HEALTH LITERACY AND OLDER ADULTS’ COMPREHENSION OF MULTIMEDIA HEALTH INFORMATION

BY

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THESIS

Submitted in partial fulfillment of the requirements for the degree of Master of Science in Human Factors in the Graduate College of the University of Illinois at Urbana-Champaign, 2010

Urbana, Illinois

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ABSTRACT

Inadequate health literacy is an important barrier to self-care, having been linked to various poor self-care behaviors and health outcomes. Low levels of health literacy likely compromise self-care by impacting patients’ ability to comprehend health-related texts that could otherwise inform self-care behavior. Chronically ill older adults, who are the individuals who most need self-care information, are also those less likely to have the literacy skills and cognitive resources required to comprehend health texts. A valuable strategy for supporting comprehension is to present materials in a multimedia format, and here we focus on supplementing health texts with picture. While much is known about how younger adults benefit from multimedia formatting, significantly less is known about how older adults’ text comprehension processes are impacted by the presence of pictures, especially with regard to health-related materials. In this study, we studied how hypertensive older adults understood multimedia (text and picture) displays of hypertension-related information, using eye tracking to investigate relationships between reading processes, health literacy/health knowledge, and comprehension. Elders’ eye movements were analyzed as participants read different types of text-picture passages at their own pace. Eye movements were analyzed using a re-reading analysis paradigm, adapted for application to the processing of multimedia. We found evidence that when processing multimedia health information, individuals with varying levels of health literacy and health knowledge appear to implement different reading strategies across two phases of situation model construction. Based upon their health literacy/health knowledge levels, readers used pictures differently and at different points of processing.
ACKNOWLEDGEMENTS

I am happy to take the opportunity to thank the many people without whose help I could never have completed this thesis. First and foremost, I would like to thank Dr. Dan Morrow, my advisor. Without his guidance and help, I absolutely would not have been able to complete this thesis. I cannot imagine having a better advisor, and his enthusiasm and belief in myself, and my work, have acted as my greatest motivation during my time at UIUC. I learned a tremendous amount from him, and I am extremely grateful for having been able to learn from him for the past two years.

I would also like to thank my second reader, Dr. Elizabeth Stine-Morrow, who also provided invaluable input during the development of this project. Her words of encouragement over the course of the last year were not only extremely motivating, but also meant a great deal to me.

Both Katie Kopren and Jessie Chin also helped with a great deal of the study. I would like to thank them both for their assistance, as I would never have been able to complete this project otherwise. Neither Katie nor Jessie ever hesitated to help me with one task or another, despite both being very busy with their own work, and I am grateful for both their help and their friendship.

I would also like to thank Soohyun Chae, Max Barkell, and Jake Bevitt. Their assistance in recruiting participants and data extraction helped me a great deal, and I very much appreciate their time and contributions to the project.

Lastly, I would like to thank my parents, Pat and Nancy D’Andrea. They have always encouraged me do whatever I love to do, and have never hesitated to provide me with the opportunities necessary to do so. If not for their generosity, I never would have been able
to attend Washington University in St. Louis for four years, and would most likely have
never come across the field of human factors. Their belief in me sustained me through
times when I did not believe in myself, both in my schooling and in life. I have no doubt that
were it not for their love and support, I would not be where I am today.
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INTRODUCTION

Overview

Chronic illness is highly prevalent amongst older adults, with more than 80% of Americans ages 65 and older suffering from at least one chronic condition (U.S. Department of Health and Human Services, 2010; Morrow & Wilson, 2010). A high level of self-care is required to manage chronic disease. Hypertension, for instance, is a chronic condition that demands significant levels of self-care in the form of adherence to both medication regimens and lifestyle recommendations (e.g., diet, exercise) (U.S. Department of Health and Human Services, 2003), especially for older adults. For example, while over 60% of older adults suffer from hypertension (AHA, 2007), the majority of those affected do not reach the levels of self-care needed to control their illness (AHA, 2008). Uncontrolled hypertension is a primary risk factor for heart attack and stroke (Chalmers & Chapman, 2001).

An important barrier to self-care is inadequate health literacy, defined as the “...capacity to obtain, process, and understand basic health information and services needed to make appropriate health decisions” (U.S. Department of Health and Human Services, 2010). Low levels of health literacy, more common in older than younger adults (Baker et al., 2000; Rudd et al., 2004), are linked to poor self-care and illness management (DeWalt et al., 2004; Murray et al., 2004; Wolf et al., 2005) as well as health outcomes (DeWalt et al., 2004). It is commonly assumed that low health literacy compromises self-care by influencing patients’ ability to understand and learn health-related materials that could otherwise inform attempts at self-care (DeWalt & Pignone, 2005) (though other factors, such as self-efficacy and community resources, probably contribute to the link as well; Wolf
et al., 2009). Health literacy level is related to general cognitive abilities, such as fluid abilities (e.g., working memory, processing speed) and crystallized abilities (knowledge) (Levinthal et al., 2008; Morrow et al., 2006). This link may explain age-related health literacy differences, as different types of cognitive abilities have varying age-related trajectories. Fluid abilities decline with age, while crystallized abilities remain stable or increase (Baker, 2006; Levinthal et al., 2008; Morrow et al., 2006). Fluid and crystallized abilities are also related to the ability to fully comprehend and learn new information (Beier & Ackerman, 2005). Because low health literacy elders experience normal declines in fluid abilities (Chin et al., 2009; Levinthal et al., 2008), and also have lower knowledge about their disease/health in general (Gazmararian et al., 2003), their ability to learn new health information is likely compromised (Chin et al., 2009; Levinthal et al., 2008). However, high levels of knowledge may offset the impact of fluid abilities and act to support accurate comprehension (Beier and Ackerman, 2005).

The populations who most need self-care information – chronically ill older adults – are also less likely to have the literacy skills and cognitive abilities needed to understand health-related texts. Consequentially, there is a pressing need to design health materials for these populations. A potentially valuable strategy for comprehension support is to present materials in a multimedia format. Both learning and health literacy research point to the benefits of multimedia presentation of health information (learning research example: Mayer, 2005; health literacy research examples: Houts et al., 2006; Nielson-Bohlman et al., 2004). We focus on the use of pictures to reinforce text comprehension, as they appear to be the media most commonly and easily implemented in patient education materials (e.g., medication prescriptions, instructions on how to use medical devices, illness information
packets, etc.). Pictures are assumed to reduce the need for reading (presumably impaired in patients with low literacy), and theoretical rationale for their use comes from theories of multimedia learning (e.g., Mayer, 2001, 2005). Perhaps as a result, it is often assumed that the use of any pictures will bolster elder patients’ comprehension, especially those with varying health-related abilities (Doak et al., 1996). However, very few studies have examined the impact of pictures on older adults’ comprehension, especially with regard to health-related materials among elders with diverse health literacy. Therefore, we investigated health literacy-related differences in processing text/picture passages about self-care topics among older adults with hypertension.

In the following sections I review the literature on health literacy and language comprehension processes. After describing how elders comprehend text, I discuss the processing of multimedia information, focusing on how the addition of pictures affects basic language comprehension processes. Finally, the present study is presented. This study used eye tracking to investigate relationships between health literacy/health knowledge, text-picture processing, and comprehension. The present study extends the literature on the actual processes underlying learning and comprehension, because eye tracking multimedia research has traditionally focused on younger adults (e.g., Rayner et al., 2001), and has seldom addressed health literacy issues. Our study also introduces a new and interesting means of investigating multimedia processing by extending a re-reading paradigm, commonly used in reading studies, to multimedia materials.
Health Literacy and Self-Care

Models of health literacy indicate that health literacy levels are in part dependent upon various individual cognitive capacities. Such models also propose a link between health literacy and health outcomes, a relationship mediated by self-care behaviors that stem from, amongst other factors, patients' ability to comprehend written health information. These various relationships will be discussed in detail in the current section. See Figure 1 for a graphic depiction of the connections between health literacy, self-care behaviors, outcomes, and cognitive abilities.

Figure 1. Example model of Health Literacy (Paasche-Orlow & Wolf, 2007).
Inadequate levels of health literacy are pervasive in the American population, effecting nearly 44 million adults (U.S. Department of Education, 2003). Older adults are more likely than younger adults to have insufficient health literacy (Baker et al., 2000; Rudd et al., 2004), in addition to being most impacted by chronic illness (U.S. Department of Health and Human Services, 2010). Because of the vulnerability of the elder population, the implications of inadequate health literacy are of even greater concern, leading to calls to improve self-care in this population (Nielson-Bohlman et al., 2004).

Lower health literacy has been linked to poorer overall health outcomes. Elders with lower levels of health literacy have higher rates of hospitalization than those with higher health literacy (Baker et al., 1998; DeWalt et al., 2004; Wolf et al., 2005). More alarmingly, lower health literacy levels have been associated with higher mortality rates (Baker et al., 2007). Though the link is not definitive, the relationship between health literacy and outcomes likely reflects inadequate self-care behaviors. For instance, uncontrolled hypertension, resulting from poor self-care, increases the risk of related life-threatening afflictions (e.g., heart attack, stroke) (U.S. Department of Health and Human Services, 2003). Lower levels of health literacy have been found to predict less effective self-care behaviors, especially amongst chronically ill older adults (Baker et al., 2000; DeWalt et al., 2004; Nielsen-Bohlman et al., 2004).

One broad and crucial component of self-care is adherence to various provider-recommended health care practices (e.g., prescribed medications, pre-operative procedures). A variety of evidence suggesting a health literacy-adherence relationship (though there are exceptions; see Powers & Bosworth, 2006) indicates that low health literacy is, indeed, probably a barrier to self-care. Elders with lower levels of health literacy
often less successfully adhere to medications for cardiovascular prescriptions (Gazmararian et al., 2006; Murray et al., 2004) and for other illnesses (Baker, 1996; Kalichman et al., 1999). Lower health literacy elders are less likely to comply with pre-operative procedures (Chew et al., 2004), and are less likely to adhere to procedural instructions regarding inhaler use (DeWalt et al., 2004). Low health literacy is also linked to less use of preventative care (Baker, 1996; DeWalt et al., 2004).

The tie between health literacy and self-care may be partially rooted in the understanding of self-care-related information. Indeed, health literacy itself is typically operationalized as a reading skill, with the most common health literacy measures (i.e., REALM, STOFHLA) requiring individuals to comprehend text. For example, the REALM (Rapid Estimate of Adult Literacy in Medicine; Davis et al., 1993) requires pronunciation of written, health-related words, while the STOFHLA (Short Test of Functional Health Literacy in Adults; Baker et al., 1999) calls for participants to fill in missing words in realistic health passages. Several review studies indicate that low health literacy impedes individuals’ ability to understand information needed for successful self-care (Ad hoc Committee, 1999; Baker, 1996; Nielson-Bohlman et al., 2004). Darnell et al. (1986) found that ability to comprehend prescription instructions predicted adherence to those medications. A study by Metlay et al. (2008) did not directly measure comprehension, but linked the availability of patient-directed health materials (Warfarin medication prescriptions) with reduced incidence of a negative health outcome (bleeding), suggesting a relationship between patients’ use of health materials and the self-care practices that may otherwise have prevented the poor outcome.
If patients’ self-care relies upon their ability to comprehend health-related texts, such documents should be designed to facilitate understanding by those who struggle most with it – older adults with low health literacy and complex self-care needs. Document design in turn requires understanding both the cognitive underpinnings of health literacy and the processes and abilities underlying general language comprehension, especially with respect to aging. In the current section, I will explain why elders with low health literacy have problems understanding health-related self-care texts. To do so, I will address the cognitive processes underlying language comprehension, as well as the cognitive abilities and resources underlying those language comprehension processes. Finally, I will examine how the varying cognitive abilities of older adults, especially those with low health literacy, can affect their ability to comprehend text.

