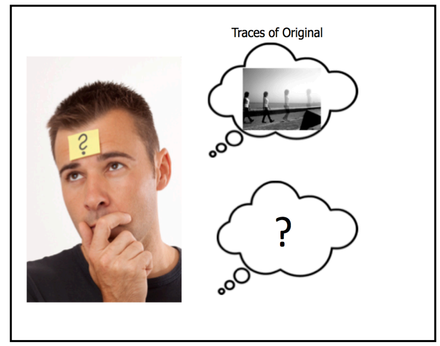
Appendix A

Presentation design examples

Split-Attention

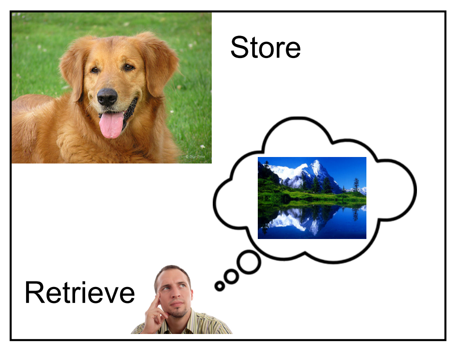


Complementary



Congruent

Incongruent



Audio: Without visual memory, we wouldn't be able to store —and later retrieve— anything we see.

Appendix B

Multiple choice questions examples (*answers in italics*)

Recognition question:

Which of the following best states the findings of the experiment by Zhang and Luck where participants were shown three coloured squares and asked to recall the colour of one particular square?
a) Participants showed either very high or very low accuracy.
b) Participants showed a gradual decrease in accuracy as the latency to recall the colour increased.
c) Participants showed the highest accuracy when the colour of the square was yellow.
d) Participants showed a gradual increase in accuracy as the latency to recall the colour increased.

Applied question:

Samantha possesses an advanced visual working memory. When compared to someone with a poor visual working memory, what task would Samantha perform more efficiently?
a) Drawing a detailed piece of original artwork.
b) Remembering her very first rollercoaster ride as a child.
c) Writing a short paragraph expressing her feelings at the time.
d) Building furniture by following images in the instruction manual.

General Discussion

This thesis has three main contributions: 1) pairing images with narration produces better learning than pairing redundant text with narration for younger adults, with a reverse effect for older adults who learn better from redundant text, 2) learners have difficulty recognizing ineffective presentations even when given direct exposure to both effective and ineffective designs, and 3) WMC is a key predictor of multimedia learning—with pedagogically-sound presentation designs mediating differences in WMC among younger adult learners and homologizing performance.

Generalizability of Multimedia Design Strategies Across all Ages and Cognitive Capacities

Given the complex interactions observed across studies, a broad generalization of effective multimedia design strategies across ages and cognitive capacities is challenging. Although we replicated the negative effect of redundant text on learning compared to complementary images across several studies (Fenesi et al., 2014, Fenesi & Kim, 2014, Fenesi et al., submitted), this finding was specific to younger adults. In Article 2, we found that older adults did not benefit from images, but rather learned better from redundant text (Fenesi et al., submitted). We offered several theoretical accounts to explain why design strategies may be age-dependent (i.e., attentional co-activation, multisensory integration, verbal proficiency, environmental support). The unifying theme across these different theories is that younger and older adult learners have fundamentally different ways of processing information. This difference could reflect normal age-related changes in cognitive function, such that older adults typically have decreased

WMC (Pachman, 2007), which reflects reduced processing resources and slower processing of incoming information. Although one limitation was that we did not have an objective measure of WMC to definitively argue that older adults had lower WMC, which drove age differences in learning outcomes, there is extensive aging research to suggest that WMC decreases as a function of increasing age (Hedden and Gabrieli, 2004; Paas, Camp, & Rikers, 2001; Van Gerven, Paas, & Tabbers, 2006). Regardless, our study (among others: Dingus, Hulse, Mollenhauer, & Fleischman, 1997; Pachman, 2007; Pachman & Ke, 2012) shows that there is clearly a dichotomy in effective multimedia design strategies depending on age. It is important that future research not only examine the cognitive mechanisms driving performance differences between age groups, but also to investigate whether there are universally applicable design principles for a wider age range.

In addition, WMC differences *within* the younger adult population also influences the efficacy of multimedia design strategies. However, adhering to various principles such as segmentation, split-attention and coherence, makes individual variance in WMC among younger adults less salient and allows those with high and low WMC to perform similarly well. In particular, low WMC learners seem to benefit the most when effective design strategies are used, while high WMC learners remain unaffected. A potential reason for this is that low WMC learners are more responsive to effective instructional design because it helps them compensate for their WM limitations; low WMC learners may also be selectively impaired by poor presentation design because it forces them devote vital WM resources to filter out unnecessary information (e.g., irrelevant images, redundant text), leaving less cognitive capacity to engage in meaningful knowledge construction (i.e., schema formation). In contrast, high WMC leaners are already functioning at optimal performance capacity, and may not benefit from effective design strategies; high WMC learners may also be somewhat immune to reduced performance from ineffective design because they are better able to inhibit interference from distracting information, or can devote WM resources to process extraneous information as well as engage in meaningful knowledge construction. Undoubtedly however, even high WMC learners have a threshold whereby their performance would begin to suffer, but this threshold is much higher than for those with low WMC.