Breaking down comprehension in light of health literacy-related cognitive abilities will help discern concrete reasons elders have problems understanding health texts, as well as identify any cognitive abilities that could be leveraged to promote comprehension. This discussion will also address how health materials should be designed to support the comprehension of elders, especially those with low health literacy. For example, the health literacy research community generally assumes that supplementing patients’ health texts with pictures will promote learning and understanding of the material (e.g., Doak et al., 1998). However, as was mentioned earlier, very little work has examined how pictorial formats impact elders’ text comprehension processes, or whether this strategy is an effective one for elders with low health literacy, the group needing the most comprehension support.
Health Literacy, Comprehension, and Cognitive Abilities

Language comprehension processes

Language comprehension is complex, tapping various cognitive resources and processes to build multiple levels of mental representation of the information conveyed by text (Kintsch, 1998). These representations (surface, textbase, and situation model) differ in the demands they place upon processing. Surface level processing involves, for each word within a text, recognition of the word and interpretation of its meaning. During textbase processing, word meanings are integrated into a propositional textbase, which represents the explicit information conveyed by the text. The situation model\(^1\) results when readers integrate this textbase with their own knowledge in order to represent the situations described the text. Engaging in situation model-level processing involves making inferences about the text’s content, as readers can extrapolate the textual content and relate it to their own lives and knowledge. Readers are especially likely to elaborate their textbase into a situation model when re-reading text, rather than during their initial read-through (Millis et al., 2000).

The levels of representation also differ in the types of performance they support, and can be constructed with different degrees of precision depending upon a reader’s goal when reading a text (Stine-Morrow, 2006). For instance, if a reader needs only to memorize the content of a passage, they can stress the textbase level processing and give very little attention to developing a situation model. On the other hand, a situation model must be created and used when a reader’s intention is to learn the information and use it to accomplish some goal (e.g., perform the described actions, relate a description of a

\(^1\) Situation models are mental models of the situations described by text (Kintsch, 1998). From this point, I will continue using situation model as it is used in comprehension theory. Any discussion of mental models is also referring to situation models.
medication to your own daily schedule, etc.). A study by Diehl (2004) illustrated readers’ differential stress on textbase and situation model representations. Readers asked to evaluate procedural instructions after only reading the text gave textbase-oriented responses (e.g., grammatical issues), while readers asked to read and apply the instructions gave situation model-based responses (e.g., ways sentences should be rearranged to improve applicability of instructions) (Diehl, 2004). By linking readers’ understanding of the text with their own circumstances and knowledge, situation models allow readers to actually apply learned material to actions and behaviors (Mayer, 2001, 2005). In the health domain, consider the example of provider-recommended dietary and exercise practices to reduce blood pressure, given to a patient in text form. Patients must use their understanding of the material’s content (i.e., their textbase representation) to infer potential causes of negative symptoms or illness complications, integrate it with their own knowledge structures (regarding their daily routine, other medications being taken, how certain foods/exercises can effect their health, etc.), and so forth, to effectively adapt their behavior to the recommendations (e.g., develop an effective medication taking plan that fits one’s daily routine). In other words, they must move beyond a textbase representation of the instruction’s literal content and construct a situation model.

Cognitive resources and language comprehension

Comprehension processes (e.g., integrating concepts into propositions; elaborating textbase with knowledge) depend upon fluid cognitive abilities such as working memory and processing speed, which determine how efficiently we process novel information, as well as crystallized abilities such as general knowledge (e.g., current events, vocabulary) and domain-specific knowledge (e.g., health knowledge) (Kintsch, 1998; Stine-Morrow et
al., 2006). For example, limited working memory can especially restrict readers’ ability to create a textbase. When working memory is heavily taxed during textbase construction – for instance, when many propositions must be integrated into a textbase representation – readers’ understanding of the text suffers (Kintsch, 1998).

However, high levels of crystallized abilities (i.e., knowledge) can alleviate the demand placed upon fluid abilities at both textbase and situation model levels of processing, thereby supporting accurate comprehension (Radvansky & Dijkstra, 2007). Readers with more expertise in the domain addressed in a text are more likely to create an accurate textbase representation, and are more likely to move on to create a situation model of the information (Schmalhofer & Glavanov, 1986). With regard to the textbase, readers with more domain knowledge will recognize/understand more words and concepts presented in the text, while readers without such knowledge will need to devote resources to deciphering their meaning. In terms of situation model processing, more knowledgeable individuals may also better allocate and regulate their cognitive resources so that they better integrate and organize the concepts within the text into a situation model (Kintsch, 1998; Mayer, 2005; Schnottz, 2005; Radvansky & Dijkstra, 2007). Applying this elaborative, knowledge-based processing can improve comprehension despite requiring more processing time (Miller, Stine-Morrow et al., 2004) and possibly, at least for younger adults, a second pass of reading the text (Stine-Morrow et al., 2004).

Because comprehension is central to health literacy, theories of comprehension processes and representations help us identify important health literacy abilities (e.g., Baker, 2006). Fluid and crystallized abilities are critical components of health literacy. For example, measures of fluid ability such as speed of processing (Levinthal et al., 2008;
Morrow, Clark et al., 2006) and crystallized ability (health knowledge) (Gazmararian et al., 2003; Williams et al., 1998) are more important than age and education in explaining performance on health literacy measures (e.g., STOFHLA).

Cognitive aging, Health Literacy, and Comprehension

The impact of aging on comprehension (and therefore health literacy) depends on the distinct age-related trajectories of fluid and crystallized cognitive abilities. Fluid abilities tend to decline with age (Baltes et al., 1999). Studies have shown that compared to younger adults, elders are less successful at comprehension processes that are highly dependent upon fluid aspects of cognition (e.g., when text contains many unfamiliar words/concepts, when reading must be done quickly) (Stine-Morrow et al., 2006). For instance, age-related differences in comprehension are more likely when the task of creating the textbase representation taxes working memory, (Johnson, 2003; Radyansky & Dijkstra, 2007).

Similar findings occur for health-related materials, where limited health literacy can affect all levels of language comprehension (surface, textbase, situation model). For instance, elders with lower health literacy can have trouble understanding conceptually dense (i.e., longer) medical documents (Doak et al., 1998), indicating difficulty creating a textbase representation, perhaps because of age-related differences in fluid abilities. Older adults with limited health literacy also have trouble creating situation models from health texts such as medication labels (Wolf et al., 2006). Older adults with lower health literacy may experience difficulty with situation model creation as a result of their health knowledge limitations (Beier & Ackerman, 2005) and age-limited fluid abilities, both of which can impede their ability to integrate health text concepts with existing health knowledge (i.e., create situation model). The significant impact of aging on language comprehension
processes clearly indicates that adding additional material to health-related texts (e.g., pictures) should be done with caution; despite the potential/apparent helpfulness of the added information, whatever its format, it could potentially impair comprehension by increasing processing demands.

In contrast to fluid ability, crystallized abilities (both general and domain-specific knowledge) typically remain stable or increase with age (Baltes et al., 1999). For instance, evidence indicates that older adults know more about a variety of health topics than do younger adults (Beier & Ackerman, 2003). Crystallized abilities may increase with age because of increasing experience related to literacy and health-related activities (e.g., lifelong experience with reading, a job that requires a great deal of domain knowledge, etc.) and education (Beier & Ackerman, 2005; Chin et al., 2009).

Older adults may be able to leverage this knowledge to scaffold comprehension processes. A variety of studies (e.g., Morrow, Soederberg, Ridolfo, Magnor, Fischer, & Stine-Morrow, 2009) provide evidence that this type of scaffolding does indeed occur, showing that elders reading texts relevant to their areas of knowledge attain high levels of comprehension. Observed comprehension benefits may occur because knowledge compensates for age-related declines in fluid ability, either by making comprehension processes more efficient or by supporting effective resource allocation strategies. Older adults’ comprehension appears to benefit from domain knowledge at least as much as does that of younger adults (Morrow, Soederberg et al., 2009). Other work indicates that age-related differences in the ability to learn/comprehend texts are reduced when learners rely upon prior knowledge of the domain referenced in the text (Miller, Stine-Morrow et al., 2004) rather than fluid abilities (Beier & Ackerman, 2005). Finally, we previously
described that domain knowledge benefits resource allocation/regulation (and the subsequent integration, organization of textual concepts), especially at the situation model level. A number of studies indicate such situation model-level processes are resilient to the effects of aging (Radvansky & Dijkstra, 2007). So, elders retain the ability to comprehend text at a level that allows them to transfer comprehension to action, though it is worth mentioning that elders are more likely than younger adults to develop situation models during their first pass of reading a text (rather than during re-reading) (Stine-Morrow et al., 2004).

Despite the marked benefits of knowledge to comprehension, little is known about how health knowledge influences older adults’ understanding of self-care-related information, especially among older adults with low health literacy (Baker et al., 2000). These elders may experience difficulty comprehending health-related information not only because of diminished fluid abilities, but also because they typically know less about their disease (Chin et al., 2009; Gazmararian et al., 2003). The presence of such health knowledge limitations indicates that strategies for helping elders’ comprehension cannot only rely on prior knowledge.

**Multimedia: A Strategy for Supporting Comprehension**

One potentially powerful approach to supporting comprehension among older adults is to present information in a multimedia format. Multimedia is defined as “…the presentation of material using both words and pictures,” the words which can be presented through various mediums (e.g., audio, text) (Mayer, 2001). With regard to information needed for self-care, multimedia formats come in the form of text accompanied by static and/or
animated pictures. As we further discuss multimedia, we are referring to text-static picture formats. The pervasive presence of pictures in various instructional texts (e.g., textbooks) (Gyselinck & Tardieu, 1999), and specifically in existing health-related materials (Houts, 2006; Houts 2007), suggests developers of educational materials assume that multimedia formatting is an effective means of supporting learning and comprehension (Gyselinck & Tardieu, 1999). Pictures are also assumed to especially benefit adults with lower health literacy (Doak et al., 1998).

The benefits of supplementing texts with appropriate pictures have been widely documented for young adults. Several reviews indicate that multimedia presentation improves comprehension compared to text alone, and the presence of pictures can benefit both understanding and memory of texts. With regard to the impact of pictures upon health text comprehension, Mayer (2001, 2005) suggests that meaningful pictures, or ones that semantically overlap with text, can benefit all readers’ comprehension and can sometimes benefit the comprehension of low health literacy patients, although the evidence is somewhat mixed (Houts et al., 2006).

Our earlier discussions indicate distinct age- and health literacy-related differences in the cognition underlying comprehension, some of which (e.g., deficient fluid abilities) could feasibly impede the processing of multimedia just as they do text. Despite such differences, and despite the potential for multimedia to support comprehension, very few studies have directly investigated the impact of pictures on comprehension processes of elders of varying health literacy levels. In order to address whether multimedia formats are an appropriate strategy for improving elders’ comprehension of health information, literature on multimedia processing will be reviewed. I will address the distinct qualities of
pictorial and textual sources of information, followed by a consideration of why/how pictures facilitate text comprehension, linking multimedia processing to our previous discussion of language comprehension processes and cognitive aging. First, though, evidence that pictures do indeed facilitate comprehension is reviewed.