More research should be devoted to understanding the role of individual differences in WMC and the impact on other multimedia design strategies (e.g., verbal redundancy, contiguity, modality, etc.), as well as how WMC differences affect other instructional treatments (e.g., distributed practice, interleaving, test-enhanced learning). In a recent review (Sana & Fenesi, revised and resubmitted), we argue that more educational research should adopt an Aptitude by Treatment Interaction (ATI) paradigm, which is an individual-differences framework that aims to determine individual readiness to profit from an instructional treatment. ATI encourages researchers to evaluate learning outcomes depending on the match between a specific cognitive ability (e.g., WMC) and an instructional treatment. Although the general finding is that learning is optimal when an instructional treatment matches the WMC of a student, this creates several challenges from an applied standpoint. How do we balance student-centric learning needs with program consistency? Is it feasible for instruction to cater to individual differences rather than develop one homogenous instructional treatment? Should we cater to the needs of lower WMC students, as higher WMC students often excel regardless of instructional treatments? Should instructors make students aware of this relation between WM and academic achievement? These are all important questions that educational researchers and instructors must consider to promote an optimal learning environment.

Alternative Theoretical Models of WM and their Benefit for Multimedia Instructional Design

Although the theoretical frameworks of CLT and CTML have dominated most of multimedia design research, these theories underestimate the influence of attentional control and LTM representations on successful learning (Fenesi, Sana, Kim, & Shore, 2014). For example, according to CTML the modality principle states that presenting information in separate modalities—visual and verbal—is better than presenting information in the same modality (Mayer, 2009). Essentially, learners are able to use separate visual and auditory WM channels to process information, and avoid overwhelming their visual channel with exclusively on-screen information. However, an *attentional control model* (Engle, 2002; Kane et al., 2001) would suggest that the detriment of multiple sources of visual information could also reflect an inability to effectively allocate attention to both information sources. The requirements of attending to both on-screen text and on-screen images exceed the learners' attentional abilities and hinders comprehension of presented material. This claim is supported by Article 3 (Experiment 1), which found that individuals with lower WMC (i.e., lower attentional control) learned significantly less than their higher WMC counterparts (i.e., higher attentional control) from a Split-Attention multimedia presentation.

Similarly, CTML explains the detriment of verbal redundancy (i.e., identical on-screen text paired with narration is worse than narration only) as a result of the auditory/verbal WM channel becoming overloaded. However, learners typically read words and sentences faster than their aurally presented counterparts. Since learners' eyes are typically a few words ahead of what they are hearing in the auditory stream, proponents of the attentional control model might predict that visual attention may be constantly disrupted and redirected several words back to realign the on-screen and auditory verbal input. We recently conducted an eye-tracking study to better understand how visual attention mechanisms are affected during verbally redundant conditions (Fenesi, Kuperman, & Kim, in prep). In this study, participants read a series of text passages (while their eye movements were tracked) that were either overlaid with no sound (Read-only condition), with verbatim narration (Narration condition), or non-verbal background noise (Noise condition). After each text passage, they answered several comprehension questions. Preliminary results suggest that pairing narration with on-screen text not only produced the worst comprehension performance, but also produced significantly more regressive eye movements and more fixations compared to when text passages were simply read without overlapping narration. These data suggest that the negative effect of verbal redundancy on learning may not be as simple as an overloaded auditory/verbal channel, but may also reflect disrupted visual attention processes and abnormal reading behaviour in the presence of overlapping narration.

In addition to attentional control models of information processing, Cowan's *embedded processes model* has the potential to make important contributions to multimedia research. The embedded processing model emphasizes that WM is a subset of LTM (rather than a dedicated temporary storage system), and that distinct types of stimuli (e.g., verbal, visuospatial) reside within a common storage medium (i.e., LTM) and not in domain-specific maintenance subsystems. Thus, there is just one memory repository with WM comprising the subset of information readily accessible by virtue of its activation: both information within the focus of attention, and information in an activated state outside of attention comprise WM (Cowan, 1995). The embedded processes model would emphasize that certain presentation styles make it more difficult to activate appropriate LTM representations. Importantly, long-term stores must be engaged to establish new information within a related context to achieve a stable mental model of the newly acquired information. Indeed, the embedded processes model more readily integrates the influence of prior knowledge in multimedia learning (Schweppe & Rummer, 2014), and directly stipulates how information is integrated between WM and LTM. For example, the model could explain the modality principle (i.e., superior learning when both visual and verbal subsystems are engaged rather than just one) in terms of modality-specific interference between LTM representations. If multimedia instruction engages the same modality, the prior knowledge representations that need to be activated to integrate with new incoming information might experience interference due to similar activation routes. Clearly, several multimedia principles can also be explained with a heavier emphasis on attentional control limitations and LTM representations rather than capacity limitations of dichotomous verbal and visual WM channels as evident in CTML and CLT models.

Regardless of the potential shortcomings of CTML and CLT in capturing all necessary mechanisms involved in multimedia learning, they are two of the most productive theories of memory and learning. These two models have generated a plethora of tractable research questions linked to empirical methods that can be widely applied. To further boost their theoretical depth and educational applicability, CLT and CTML would benefit from a greater emphasis on attentional control mechanisms and LTM memory representations, and should strongly consider more actively representing the role of individual differences in WMC on multimedia learning.

Strengths, Limitations and Future Directions

An important strength of the studies explored in this thesis was the examination of multimedia design strategies that extended beyond the scope of the well-established design principles put forth by Mayer and colleagues (2002, 2009). Specifically, Fenesi et al. (2014), and Articles 1 and 2 investigated differences in comprehension between presentation designs containing redundant on-screen text versus complementary images. Much of the research on multimedia design has focused on evaluating design principles such as contiguity (Mayer, 2002, 2009; Moreno & Mayer, 1999), segmentation (Lusk et al., 2008; Mayer & Moreno, 2003), signaling (Mayer, 2002; Ozcelik, Arslan-Ari, & Cagiltay, 2010), redundancy (Kalyuga et al., 1999; Mayer 2002, 2009; Moreno & Mayer, 2002), coherence (Moreno & Mayer, 2000; Mayer, 2002, 2009), split-attention (Kalyuga, Chandler, & Sweller, 1999; Mayer & Moreno, 1998; Schmidt-Weigand, Kohnert, &

Glowalla, 2010), pre-training (Mayer, Mathias, & Wetzell, 2002; Moreno & Mayer, 2003), among others—none of which capture a targeted comparison between presentation designs containing redundant text versus images; this comparison has immense practical significance as it captures two of the most commonly used approaches in multimedia design. In fact, in publishing Fenesi et al. (2014), a recurring reviewer criticism was that comparing a redundant presentation to a complementary images presentation did not align with the current state of the multimedia literature. However, we felt it was important to represent this comparison as it reflects real-world approaches to presentation design (i.e., overuse of on-screen text vs. incorporating images to convey information). It also underscored an important lesson: in order to progress and evolve our understanding of memory, learning and effective instruction, we should not feel encumbered by predefined theoretical frameworks to solely define our research questions. We should be encouraged to explore alternative explanations and approaches even if they are unconventional.

This mindset was a catalyst for a recent review paper on reconceptualizing working memory in education research (Fenesi, Sana, Kim, & Shore, 2014). Our goal was to highlight how research in many educational domains such as reading, writing, mathematics, second language learning and even multimedia instruction has been guided by the application of Baddeley's multicomponent model of WM. We argue that an over-reliance on this single perspective has led researchers to overlook the theoretical diversity of contemporary research into WM. We offer two alternative theoretical views (i.e., the attentional control model, and the embedded processes model) that can support a reconceptualization of the contributions of WM to academic learning that may not be afforded by interpretations of the prevailing multicomponent model.

Another important strength of this thesis was the incorporation of an individual differences perspective in WMC across and within age groups. There is a fundamental difference in cognitive ability between younger and older adults that should influence how information is delivered to optimize learning for both age groups. Although some researchers argue that existing design strategies can be used to accommodate the needs of older learners (Van Gerven et al., 2006), as current instructional theories support an efficient use of available cognitive resources, Article 2 suggests otherwise. We demonstrated that while younger adults had superior comprehension when exposed to complementary images, older adults performed better with redundant text. This dichotomy in multimedia learning outcome due to age differences has also been shown in other studies (Dingus, 2010; Pachman & Ke, 2012; Pachman, 2007). These findings suggest that older adults clearly require unique multimedia design tailored to their cognitive abilities for effective learning.