*Pictures and texts: two types of representation*

Texts, a form of descriptive representation, are symbols arbitrarily related to their referents (Schnotz, 2005). Pictures, on the other hand, are depictive in nature. Depictive representations are, in some manner, analogous to their referent. In other words, the structure of pictures, as a form of representation, reflects the nature/content of their referent, and may be more or less complex (e.g., a picture of a heart vs. a diagram of the circulatory system) in doing so (Schnotz, 2005).

While text can communicate abstract concepts much more explicitly than can depictive representations, pictures are informationally complete (Schnotz, 2005). In other words, a single picture (e.g., a diagram of a heart) can visually display information that text could only provide by describing a series of discrete concepts (e.g., the different components of the heart, spatial relationships between those components, direction of blood flowing through the heart, etc.).

*Multimedia and comprehension processes*

As was mentioned previously, the benefits of multimedia formatting to comprehension have been widely documented. Reviews by Mayer (2001, 2005), Gyselinck & Tardieu (1999), and Schnotz (2005) suggest that supplementing text with appropriate pictures can improve readers’ understanding of text, as compared to when readers are given text alone. Specific to health-related information, Morrow et al. (1998) found the presence of pictures
(i.e., timelines depicting when to take medications, dose sizes) to benefit both older and younger adults’ comprehension of medication information (other examples can be found in Houts et al., 2006). To better understand how multimedia formatting can benefit text comprehension, we next focus on the number of ways that texts and pictures can relate to/interact with each other in a multimedia context. First, the various possible relationships between text and picture are:

- Pictures can complement text. They can illustrate hard-to-understand and/or abstract textual concepts (Gyselinck & Tardieu, 1999). They can also provide novel information that is related to the text’s content but distinct from what is explicitly discussed in text.
- Pictures can be entirely redundant with certain aspects of the text, depicting important textual content (Gyselinck & Tardieu, 1999). In doing so, they can reinforce specific aspects of text by causing readers to process those points more than once.
- Pictures can be entirely unrelated to the text.

Next, the ways in which pictures can impact text processing, and how these interactions may benefit comprehension are:

- Regardless of whether pictures are complementary, redundant, or entirely unrelated to text, they can act to motivate or catch the interest of readers, which could induce readers to work harder at understanding text and improve
comprehension as a result (Glenberg & Langston, 1992; Houts et al., 2006). The assumption that motivation will benefit comprehension may be the reason pictures are so heavily used in educational contexts. However, there is little-to-no evidence that pictures unrelated to text actually improve comprehension (Gyselinck & Tardieu, 1999; Mayer, 2005). On the contrary, if unrelated to text, pictures can draw critical processing away from reading text and thus impair comprehension (Mayer & Moreno, 2003; Schnotz, 2005).

- In the case that a picture is entirely redundant with certain components of text (concepts mentioned in the text), it can reinforce those specific components. Readers who read the text and examine the picture will process the same information more than once, using two different types of information (visual pictures and verbal text). Paivio’s Dual Coding Hypothesis suggests that in this manner, pictures can benefit memory, but not comprehension, of the redundant points (Gyselinck & Tardieu, 1999).

- Supplementing text with meaningful, appropriate pictures (those that are complementary to text) impacts language comprehension processes in a manner that facilitates comprehension (Gyselinck & Tardieu, 1999; Mayer, 2001, 2005; Schnotz, 2005). Multimedia perspectives argue that comprehension is facilitated because pairing appropriate pictures with text can facilitate situation model construction (Glenberg & Langston, 1992; Gyselinck & Tardieu, 1999; Mayer, 2005; Schnotz, 2005). However, multimedia formatting can only benefit situation model construction if there is overlap in semantic content between pictures and text (Mayer, 2001).
The last point – that meaningful (complementary) pictures impact language comprehension processes/situation model construction in a positive manner – is the most well accepted rationale for why pictures facilitate comprehension (Mayer, 2005). We thus shift our focus to how pictures impact readers’ ability to construct mental representations of information. An important note is that the above categories of picture-text relationships overlook picture type, as pictures can be more or less complex (see Figures 2a, 2b for examples) and can have varying degrees of semantic overlap with text. However, pictures’ potential impact on situation models should not be gauged simply by their visual complexity. So long as they are meaningful with regard to the text, their complexity level should not restrict their impact on situation model processing.

**Figure 2.** Examples of meaningful pictures with varying levels of complexity. On the left, a complex diagrammatic picture that makes use of color, arrows, and text integrated with the diagram, to illustrate the point of the caption (taken from Ainsworth & Loizou, 2003 – some text not depicted). On the right, a simpler, non-diagrammatic depiction that uses only a few lines to illustrate the point of the caption (taken from Mayer, 2001).
There are two basic ways that pictures can help readers build situation models:

1) First, pictures can explicitly link textual concepts, thereby easing the need for various language comprehension processes such as integrating concepts mentioned in the text, which makes it easier for readers to build situation models.

Presenting pictures alongside text can provide readers with valuable information that is not immediately apparent in text alone, and can consequently impact comprehension (Mayer, 2005). As was explained previously, a single picture can depict information that text can express only by describing multiple discrete concepts. As a result, pictures are able to concisely, efficiently make explicit the relationships between concepts discussed in a text (Glenberg & Langston, 1992; Larkin & Simon, 1987; Schnotz, 2005), while text demands much more active cognitive processing in order for readers to reach the same conclusions. Readers must explicitly process each component of a text and actually construct their own understanding of the relationships between textual concepts, as opposed to relying upon the perception of visual elements that depict those same relationships (Larkin & Simon, 1987). Ainsworth and Loizou (2003) explain that pictures facilitate understanding in part because they promote cognitive offloading, similar in nature to what Larkin & Simon call computational efficiency (1987), or a reduction in the memory load and overall cognitive effort needed to understand information. And because pictures can depict the relationships that are not immediately observable/explicitly described within text, they are more useful for drawing inferences about the overall meaning of the represented information (Larkin & Simon, 1987).
Because pictures and text can provide such different, complementary information, pairing the two can ease situation model construction as compared to when readers are given text alone. By explicitly depicting textual relationships that would otherwise have to be inferred using cognitive abilities (e.g., working memory) and/or knowledge (see previous discussion on language comprehension processes), multimedia formatting provides readers a not-exclusively-verbal route to situation model construction (Gyselink & Tardieu, 1999; Schnitz, 2005). Pictures’ ability to ease situation model construction in this manner is key motivator in including pictures in health texts as a means of helping educate lower health literacy patients.

With text-only information, readers, process the text at different levels in order to ultimately develop a situation model. Each level of understanding, from textbase through situation model level, is dependent upon readers’ ability to process relatively disconnected, abstract textual concepts. To develop a situation model of multimedia, readers must work to comprehend both the text and the picture and at some point combine the information into a single mental model of understanding, which can then be integrated with knowledge to result in a situation model-level representation (Mayer, 2005; Schnitz, 2005). Though multimedia comprehension processes are constrained by verbal and nonverbal abilities (working memory), just as are text comprehension processes, readers can use the beneficial aspects of pictures to alleviate some of the aforementioned steps involved with processing text alone (Mayer & Moreno, 2003; Schnitz, 2005). Morrow et al. (2006) provided evidence of such benefits, finding that readers’ comprehension of a health-related text was better when the text was supplemented with pictures that integrated various textual components than when the text was presented alone. Readers who are able to build
“meaningful connections” between text and picture (i.e., understand how different aspects of the picture and text relate to each other) and devote processing to integrating the two types of information develop a deeper understanding of the information than would have resulted from text alone (Mayer, 2005).

2) Secondly, pictures can facilitate situation model construction for a reason entirely independent of the interaction between text and pictures during language comprehension processes. Mental models (e.g., situation models) are viewed as closely related to mental imagery; for instance, some researchers characterize them as visual image-like representations of the situations discussed within text. As was addressed earlier, pictures are analogous to their referent (e.g., the ‘situations’ discussed within text), while verbal representations are arbitrarily related to theirs. Consequentially, situation models and pictures are much more structurally similar/compatible than are strictly-verbal texts. By clearly depicting the components and relations that must be a part of a mental model, pictures can act as an example of an accurate mental model. Readers could use the picture to scaffold their understanding of text, essentially building their situation model off of the existing picture (Gyselink & Tardieu, 1999). In this manner, presenting pictures alongside text can facilitate situation model construction (Glenberg & Langston, 1992; Gyselinck & Tardieu, 1999).

These two possibilities are not incompatible, and it is beyond the scope of this project to delve into which viewpoint is most appropriate. However, the overriding idea behind both frameworks is that pictures provide a concrete visual depiction of texts’ concepts and the
relations between concepts, both of which are crucial components of situation models. As a result, pictures are able to act as a support tool for text comprehension, capable of relieving readers of some of the language processing they would need to do if text was presented alone. With text, readers must rely upon their knowledge and fluid cognitive abilities, especially working memory, to progress through language comprehension processes and construct a situation model. When the same text is supplemented with a meaningful picture, readers can place less demand on working memory and existing knowledge when recognizing words, integrating textual concepts, and making inferences on the overall meaning of the text.

*Picture-text integration*

Multimedia learning theories offer varying opinions on when pictures and texts are integrated to construct a situation model during multimedia processing. Mayer (2001) believes that readers construct separate verbal and pictorial mental models, later integrating the two to form their overall situation model. On the other hand, Schnotz (2005) states that readers construct only one model, integrating information from picture and text into a single representation from the beginning of reading. Despite their differences, both perspectives emphasize the role of working memory as a constraint on integration (Mayer, 2001; Schnotz, 2005).

Eye tracking is a direct means of investigating how readers actually process multimedia documents, though few eye tracking studies have focused on examining the process of picture-text integration. These studies typically concentrate upon reading behaviors of younger individuals, and integration is measured by the amount/frequency of looks made between pictures and semantically related components of text during reading.
Hegarty and Just (1993) studied readers’ eye movements as they processed texts and diagrams, finding that readers incrementally constructed mental models by integrating components of textual and pictorial information while reading, rather than treating the pictures/text as entirely separate information sources. The researchers also differentiated between different types and purposes of looks to pictures. They theorized that readers used more *local* looks, from specific phrases/sentences to the corresponding components of pictures, to construct representations of small portions of text. Readers then used more *global* looks to consolidate the smaller-scale representations into a situation model, and confirm the developed model (Hegarty & Just, 1993).

Holsanova et al. (2008) found that readers’ integration-related processing is heavily influenced by the organization of pictures and text within a multimedia document. When reading a document where pictures and text were far apart, individuals barely integrated the pictures and text, essentially treating them as entirely unrelated sources of information despite the pictures’ potential value. When the pictures and text were close together, readers looked a great deal between pictures and text, integrating the semantically related information between the two sources and processing the material more deeply (Holsanova et al., 2008; also see Rinck, 2008).