Importantly, Article 3 addresses how the substantial variance in WMC within the younger adult population also directly affects the efficacy of instructional design strategies. By adhering to pedagogically-sound design principles (e.g., split-attention, coherence, segmentation) learners with lower WMC, who often have greater learning challenges, are able to perform equally well as learners with higher WMC (Dehn, 2008). As mentioned previously, in a recent review (Sana & Fenesi, revised and resubmitted), we argue that more educational research should adopt an Aptitude by Treatment

Interaction (ATI) paradigm, which is an individual-differences framework that evaluates learning outcomes depending on the match between cognitive ability and an instructional treatment. Importantly, ATIs assume that individuals with different abilities learn in different ways. The assumption is not that those with reduced ability are simply less capable in that area, but that they are qualitatively and quantitatively different. This disparity may be counteracted if varying methods are used to support their unique learning needs. This intuitively makes sense; when you have several proposed instructional treatments (Dunlosky, Rawson, Marsh, Nathan, & Willinghma, 2013), some must be better for one group of students than another group of students. ATIs then describe the learning outcomes of different groups who receive alternative treatments based on their abilities. Importantly, this thesis contains several studies that acknowledge the importance of individual differences in WMC and its impact on learning outcomes.

An important limitation to consider, not only in the studies described here but also in the field of multimedia research in general, is whether certain design strategies are context-specific. For example, redundant on-screen text in computer-based instruction might only be detrimental for younger adult learners when they are unable to self-pace their learning by pausing the presentation whenever desired. Work by Harskamp et al. (2007) suggests exactly this; when learners are able to self-pace the flow of information with user controls (e.g., pause, play), redundant on-screen text paired with narration promotes equally effective learning compared to images paired with narration. Only when learner-control is removed does redundant on-screen text impair learning compared to images. Similarly, as we demonstrated, redundant text paired with narration might actually promote learning for older adults who benefit from redundant coding across modalities. This reverse redundancy effect was also observed during multimedia learning of English as a foreign language for students where textual information was novel (Toh, Munassar, & Yahaya, 2010). In this study, the goal of the multimedia presentation was to promote learning of English as a foreign language, rather than to promote learning of specific content (e.g., different brain regions). Perhaps redundant on-screen text may be selectively detrimental to younger adult learners when the goal of the instruction is to increase content knowledge. However, when the goal is to promote learning of more content-free knowledge (i.e., language), redundant text may help support learning by fostering germane processes rather than imposing extraneous cognitive load.

In line with this assumption of context-specific multimedia design strategies is research on concrete vs. abstract concepts (Paivio, 1969; Schwanenflugel & Shoben, 1983). Concrete concepts (e.g., heart, house, apple) typically have greater sensory referents than abstract concepts (e.g., victory, humility, deceit). Importantly, the modality of information presentation (i.e., verbal vs. pictorial) during multimedia instruction may interact with the underlying concreteness of the presented content. For example, the majority of the multimedia content in my research along with others (Kalyuga et al., 1999; Leahy, Chandler, & Sweller, 2003; Mayer, Heiser, & Lonn, 2001; Moreno & Mayer, 2002) has primarily involved concrete concepts that are presumed to have strong sensory referents (e.g., lightning cycle, how a brake works, how a pump works, brain and body anatomy, etc.). During these multimedia presentations, a dual-modal instructional design seems to be optimal for learning (i.e., auditory narration and visual images), as the underlying concrete nature of the information matches the presentation design. However, other types of educational content such as historical knowledge or linguistic information likely contain significantly more abstract concepts with less salient sensory referents (e.g., language rules, grammar rules, historical dates, alliances, etc.) and may thus benefit less from a dual-modal presentation design combining auditory narration and visual images. Perhaps redundant verbal coding with auditory narration and on-screen text is better for learning of more abstract concepts. This is an important area of future work, and will help determine the boundary conditions of various multimedia design principles.

Additionally, in real educational contexts, students can revisit course content using notes taken during class or through online resources, which could negate any benefits or costs of design strategies. However, it is important to note that although additional exposure to content may mitigate the effects of instructional design on learning, presentations that are designed to maximize learners' limited attentional capacity are still likely to promote better *immediate* understanding. Initial learning is therefore more efficient, and can free up cognitive resources to learn more complex information and engage in higher-level thinking.

Instructor quality also has a direct impact on student success, and high quality instruction could potentially override ineffective instructional design. In fact, some research suggests that the effect of instructor quality on student learning is greater than student ethnicity or family income, school attended or class size (Centre for Public Education, 2005). Highly engaged and enthusiastic lecturers may capture student attention and motivate learning despite poor presentation design. In contrast, unenthusiastic and disengaged lecturers may inhibit student attention and learning, even if their presentations are designed according to pedagogical principles. An important avenue of future research would be to better understand the boundary conditions of effective multimedia instructional design. For example, asking questions such as: Are certain design strategies more effective for learning science versus history content? Are certain design strategies more effective for shorter versus longer duration presentations (e.g., 30mins vs. 60mins vs. 180mins)? Are certain design strategies more effective for spatial (e.g., anatomy) versus verbal (e.g., linguistics) information? Determining the robustness or specificity of design techniques will allow multimedia researchers to more confidently prescribe instructional strategies for a wider range of educational contexts.

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