The eye movement literature suggests that although readers often strive to take advantage of pictorial information when reading text, their success in doing so depends on how the multimedia document is organized and presented. If integration processes are modulated depending upon the material being read, they are likely also subject to the characteristics and abilities of the readers themselves (e.g., age, cognitive resources/abilities).
Cognitive aging, health literacy, multimedia, and comprehension

The cognitive abilities needed to comprehend multimedia information are essentially those needed for text comprehension, and are also components of health literacy. The demand placed upon crystallized abilities remains essentially the same regardless of material type, as situation model development is characterized by integrating novel information with knowledge. However, because pictures can make explicit some textual relationships that would otherwise have to be inferred using knowledge, supplementing texts with pictures can especially facilitate situation model construction for learners with low knowledge (Mayer, 2001; Gyselinck & Tardieu, 1999; Schnottz, 2005).

Although pictures help relieve stress on fluid abilities during language comprehension processes (e.g., recognition and integration of concepts within text), these abilities (especially working memory) are needed in order to process multimedia information (Mayer, 2005; Schnottz, 2005). Readers must both process text and integrate it with their understanding of pictures in order to understand multimedia, a more complex practice than processing text alone. As a result, fluid abilities may be more stressed during multimedia comprehension than during text alone.

Because of the relationship between multimedia, fluid abilities, and comprehension, cognitive aging will play a role in how multimedia information is processed and understood. On one hand, multimedia formatting may be helpful to elders, especially those with low health literacy who typically have low working memory and health knowledge, both needed to build representations of language. Indeed, some evidence indicates that patients with low general literacy sometimes benefit when given health texts supplemented with appropriate pictures (Houts et al., 2006). But, elders could be less likely
than younger adults to benefit from the presence of pictures. Just as comprehension of overly complex multimedia is made difficult when fluid abilities are strained, elders’ age-related declines in fluid ability (and lower health literacy individuals’ often-low health knowledge) could negatively impact their ability to integrate information from text and pictorial formats (Liu et al., 2009; Mayer & Moreno, 2003), potentially negating the potential benefits of pictures. For instance, Hegarty and Just (1993) found that readers’ integration strategy depends upon their level of domain expertise and ability, with less knowledgeable participants looking more frequently between picture and text during reading. Similarly, Liu et al. (2009) found that compared to younger adults, elders devoted more time and fixations to pictures but had poorer comprehension of the illustrations, suggesting that older adults (and possibly individuals with lower abilities/knowledge) experience difficulty integrating pictures and text,

Multimedia materials that overly stress fluid abilities can negate the comprehension benefits provided by the multimedia formatting (Mayer & Moreno, 2003). Such stress can occur in various ways; for instance, the presence of too many potentially-useful pictures alongside a text may make it extremely difficult for a reader to hold content from each information source (text, pictures) in working memory long enough for him to integrate the information (e.g., Holsanova, 2008). Multimedia designs such as this one can easily overload readers’ cognitive capacity, demanding more essential processing (i.e., comprehension processes – construction of surface/textbase/situation model representations – needed to understand the material) than readers are able to make available (Mayer, 2001; Mayer & Moreno, 2003). Pictures can also overload cognition by promoting non-essential, incidental processing, which is not needed to understand the
material but is primed by poorly designed materials (e.g., including decorative, irrelevant pictures alongside text). Additional, incidental processing can pull resources from essential processing as well as overload cognitive capacity, both of which can be detrimental to comprehension (Mayer & Moreno, 2003). Lastly, if multimedia is designed poorly, pictures could act to distract older adult readers from processing critical text components. Older adults are especially susceptible to distraction during reading, having been shown to experience problems inhibiting extraneous pictures when reading (Griffin & Wright, 2009).

To sum up, multimedia comprehension processes can place heavy demands on fluid abilities, which may disadvantage older adults due to age-related declines in fluid ability. If pictures do reduce working memory demands during situation model construction, they should benefit elders’ comprehension. But elders, especially those with low health literacy, have limited fluid abilities to begin with, and are likely especially vulnerable to poor multimedia design. So, if readers must spend working memory to integrate pictures and text, or if elders are unable to use pictures while also sufficiently processing text, we may see no age-related benefits (and possibly declines) in comprehension. However, we know little about how pictures impact the processing of older adults, especially with regard to elders with varying health literacy (and their corresponding differences in the fluid, crystallized abilities that are critical to comprehension). A better understanding of how these individuals actually use pictures during comprehension, we should lead to recommendations for designing multimedia health documents, especially for patients with low health literacy.

**Current Study**
Summary of literature

Older adults, especially those with low health literacy, may experience self-care difficulties that stem in part from problems comprehending self-care information. The processes underlying language comprehension are dependent upon both fluid (e.g., working memory) and crystallized abilities (knowledge). However, due to the age-related decline of fluid abilities and the prevalence of low health knowledge amongst the older adults with low health literacy, many elders have difficulty understanding health-related texts well enough to translate their comprehension to action (e.g., proper self-care behaviors). These issues signal the need for a comprehension support strategy that reduces demands on fluid ability and supports knowledge.

One strategy is to supplement health-related texts with appropriate, meaningful graphics (e.g., pictures, diagrams). Support for this strategy comes from a large literature with young adults showing pictures can improve text comprehension under certain conditions. However, the cognitive processing underlying multimedia comprehension depends upon fluid and crystallized resources. Therefore, it is unclear whether multimedia will benefit older as well as younger adult comprehension. Adding graphics can reduce age differences if the pictures help readers compensate for low abilities and knowledge. However, pictures can increase age differences if older adults do not have the cognitive resources needed to process a multimedia display (e.g., more working memory is needed to integrate text and pictures) (Morrow & Rogers, 2008).

Addressing gaps in the literature

Very few studies have directly investigated the impact of pictures on elders’ comprehension of text. As a result, little is known about how aging, through its influence on
cognitive resources, affects multimedia comprehension. Even less is known about the similar impact of health literacy on older adults’ comprehension, even though health literacy differences in understanding self-care information are often presumed to contribute to poor health outcomes. Although eye tracking has been used to study the processing (e.g., global fixation patterns on pictures vs. reading text, integration of pictures and text) and underlying comprehension of various multimedia documents, the focus of such research has almost exclusively fallen upon younger adults. In using an eye tracking methodology to study elders’ reading of health-related picture-text passages, we hope to reveal how elders use pictures when building an understanding of text, especially with respect to the impact of varying health literacy and cognitive resource levels.

Although most previous work has examined readers’ overall looking at text and pictures, a point of interest is how readers integrate information from text and pictures to form a situation model, which reflects a learner’s deep, meaningful understanding of a topic. Situation model-level understanding is reflected by readers’ ability to translate their understanding into behavior, in familiar and novel situations (Mayer, 2005). So, readers’ development of situation models determines how well they understand the implications of health information for their own self-care. The literature on picture-text integration focuses on more global factors, such as the overall numbers of saccades made between text and pictures. While these overall looking patterns are valuable and we address them in our work, we will attempt to further analyze the processes underlying the benefit of pictures to comprehension. If we can better understand why elders with low health literacy have trouble processing multimedia documents, we will be more able to provide insight on improving the design of these documents.
This work further contributes to the literature by utilizing a new, re-reading based paradigm to study eye movements involved with multimedia comprehension. Work on language comprehension processing suggests that when reading text, readers typically elaborate their textbase representation into a situation model when re-reading (after having read through the text once) (Millis et al., 2000), though older readers emphasize the situation model to a greater extent than younger adults during the initial read (Stine-Morrow et al., 2004). The re-reading paradigm has not been applied to multimedia materials before, but by allowing our participants to engage in their natural reading process we can link readers’ eye movements to their stage of comprehension construction. Because multimedia research typically finds that readers spend more of their total multimedia processing time on text (e.g., Hegarty & Just, 1993, Rayner et al., 2001), phase-based processing multimedia is done with regard to the reading of text (i.e., initial read vs. re-reading) rather than looking at pictures (i.e., initial look at picture vs. re-looking). We examine reading and re-reading processes (as well as more global processes) with special regard to readers’ health literacy and health knowledge. According to language comprehension theories, health knowledge will play an important role in comprehension of health texts. By studying eye movements in relation to reading phases (i.e., reading vs. re-reading), we can study how readers utilize pictures during different stages of processing health-related text, and how such processing relates to their cognitive resources and resulting comprehension.

Current Study and Predictions

In the present study, eye tracking was used to explore how older adults with hypertension understand realistic, health-related multimedia documents, as well as whether their
reading processes are related to health literacy, health knowledge, and comprehension. Elders’ eye movements were tracked as they read three different types of text-picture passages at their own pace, answering comprehension questions following each passage. The three passage types were related to hypertension, stretching exercises, and medication-taking. Multiple types of passages relevant to hypertension were explored so as to broadly sample existing documents related to self-care and different types of relationships between text and picture.

Hypertension-specific passages were pulled from hypertension education/self-care resources for patients. Exercise-related passages were selected because exercise is a critical component of successful hypertension self-care, and because the semantic overlap between exercise/stretching texts and pictures is greater than is the overlap with our hypertension texts and pictures. Additionally, stretching pictures are more diagrammatic in nature than are the pictures most hypertension education documents. Medication-taking pictures and texts were pulled from a study by Morrow et al. (1998). The pictures in these passages were timelines that explicitly, succinctly convey dose/time information, compared to textual descriptions of the same information. Morrow et al. (1998) found that the presence of the timeline picture improved comprehension and memory of medication information equally for both older and younger adults. Because they clearly benefitted comprehension, and because medication adherence is a critical self-care activity for hypertensive patients, we included these medication-taking passages in our study.

The three passage types were investigated in three sub-experiments involving the same participants. Eye movements, comprehension question accuracy, health literacy, and various cognitive resources were measured to address general predictions across the three
experiments, as well as predictions specific to each experiment. Our general predictions are described below, while the material-specific predictions are described in following chapters. Below each prediction, I note the data that, if found, would support the prediction.

1) My primary predictions address specific abilities and comprehension of text-picture passages:

1a) Participants with higher health literacy will better comprehend health-related multimedia passages.

- *Evidence*: Positive correlation between health literacy score and accuracy on passage comprehension questions (*accuracy*).

If health literacy is a multifaceted construct such that people with higher health literacy also have higher fluid abilities (Levinthal, et al., 2008; Morrow et al., 2006) and crystallized abilities (Gazmararian et al., 2003), then the following predictions apply:

1b) Participants with higher levels of hypertension knowledge and general knowledge will better comprehend hypertension-related multimedia passages.

- *Evidence*: Positive correlations between hypertension and general knowledge scores and accuracy.
1c) Participants with higher levels of fluid ability (i.e., working memory, processing speed) will better comprehend hypertension-related multimedia passages.

- **Evidence:** Positive correlations between fluid ability measure scores and accuracy.

2) We also make predictions regarding how higher ability participants utilize pictures and text in order to achieve their more accurate comprehension. Our predictions focus on the role of health-specific knowledge (both in the form of hypertension knowledge and, more generally, health literacy) during reading and re-reading processing phases. We chose hypertension knowledge, rather than fluid ability, as a key predictor of comprehension because high knowledge can support accurate comprehension by offsetting the impact of fluid abilities. The possible moderating effect of knowledge indicates that we should explore whether multimedia supports comprehension for elders who lack prior knowledge.

2a) Compared to lower ability participants, those with more health literacy and health knowledge will spend more time reading the text and less time on pictures during the first read of a text, as they build an initial representation of the information. They will also look less often to pictures during the first read.

This prediction is based on the idea that while pictures facilitate the identification of concepts and relationships amongst concepts within text, individuals with higher levels of domain knowledge can use their knowledge to infer textual concepts/relationships on their own. Because knowledge supports comprehension, more knowledgeable individuals are
less likely to benefit from pictorial support simply because they do not need to use it (Morrow & Rogers, 2008). So, higher health literacy/knowledge individuals can rely less on pictures compared to lower ability individuals (Mayer, 2001; Hegarty & Just, 1993; Schnottz, 2005).

- **Evidence:** i) Positive correlations between health literacy/health knowledge and the proportion of time during the first pass of reading that is spent on text; ii) Negative correlations between health literacy/health knowledge and the number of looks to pictures (integrative saccades) during the first pass of reading.

2b) Participants with varying levels of knowledge take advantage of pictures differentially during re-reading. Those with more health literacy and health knowledge will look more at pictures after first reading. So, rather than using pictures to help build an initial representation of the material during their first read, these participants will use the pictures more to ‘wrap up’ their initial representation of the information and consolidate/confirm a situation model. Lower knowledge participants may rely more on pictures than their higher knowledge counterparts through the entire trial of reading a passage (rather than shifting their re-reading focus to text).

These predictions are rooted in previous findings that high knowledge/ability individuals looked at pictures less frequently than did low ability individuals when reading through the text initially, but were just as likely to look to them towards the end of their reading session (Hegarty & Just, 1993). The shift in
higher ability individuals’ looking at picture may reflect pictures’ ability to especially support situation model construction (Glenberg & Langston, 1992), as well as the fact that readers tend to elaborate text into situation model when re-reading (Millis et al., 2000).

- **Evidence:** i) Negative correlations between health literacy/health knowledge and the proportion of time after the first pass of reading that is spent on text; ii) Positive correlations between health literacy/health knowledge and the number of looks to pictures after the first pass of reading.
METHODS

The method was the same for all three subexperiments, aside from the types of text-picture passages used. While participants performed all three subexperiments, the subset of participants who contributed valid eye-tracking data to the analyses (e.g., eye movements that were successfully tracked) varied for each subexperiment. Details of the participants included in data analysis will be discussed in the appropriate subexperiment section; information about the complete sample and general characteristics of the text-picture passages are given in the next section.

Participants

Participants were 41 older adults recruited (by phone) from Champaign, IL and the surrounding community. Participants were screened for a diagnosis of hypertension, normal vision (use of both eyes; presently have no cataracts; no macular degeneration), normal motor skills (no diagnosed neurological disorder; sufficient use of both hands), and for cognitive impairment that would preclude participation (no stroke within the last 3 years; not currently receiving radiation/chemotherapy). All participants were also at least 60 years old and native English speakers (or had learned English before age 6). Participant responses were self-reported. The university’s Institutional Review Board approved the experiment. Participants were paid $20 for their participation.

Participants’ ages ranged from 60 to 86 (mean age=72.32, SD=7.69), and 30 were female. Participants had been diagnosed with hypertension for 11.65 years on average (0-34 years; one person who had not been diagnosed with hypertension also participated).
The sample was well educated: 5% of participants had less than a high school degree; 37% had a high school degree; 59% had more than a high school degree.

**Participant Ability Measures**

*Domain-general cognitive ability.* Because health literacy is a multi-faceted construct related to both fluid and crystallized cognitive abilities (Levinthal et al., 2008) as well as health knowledge (Gazmararian et al., 2003), and because these abilities have varying age-related trajectories (Beier & Ackerman, 2005), we measured both types of abilities. While fluid and crystallized abilities are ideally measured with multiple measures, there was limited time to do so in this preliminary study. Instead, a few representative measures of fluid and crystallized abilities were used in order to examine their impact on text-picture passage processing as they relate to health literacy. We chose measures based upon an earlier analysis of fluid and crystallized ability predictors of health literacy measures (Morrow, Chin et al., 2009).

Speed of processing and working memory were the fluid abilities measured in our study. Speed of processing was measured by The Identical Pictures Test (Ekstrom et al., 1976), which required participants to mark which of four patterns matched a target pattern. Participants had 30 seconds to complete as many items as possible. Scoring was based upon subtracting the number of incorrect responses from the number of correct responses.

Working memory was measured by the Letter-Number Sequencing test (Wechsler, 1997). In this test, the experimenter read a sequence of letters and numbers, which the participant had to read back, numbers first (in order from lowest to highest), followed by
letters (alphabetical). The length of the letter-number sequence increased every 3 sequences. When participants incorrectly responded to three sequences of the same length, the task was ended. Scoring was based upon the number of correct sequence read-backs.

Crystallized ability (general knowledge) was measured by The Advanced Vocabulary Test (Ekstrom et al., 1976). The test prompted participants to choose which of four words had the same meaning as a target word; the test contained 12 such tasks. Scoring was based upon subtracting the number of incorrect responses from the number of correct responses.

*Hypertension knowledge.* Participants’ factual knowledge about hypertension was measured using Chin et al.’s (2009) questionnaire, which probed facets of hypertension, including its cause, symptoms, consequences, risk factors, self-care, and the function/structure of the heart. It consists of 33 True/False questions and 4 multiple choice questions, and is based on Gazmararian et al. (2003), additional items from AHA website, Oliveria et al. (2005) and Miller, Stine-Morrow et al. (2004) in order to more fully cover relevant hypertension-related concepts. The measure has acceptable reliability (Cronbach alpha=0.90; Chin et al. 2009).

*Health literacy.* The Short Test of Functional Health Literacy (STOFHLA; Baker, Williams, Parker, Gazmararian, & Nurss, 1999) was used to measure participants’ health literacy. The STOFHLA measures participants’ ability to understand realistic health passages using a Cloze procedure (a test consisting of a passage of text with specific words removed, and participants are asked to replace the missing words). Performance on this test is predictive of medication information recall (Morrow, Weiner, Young, Steinley, Deer, & Murray, 2005) and adherence (Gazmararian, Kripalani, Miller, Echt, Ren, & Rask, 2006).
Scores range from 0-36, and reflect participants’ health literacy level as inadequate, marginal, and adequate (0-16=inadequate health literacy, 17-22=marginal literacy, 23-36=adequate literacy). Mean STOFHLA score in our overall sample (N=41) was 33.9 (SD=2.81), and all participants had adequate health literacy. Thus, the entire sample had high levels of health literacy, reflecting their education level.

STOFHLA scores were correlated with hypertension knowledge (r= 0.49, p<0.01) and vocabulary knowledge (r=0.66, p<0.001), while hypertension knowledge correlated with vocabulary knowledge (r=0.45, p<0.01), replicating previous findings of relationships between health literacy, health knowledge, and general knowledge (Chin et al., 2009; Gazmararian et al., 2003). However, contrasting with previous findings, neither STOFHLA scores nor hypertension knowledge correlated with processing speed (STOFHLA: r=0.14, p=0.41; HypKnow: r= -0.05, p=0.75) or working memory (STOFHLA: r=0.27, p=0.10; HypKnow: r=0.18, p=0.25). The lack of correlation between health literacy/hypertension knowledge and working memory likely stemmed from our small sample size (as compared to previous studies, e.g., Chin et al., 2009). The lack of relationship between health literacy/hypertension knowledge and processing speed probably largely resulted from issues with administration of the Identical Picture Task (i.e., inconsistent task instructions given across participants probably resulted in unreliable/inconsistent processing speed scores across participants). Again contrasting with previous findings (Chin et al., 2009), participants’ years of having hypertension did not correlate with participants’ hypertension knowledge (r=0.12, p=0.46), though it was marginally related to vocabulary knowledge (r= -0.30, p=0.06).
The correlations between the STOFHLA and fluid ability measures indicate that in this study, participants’ fluid ability scores do not predict health literacy. Subsequently, I do not anticipate finding support for prediction 1c (a relationship between fluid ability measures and comprehension scores), though relevant correlations will still be reported.

Materials

**Text-Picture Passages.** Three different sets of text-picture passages (one type per subexperiment) were developed (see Appendix A for examples of materials for each subexperiment):

1. **Hypertension:** Participants saw 6 hypertension-related passages (2 used as practice). These texts/pictures addressed issues such as the diagnoses and treatment of hypertension. In this subexperiment, each passage consisted of a paragraph of text and two types of pictures (*Relevant* and *Irrelevant*). The *Relevant picture* was related to some of the concepts addressed in the text, and explicitly depicted and/or integrated these concepts. The *Irrelevant pictures* were unrelated to any concepts mentioned in the text and were intended to be decorative rather than directly relevant to the text (i.e., they were not ‘meaningful pictures’). The positions of texts and pictures (on the left or right half of the display), and of the two pictures (relevant picture above or below irrelevant), were counterbalanced across participants.

2. **Exercise/stretching:** In this subexperiment, participants saw 8 passages (2 used as practice) with text instructions on how to do a variety of stretches (e.g,
hamstring, triceps), accompanied by a picture of the stretch. Each passage consisted of a paragraph of text and one picture, depicting an individual doing the described stretch. Texts were presented on either the top or bottom half of the display (above/below pictures), with position of text and picture counterbalanced across participants.

3. Medication-taking/Timeline: these texts/pictures presented information on different types of medications, their purposes, their dosages, and when to take doses throughout the day. The picture portion of the passage was a timeline depicting the dosage amounts and when to take them during the day. Texts were presented on either the top or bottom half of the display, and pictures were presented on the opposite half. Participants saw 8 medication taking/timeline-related passages (2 used as practice).

The subexperiments will henceforth be referred to as the Hypertension, Exercise, and Medication-taking subexperiments, for ease of referencing. The results of each of these subexperiments will be reported separately within the Results chapter.

Text-Picture Passage Development. Hypertension and Exercise passages were developed by pulling textual and pictorial information from previously existing sources. Hypertension texts were adapted from materials on MedlinePlus (http://www.nlm.nih.gov/medlineplus/highbloodpressure.html), a hypertension information resource supported by the National Institutes of Health. Relevant pictures were pulled from the same resource, and these pictures co-occurred with most of their
accompanying text (as they appeared in our text-picture passages). Any text not pulled from the same location as its accompanying relevant picture was generic hypertension information (e.g., being overweight increases risk of hypertension) clearly related to the existing text/relevant picture, and was included to lengthen text passages. Irrelevant pictures were pulled from both MedlinePlus and other resources. When choosing irrelevant pictures, we did not specifically select pictures depicting certain types of information. As a rule, we selected pictures that had no semantic overlap with text, either in their original context or in our developed passages. Because pictures were typically pulled from materials geared towards older adults, and because of the nature of many of the decorative images in such materials, our Irrelevant pictures incidentally often contained depictions of adult older individuals. Texts were consistently paired with the same two pictures (one irrelevant, one relevant).

Exercise passages were adapted from commonly-found online stretch descriptions. We chose a series of stretch pictures that were drawings (not photographs) of middle aged individuals doing a stretch, and short descriptions of the stretches were pulled from a separate website. Medication-taking passages were adapted from a previous study regarding the use of pictorials in medication taking instructions (Morrow, et al., 1998).

When passages were presented onscreen, font type, font size, line spacing, and picture size were the same across all trials. The eye tracking system used for the study requires a specific font size (20 point), which is an appropriate size for older adults with normal or corrected-to-normal vision. As a result, many passages were shortened to ensure that when paired with text and displayed on the eye tracking system’s monitor, they occupied an appropriate amount of the computer screen. Modifications to text typically
involved removing small chunks of text that were not central to the meaning of the entire passage, or adding a small amount of text in order to lengthen the passage.

*Passage comprehension measure.* Comprehension of text-picture passages was measured with True/False questions. Immediately after participants read a passage, they were presented with 3 comprehension questions. We chose the True/False format in order to simplify question responses and minimize participants’ need to look down at the controller (moving their head/eyes) when responding. Questions were developed to measure the accuracy of both textbase and situation model representations constructed from the passages. The textbase representation was probed by asking about information provided explicitly in text, while the situation model was probed by asking whether textual and pictorial information was integrated, and/or by requiring inference to be drawn from the presented passage in order to respond accurately. Figure 3 provides examples of both question types. See Appendix C for examples of actual questions, for all subexperiments.
The cells of the body need oxygen and food to survive. Oxygen and nutrients are carried to all parts of the body through the blood. The heart pumps blood out of its chambers through blood vessels and arteries. Blood pressure is the force applied against the walls of the arteries as the heart pumps blood through the body. The pressure is determined by the force and amount of blood pumped and the size and flexibility of the arteries. This can lead to atherosclerosis, where fatty material and plaque are deposited in the wall of an artery, impairing blood flow.

- A possible textbase question: *Are the size and flexibility of the arteries the only things that determine blood pressure?*
- A possible situation model question: *Does blood pressure apply force from the outside of the artery wall?*

**Figure 3.** On top is an example image and text used in the Hypertension subexperiment (note: the content and spatial organization in this figure does not depict how passages were actually presented). Below are example textbase and situation model-oriented questions.

**Apparatus**

*Eye tracker.* An SR Limited EyeLink 2000 desk-mounted remote eye tracking system was used to track and record eye movements as participants read the passages. The SR Limited software was used to calculate eye movement measures (e.g., variables reflecting fixation location; see Results section). The desk-mounted eye tracking system includes a padded, adjustable chin-rest, as well as a forehead band to prevent participants from leaning too far forward when reading. The chin rest and forehead band were adjusted to ensure participants’ comfort, as well as optimal location of the eyes in relation to the camera. The eye tracker reflects a small amount of infrared light off participants’ cornea and lens, using the reflected light to track eye movements. The amount of infrared light
directed at participants’ eyes was non-harmful. The system was calibrated until average eye position error was less than 1°. Viewing was binocular, but eye movements of only one eye were recorded (the eye which tracked best). Text-picture passages were presented on a computer monitor located 24 inches from the subject. The resulting eye tracking data were stored on a PC. See Figure 4 for picture of the basic eye tracker setup.

Areas of Interest (AOIs) were identified post-data collection in order to test our predictions. The number of these AOIs varied depending upon the presented passage and the type of analysis needed, and will be discussed in more detail in the appropriate subexperiment sections.

**Figure 4.** Picture of Eyelink 2000 desk-mounted system setup (picture from <http://www.sr-research.com/mount_desktop.html>)

**Keypad.** Participants used a Microsoft Sidewinder Game Pad controller to move through stimulus displays at their own pace, as well as respond to comprehension questions after viewing passages. To respond to comprehension questions, two buttons on the controller were marked “T” and “F” to reflect possible true/false responses. A separate button was programmed to control moving through stimulus displays.
Procedure

All participants progressed through the three subexperiments in the same order: Exercise first, followed by Hypertension, and finishing with Medication-taking. The entire experimental session lasted 1.5 hours or less. Participants began their session by providing informed consent. They then completed the demographic questionnaire, which included having their vision tested (far and near vision). They then moved to the eye tracking room and were seated in an adjustable chair in front of the desk-mounted system and computer monitor. The experimenter adjusted the chin-rest and chair until the participant was comfortable and their eyes were at a level appropriate for eye tracking (i.e., not too high or too low for the camera to consistently detect the cornea/lens). The experimenter would give a verbal overview of the experiment (e.g., their goals, how to respond, the process of calibration). They were told to examine the text and picture display so they could answer questions about the information (that is, read for comprehension). The Game Pad controller was pointed out as the mechanism by which they could move through screens and respond to questions.

When the participant was situated and comfortable, the experimenter began the first subexperiment (Exercise). The participant first viewed the instruction screen, which provided more information about the study task. Participants were allowed to ask any questions about the task or eye tracking system. When done reading, the experimenter focused the camera and calibrated the system. During calibration, participants were asked to stare at a white dot at whatever location it appeared onscreen. Calibration allowed the system to ensure an average eye position error of less than 1°. If an individual's eyes were
somewhat difficult for the system to accurately detect (due to drift, reflection off glasses, line in glasses, etc.), the calibration process was repeated until eyes were accurately tracked.

Participants then began two practice trials, each consisting of a text/picture passage viewed at the participant’s own pace, followed by the three comprehension questions. The practice trials were the same format as the experimental trials.

After the practice trials, calibration was adjusted as needed, and the experimental trials began. After viewing each display, participants answered the three true/false comprehension questions regarding that display, and then moved to the next trial. A drift correction was included at the beginning of each trial. After completing all six trials within the Exercise subexperiment, participants completed the Identical Picture and Letter-Number Sequencing tasks. They then moved to the Hypertension subexperiment, following the same procedure. After completion of this subexperiment, participants completed the Advanced Vocabulary task. Then, they moved to the Medication-taking subexperiment, and afterwards completed the STOFHLA and Hypertension Knowledge Questionnaire. After the experiment was finished, participants were paid and debriefed.

If calibration was problematic, experimenters would attempt to move around chair or head position. If calibration remained problematic, the experimenter would take a short break so they participant could rest their eyes.

Design. Each participant completed all three subexperiments in the same order. The position of the text and picture components (for Hypertension: left side of screen/right side for text vs. pictures, top/bottom for picture types; for Exercise, Medication-taking: top/bottom for text vs. picture) and order of passage presentation were counterbalanced
across participants. The order of the three questions after each passage was the same for each participant.
RESULTS

Plan of Analysis

Following an explanation of how eye movement data were extracted and manipulated, results will be discussed with respect to each subexperiment. Each section will be organized as follows:

A) Participants: Subexperiment-specific participant information.

B) Global eye movement measures: Pictures vs. Text: A comparison of participants’ eye movements on text versus pictures.

C) Passage Comprehension Results: addresses individual differences in how readers comprehended the passages. Comprehension results are discussed with regard to subexperiment predictions.

D) Phase-based analysis Results: addresses individual differences in how readers used the multimedia material. The phase-based analysis begins with an analysis of various measures of overall time allocation, so as to justify further analyses of whether comprehension and cognitive abilities were related to individuals’ allocation of time during and after the initial read. During/after first pass of reading results are then discussed with regard to subexperiment predictions.

E) Discussion: Hypertension/Exercise/Medication-taking Subexperiment

Eye movement data

As was previously mentioned, some data were lost and/or were not usable for specific analyses due to eye tracking failure or excessive drift during eye tracking.
Subsequently, some participants’ data were not usable in all subexperiments, causing the sample to vary across subexperiments. Data were deemed invalid if eye movements were clearly not tracked (at all, or for portions of trials), or if drift was excessive to the point fixation locations were unclear. If an eye movement was subject to minor drift (only to the extent that it was clear where the readers’ fixation actually fell), I corrected for the drift by slightly moving the fixation. This was almost exclusively done only for fixation data points that appeared partially on the display, but had clearly occurred when the reader was reading text/looking at a picture. This type of manipulation was done on less than 10% of trials within each subexperiment. For each subexperiment, participants’ eye movement data were only used if at least half their trials contained usable data, and in this case, only the usable data were extracted and analyzed.

Before extracting data, Areas of Interest (AOIs) were created around text and picture regions of each display, encompassing fixations made on each area. For the purposes of the phase analysis, the last fixation (on text) of the first read of a text was given its own AOI During data analysis, this last-fixation-AOI acted as a marker as to when readers had read through the text one time, allowing a comparison of looking behaviors during versus after the first read of text. Any fixations occurring within the last-fixation-AOI were classified as occurring during reading of text. The actual size of AOIs made no difference in the testing of our predictions, as data extraction relies only upon the fixations being located within an AOI, and not upon the nature (e.g., size, location) of the AOI. See Appendix B for examples of AOIs for each subexperiment. Fixations with duration of less than 100 ms. were excluded from the analysis (see Hegarty & Just, 1993), as readers cannot process information from either text or picture with fixations shorter than 100ms.
Extracted data consisted of a report on each fixation, in the order that they occurred. Additional data were provided for each fixation (e.g., the AOI in which it fell, fixation duration, etc.). These data reports were generated for each participant by the Eyelink data management software, and were manipulated within Microsoft Excel to create the desired variables (e.g., the number of looks between picture and text was found by noting when a fixation on a picture AOI had followed one on a text AOI). The created variables were further analyzed using SPSS.

Analysis of eye fixations provided insight into elders’ comprehension processing differences as they read text-picture materials. For each subexperiment, I will make some very global comparisons of eye movements on text and picture (e.g., Rayner, 2001, 2008), examining how readers looked differently at pictures and text. The following global eye movement variables were examined, to compare readers’ looking at text versus pictures:

- **Dwell time**: overall time spent on text, picture.
- **Number of fixations**: total number of fixations made on text, picture.
- **Fixation duration**: average duration of each fixation on text, picture.

The phase-based analysis is based upon re-reading literature (e.g., Millis et al., 2000), and involves examining looking behaviors during and after the initial read of text. As was explained earlier, phase-based multimedia processing will be viewed in light of reading/re-reading of text rather than looking at pictures, both because eye tracking multimedia studies similar to our own indicate that people spend more of their overall processing time reading text (e.g., Hegarty & Just, 1993), and because text took up more display space than did pictures in our passages. During this analysis I will investigate whether there are
individual differences in how readers actually use the different types of media. Within the phase-based analysis, the following types of variables will be addressed:

- **Proportion of time spent reading text during each phase** (e.g., time spent on text during the first pass of reading / overall time during the first pass): indicates whether readers allocated more attention/time to reading text or looking at pictures, during each phase. Note that overall time during a phase is equal to (time spent on picture(s) + time spent reading text) during that phase. So, proportion of time spent reading text is the complement of the proportion of time spent looking at picture(s).

- **Average number of looks from text to pictures per trial**: measures how often participants interrupted reading to look to pictures.

- **Picture run time** (when a reader looks from text to a picture, the duration from the first fixation on the picture to the last fixation made on the picture before the reader looked elsewhere): indicates for how long participants interrupted their reading to examine the picture.

- **Overall looking behavior measure**: calculated by taking the difference in the proportions of time spent on text during versus after the first read (i.e., [proportion of time spent reading text during the first read of text] - [proportion of time spent reading text after the first read of text]). This variable signifies differences in time allocation across the two phases. In other words, it is a single value representing how participants shift their looking behavior (e.g., from focusing on text to focusing on pictures) across phases.
Subexperiment 1: Hypertension passages

A) Participants

29 of the 41 older adults (mean age=73.24; SD=13.73) were included in the Hypertension phase-based analysis. Of these 29 elders, 21 were female, and all but one participant was diagnosed with hypertension. Participants reported having hypertension for an average of 11.69 years (from 0 to 34 years). Forty-one percent of participants had a high school education or less.

B) Global eye movement measures: Pictures vs. Text

Readers spent more time viewing text (29.94 sec/trial) than pictures (6.09 sec/trial), t(28)=9.15, p<0.001. This difference in viewing times likely occurred because participants made more fixations on text (mean=119 fixations/trial) than on pictures (21 fixations/trial), t(28)=11.65, p<0.001. The viewing time and fixation count results are consistent with Rayner et al. (2001). Unlike that study, mean fixation duration on text (251 ms) and pictures (270 ms) did not differ t(28)= -1.37, p=0.18.

C) Passage comprehension Results and Subexperiment-specific predictions:

Prediction: Participants with higher health literacy, hypertension knowledge, general knowledge, and fluid ability will better comprehend Hypertension passages. For the total sample (N=41), the mean proportion of Hypertension comprehension questions answered accurately was 0.68 (SD=0.14). As predicted, comprehension was related to hypertension knowledge (r=0.44, p<0.01), STOFHLA score (r=0.39, p<0.05), and vocabulary knowledge
(r=0.49, p<0.01). Accuracy was unrelated to performance on processing speed (Identical Pictures Task: r=0.02, p=0.89) or working memory (Letter-Number Sequencing Test: r=0.14, p=0.39) tasks.

For the 29 individuals included in the reading phase analysis, comprehension accuracy was also related to hypertension knowledge (r=0.41, p<0.05), STOFHLA (r=0.37, p=0.05), and vocabulary knowledge (r=0.61, p<0.05). Fluid abilities again did not correlate with comprehension accuracy (-0.032 < r > 0.13, p > 0.10 for both measures).

D) Phase-based analysis Results and Subexperiment-specific predictions²

Overall time allocation. I first investigated whether passage comprehension, hypertension knowledge, or health literacy related to the following measures of overall time allocation: total trial time, total time spent reading text, total time spent looking at pictures, total time spent during versus after the first pass of reading, and percentage of trial time spent during versus after the first pass. All correlations were nonsignificant (-0.20 < r > 0.26, p > 0.10, for all measures). Because neither comprehension nor health literacy/knowledge variables were related to participants’ overall allocation of time, we next considered the more interesting issue of whether comprehension and health literacy/knowledge were related to participants’ allocation of processing time during and after the first pass of reading.

Prediction: During the first pass of reading, participants with higher health literacy and health knowledge will spend more time reading text than looking at pictures, compared to lower ability participants. On average, participants spent 0.80 (SD=0.14) of their total

²Partial results for phase-based analysis of the Hypertension subexperiment were reported earlier (D’Andrea et al., 2010).
trial time during the first pass of reading. The proportion of first-pass time spent reading text (mean=0.94, SD=0.06) (as was noted earlier, this is the complement of the proportion spent viewing the pictures) correlated with hypertension knowledge (r=0.42, p<0.05), but not with health literacy (r= -0.06, p=0.77) or comprehension (r=0.22, p=0.26). So, more knowledgeable participants spent more time reading text than looking at pictures during their first read of a text compared to less knowledgeable participants, though this strategy did not predict comprehension.

With regard to picture usage, the number of looks from text to pictures per trial during the first pass was not correlated with health literacy (r= -0.30, p=0.12) or comprehension (r= -0.30, p=0.12), but was negatively correlated with hypertension knowledge (r= -0.52, p<0.01). This relationship held for both picture types, because hypertension knowledge was negatively correlated with looks to both relevant (r= -0.58, p<0.05) and irrelevant pictures (r= -0.36, p<0.05), while health literacy and comprehension were not correlated with either. So, participants with more knowledge looked less frequently to pictures during the first pass of reading. Finally, both average and maximum picture run times were unrelated to hypertension knowledge, health literacy, and comprehension (-0.26 < r < 0.09, p>0.10 for all measures). To sum up, participants with more hypertension knowledge were less likely to interrupt reading by looking to pictures, but spent the same amount of time viewing the pictures if they did so, compared to lower knowledge elders.

Prediction: After the first pass of reading, participants with more health literacy and hypertension knowledge will look more at pictures than text. While the findings from first pass reading analysis indicate that more knowledgeable readers were more likely than less
knowledgeable to rely on text rather than pictures, the after first pass analysis suggests an additional strategy. The proportion of after-first-pass time spent reading text (mean=0.39, SD=0.28) was negatively correlated with hypertension knowledge (r= -0.44, p<0.05), and marginally correlated with comprehension accuracy (r= -0.32, p=0.09), though still unrelated to health literacy (r= -0.16, p=0.43). So, after initially reading the text, participants with more knowledge and a better understanding of the information spent less of their time reading and more looking at pictures, compared to participants with less knowledge and poorer comprehension.

Of all the time they spent looking at pictures, more knowledgeable participants spent the majority of it after their initial read of the text (r=0.41, p<0.05). No such pattern was found with regard to health literacy or comprehension (0.11 < r > 0.28, p>0.10 for both measures). So, higher knowledge participants did most of their looking at pictures after they had initially read through text and had developed a base understanding of the information. On the other hand, lower knowledge participants distributed their looking at pictures more evenly throughout the trial. However, neither behavior was associated with better comprehension.

Despite the shifts in picture viewing after the first pass of reading, the number of looks from text to pictures was not correlated with knowledge, comprehension, or health literacy (0.14 < r < 0.20, p >0.10 for all measures). More knowledgeable participants may have changed how they look at pictures, though, as they made somewhat longer looks on relevant pictures after the first pass of reading (max. run time on relevant pictures: r=0.36, p=0.06), as compared to lower knowledgeable participants.
Lastly, analysis of the overall looking behavior measure (discussed earlier in this section, the measure is “...a single value representing how participants shift their looking behavior (e.g., from focusing on text to focusing on pictures) across phases”) revealed that it marginally correlated with comprehension (r=0.38, p=0.07), indicating that there is an optimal overall pattern of looking across phases. In addition, the measure correlated with knowledge (r=0.48, p<0.05), suggesting that the optimal looking strategy characterized the more knowledgeable readers. The positive correlations indicate that an effective looking strategy is a shift from a focus on text during the initial read, to a focus on pictures after the initial read, and more knowledgeable participants are more likely to engage in this strategy.

Prediction: Higher health literacy/hypertension knowledge participants will spend more time looking at the relevant than the irrelevant picture, compared to participants with lower abilities. Their differentiation in picture looking (looking for more time, and more often, to relevant than irrelevant pictures) is more likely to occur during re-reading, because higher ability individuals are predicted to spend more time processing pictures during this phase. This prediction is based upon two separate influences on processing. First, higher ability individuals are better at understanding relationships between textual concepts without the use of pictorial support (Hegarty & Just, 1993; Mayer, 2001; Schnotz, 2005). So, after they build a mainly text-based initial representation of the information, higher ability readers may be better able to recognize which pictures correspond to (i.e., relevant pictures), and which do not correspond to (i.e., irrelevant pictures), their existing representation. Another possible reason that higher ability elders will better differentiate between relevant/irrelevant pictorials is rooted in how they inhibit extraneous
information when processing. Readers with higher knowledge can better allocate/regulate their attention as they process textual information into a situation model (Radvansky & Dijkstra, 2007). Perhaps readers recognize that irrelevant pictures need not be processed regardless of their health literacy/knowledge level, but as a result of their ability to better allocate/regulate attention, those with higher abilities are better able to ignore the extraneous irrelevant pictures. The after-first-pass time spent looking at pictures can be primarily attributed to the relevant picture. The proportion of time spent on the relevant picture (i.e., time on relevant picture after the first pass/total time after first pass) was correlated with knowledge ($r=0.52$, $p<0.01$) and was marginally correlated with comprehension ($r=0.32$, $p=0.09$), while neither measure was correlated with the proportion of time spent on the irrelevant picture ($0.07 < r > 0.17$ with $p > 0.10$, for both measures). These picture-looking findings suggest that after reading through text once, higher knowledge participants better distinguished between relevant and irrelevant pictorial information than did lower knowledge participants.

E) Discussion: Hypertension Subexperiment

As expected, participants with higher health literacy, hypertension knowledge, and general knowledge (vocabulary knowledge) better understood the passages, while fluid abilities were unrelated to performance (due to measurement limitations for the latter and/or limited sample size).

Of most interest was how participants with higher health literacy and hypertension knowledge built their better understanding (as reflected in the eye-tracking measures). Though health literacy was not related to the process measures, hypertension knowledge
and comprehension were. Knowledge-related differences in comprehension were not explained by participants’ overall allocation of time when viewing displays. However, when eye fixation data were partitioned into phases (first pass reading vs. re-reading), patterns of reading processes began to emerge. During their initial read of text, more knowledgeable elders spent more time reading, and interrupted their reading to view pictures less frequently, than did lower knowledge elders, similar to the patterns found by Hegarty & Just (1993). After the initial read of a text, higher knowledge elders focused more of their time/attention on the relevant pictorial information, and may interrupt their re-reading of text for longer amounts of time to view the relevant picture, compared to lower knowledge elders. Looking patterns during re-reading were also correlated with comprehension, suggesting this process strategy was successful. Finally, more knowledgeable elders’ entire pattern of processing (looking more at text during the first read, and more at pictures after) was linked to comprehension. Importantly, although general (vocabulary) knowledge was related to comprehension, it was not related to any of readers’ time allocation patterns (e.g., time on text during first pass/total time during first pass), providing evidence against the possibility that general knowledge (rather than hypertension knowledge) is the most important predictor of how readers build their comprehension.

Subexperiment 2: Exercise passages

A) Participants

32 elders (mean age=71.78; SD=7.50) were included in the Exercise phase-based analysis. 26 of these older adults were female. All but one participant was diagnosed with
hypertension, and participants reported having hypertension for an average of 10.75 years (from 0 to 34 years). Forty-seven percent of the participants had a high school education or less.

B) Global eye movement measures: Pictures vs. Text

As in the Hypertension subexperiment, readers spent more time looking at text (15.06 sec/trial) than pictures (2.98 sec/trial), \( t(31)=9.85, p<0.001 \). They again made more fixations on text (mean=63.45/trial) than on pictures (mean=11.27/trial), \( t(31)=11.63, p<0.01 \). Mean fixation duration did not differ between text (mean=241.88 ms) and picture (mean=248.98), \( t(31)=-0.86, p=0.40 \).

C) Passage comprehension Results and Subexperiment-specific predictions:

Prediction: Participants with higher health literacy, general knowledge, and fluid ability will also better comprehend Exercise passages. For our entire sample (N=41), the average proportion of Exercise questions answered correctly was 0.68 (SD=0.15). Comprehension was marginally correlated with hypertension knowledge \( (r=0.30, p=0.06) \), and vocabulary knowledge \( (r=0.29, p=0.06) \), but was not correlated with STOFHLA \( (r=0.25, p=0.12) \). Accuracy was unrelated to processing speed \( (r=0.09, p=0.59) \), but was marginally correlated with working memory \( (r=0.27, p=0.08) \).

Within the sample of 32 participants included in the Exercise reading phase analysis, comprehension accuracy was related to vocabulary knowledge accuracy \( (r=0.38, p<0.05) \), but not to health literacy \( (r=0.19, p=0.30) \), hypertension knowledge \( (r=0.27, p=0.14) \), or fluid abilities \((-0.06 < r > 0.07, p > 0.10\) for all measures).
D) Phase-based analysis Results and Subexperiment-specific predictions

*Overall time allocation.* Within the Exercise subexperiment, measures of overall time allocation (total trial time, total time spent reading text, total time spent looking at pictures, total time spent during versus after the first pass of reading, and percentage of trial time spent during versus after the first pass) were unrelated to hypertension knowledge, health literacy, and comprehension of exercise passages (-0.24 < r > 0.19, p > 0.10 for all measures). As in the hypertension subexperiment, I next examined whether comprehension and hypertension knowledge/literacy were related to reading behaviors during and after the first pass of reading.

*Prediction:* During the first pass of reading, participants with more health literacy and general knowledge will spend more time reading text and less time on pictures, and will look less often to pictures, compared to participants with less health literacy and general knowledge. On average, participants spent 0.61 (SD=0.15) of their total trial time during the first pass of reading. The proportion of first-pass time spent reading text (mean=0.88, SD=0.07) correlated with health literacy (r= -0.42, p<0.05) and comprehension (r= -0.51, p<0.01), and was unrelated to hypertension knowledge (r= -0.18, p=0.33). So, in contrast to the hypertension subexperiment, participants with higher health literacy and better comprehension spent less time reading text than looking at the picture during their first read of a text. Of all the time they spent looking at pictures, participants with better comprehension spent most of it during the first pass of reading (r=0.37, p<0.05).
During the initial read, the number of looks to pictures per trial were uncorrelated with health literacy ($r=0.23$, $p=0.21$) or hypertension knowledge ($r=0.06$, $p=0.74$), but were related to comprehension ($r=0.35$, $p<0.05$). Similarly, maximum picture run time was unrelated to health literacy ($r=0.16$, $p=0.40$) and hypertension knowledge ($r=-0.72$, $p=0.70$), but was correlated with comprehension ($r=0.35$, $p=0.05$). So, participants who better understood the passage had interrupted their reading to look to pictures more frequently and for longer stretches of time, as compared to participants who understood the material less well.

**Prediction:** After the first pass of reading, participants with more health literacy and knowledge will look more at pictures than text. While the first-read analysis revealed clear reading strategies related to both abilities and comprehension, participants did not appear to follow any clear patterns after the initial read of the text. The proportion of after-the-first-pass time spent reading text (mean=0.73, SD=0.17) was unrelated to health literacy, comprehension, and hypertension knowledge ($0.11 < r > 0.17$, $p>0.10$ for all measures). After the initial read of text, the number of looks from text to pictures per trial was not correlated with health literacy, comprehension, or hypertension knowledge ($-0.008 < r > 0.075$, $p>0.10$ for all measures). However, picture run length was marginally correlated with health literacy ($r= -0.35$, $p=0.06$), though it was unrelated to comprehension ($r= -0.04$, $p=0.83$) and hypertension knowledge ($-0.05$, $p=0.79$).

So, after focusing more on pictures than text during their initial read, participants with higher health literacy and better comprehension moved on to behave essentially the same after the first read as did those with less knowledge and worse comprehension. The only exception was that when looking to pictures after the first pass, higher health literacy
participants interrupted their reading for shorter amounts of time than did those with lower health literacy.

Despite the lack of clear reading patterns after the first read of text, the overall looking behavior measure was marginally correlated with both health literacy ($r = -0.33$, $p=0.07$) and comprehension ($r = -0.34$, $p=0.06$). The negative correlations indicate that the effective looking strategy was a shift from focusing on pictures during the initial read to focusing more on text after the initial read. However, the correlations are marginal, and this overall looking behavior pattern cannot be endorsed as certain.

**E) Discussion: Exercise Subexperiment**

As predicted, participants with higher general knowledge better understood the passages. However, contrary to our predictions, neither health literacy nor hypertension knowledge predicted comprehension. Fluid abilities were also unrelated to comprehension.

Elders’ overall allocation of time when viewing displays was unrelated to all individual difference measures, as well as comprehension. However, splitting the eye movement data into phases revealed health literacy- and comprehension-related reading patterns, though the patterns ran contrary to our predictions. During the first read of text, elders with higher health literacy and comprehension focused more of their time/attention on looking at pictures than on reading text, compared to those with lower health literacy and comprehension (although all participants spent more time on text than pictures). Participants who better understood passages also made more, longer looks to pictures, interrupting their reading more frequently and for longer amounts of time. After the first read of a text, there were no clear-cut reading patterns, although higher health literacy
elders made somewhat shorter looks to pictures. Despite the lack of patterns within the re-reading phase, elders with higher health literacy exhibited an overall reading behavior characterized by a shift from focusing on pictures during their initial read to focusing more on text afterwards, was also linked to comprehension levels. However, correlations between the overall reading pattern and health literacy/comprehension were only marginal.

The reading behaviors revealed in the Exercise subexperiment are exactly opposite those found in the Hypertension subexperiment, in which higher hypertension knowledge readers spent more time on text during the first pass of reading, and more time on pictures during re-reading. Also interestingly, high ability readers’ increased time spent on pictures predicted comprehension within both subexperiments. However, in the present subexperiment, spending more time on pictures (and thus less on text) during the initial read was the relevant predictor of comprehension, while in the Hypertension study, spending more time on pictures (and thus less on text) after the first read was the relevant predictor. I will speculate as to why these patterns occur in the General Discussion section.

Subexperiment 3: Medication-taking passages

A) Participants
22 older adults (mean age=72.45; SD=7.00) were included in the Timeline phase-based analysis. Of these older adults, 16 were female, and all but one had been diagnosed with hypertension. Participants reported having hypertension for an average of 11.38 years (from 0 to 30 years). Thirty-six percent of participants had a high school education or less.
B) Global eye movement measures: Pictures vs. Text

As in the first two subexperiments, readers spent more time looking at text (22.24 sec/trial) than pictures (2.90 sec/trial) when reading the Medication-taking passages, \( t(21)=11.26, p<0.001 \). They also again made more fixations on text (mean=97.28/trial) than pictures (12.44/trial), \( t(21)=14.24, p<0.001 \). However, participants’ fixation durations were longer on text (mean=244.41 ms) than picture (mean=175.91 ms), \( t(21)=5.23, p<0.001 \). This finding is in contrast to Rayner et al. (2001, 2008), who found that viewers tend to make longer fixations on pictures, thus suggesting that readers were not processing the timeline pictures as deeply (with each look) as they were processing text.

The difference in fixation duration findings could stem from a difference in material types, as Rayner et al. studied advertising prints that consisted of small amounts of text printed on full-page pictures. Rayner et al. suggested that fixations were longer on pictures because readers could process information from a wider area when looking at one point on a picture. However, because our pictures were timelines for when/how medication should be taken, the meaningful/valuable information within the pictures was located at very specific points. These pictures contrast those used in Rayner’s advertisements, which were large-scale and did not direct viewers to specific points of the picture (see Figure 5 for examples of each). Perhaps because the important information within timelines was located at very specific points, Rayner’s finding did not hold true for the timeline pictures. This pattern did not occur within our other subexperiments, indicating that the timeline pictures were unique in this regard.
Figure 5. On top, an example of the types of pictures used by Rayner et al. (2001). On bottom, an example of the medication timelines used in the present study (from Morrow et al., 1998). Pictures not to scale.

C) Passage comprehension Results and Subexperiment-specific predictions:

Prediction: Participants with higher health literacy, hypertension knowledge, general knowledge, and fluid ability will better comprehend Medication-taking passages. Across the entire sample (N=41), the average proportion of Medication-taking questions answered correctly was 0.53 (SD=0.10). This proportion is essentially at the level of chance, indicating that participants guessed in response to the comprehension questions responses. Analysis of accuracy by passage type did not reveal any one passage that was more poorly understood than the others, thereby skewing the comprehension results (mean accuracy levels for each of the 4 passage types: 0.49, 0.51, 0.50, 0.62). Poor performance on comprehension questions likely resulted from limitations of the
comprehension questions and the testing environment, rather than from participants not understanding the passage (see General Discussion).

Unsurprisingly given the limitation on the comprehension measure, even within the full sample, accuracy was uncorrelated with health literacy ($r=0.06, p=0.74$), hypertension knowledge ($0.16, p=0.33$), vocabulary knowledge ($0.06, p=0.71$), or working memory ($r=-0.05, p=0.76$), though it was marginally related to processing speed ($r=-0.30, p=0.07$).

Within the sample of 22 participants included in the Medication-taking reading phase analysis, accuracy was not correlated with health literacy, hypertension knowledge, vocabulary knowledge, processing speed, or working memory ($-0.35 < r > 0.17, p > 0.10$ for all measures). Because participants’ accuracy on comprehension questions was at the level of chance, analysis of eye movements will not address effective comprehension.

**D) Phase-based analysis Results and Subexperiment-specific predictions**

*Overall time allocation.* Within the Medication-taking subexperiment, hypertension knowledge was unrelated to all measures of overall time allocation (total trial time, total time spent reading text, total time spent looking at pictures, total time spent during versus after the first pass of reading, and percentage of trial time spent during versus after the first pass) ($-0.27 < r > 0.23, p>0.10$ for all measures). Health literacy was correlated with the total time spent reading text ($r= -0.44, p<0.05$) and the total trial time ($r= -0.43, p<0.05$). These relationships likely occur because higher health literacy individuals can more efficiently process health information (or just more efficient readers of any text), and simply were able to read the medication-related texts more quickly than lower health literacy participants. However, it is worth remembering that higher health literacy
participants did not exhibit this trend in the previous two subexperiments. Health literacy was also related to the total time spent during the first read of text ($r = -0.50$, $p<0.05$). It was unrelated to all other process measures ($-0.12 < r > 0.18$, $p>0.10$ for all other measures).

**Prediction:** *During the first pass of reading, participants with more health literacy and hypertension knowledge will spend more time reading text and less time on pictures, and will look less often to pictures, compared to participants with less health literacy and hypertension knowledge.* On average, participants spent 0.76 (SD=0.12) of their total trial time during the first pass of reading. Health literacy and hypertension knowledge were not correlated with any process measures during the first pass of reading, including: the proportion of first pass time spent reading text (mean=0.97, SD=0.06); number of looks to pictures per trial; picture run time ($-0.18 < r > 0.12$, $p>0.10$ for all measures). As expected, none of the process measures related to comprehension ($-0.16 < r > 0.07$, $p>0.10$). So, there were no ability- or comprehension-related looking behaviors during the initial read of text.

**Prediction:** *After the first pass of reading, participants with more health literacy and hypertension knowledge will look more at pictures than text.* Health literacy and hypertension knowledge were unrelated to any process measures after the first pass of reading, including: the proportion of after-first-pass time spent reading text (mean=0.59, SD=0.20); number of looks to pictures per trial; picture run time; overall looking behavior measure ($-0.36 < r > 0.21$, $p>0.10$ for all measures). And as expected, none of the process measures related to comprehension ($-0.31 < r > 0.23$, $p>0.10$). Therefore, no looking behaviors during re-reading, or across both phases, were related to health literacy, hypertension knowledge, or comprehension.
E) Discussion: Medication-taking Subexperiment

Contrary to our predictions, passage comprehension was unrelated to all ability-related variables, an unsurprising result considering the chance-level comprehension accuracy. Also unexpectedly, no looking patterns on either text or pictures, during or after the first read of text, were related to either health literacy or hypertension knowledge. The lack of any ability-related reading strategy may have resulted from our comprehension questions, which clearly targeted certain aspects of the passages, as well as the nature of the timeline pictures, and participant fatigue. These rationales, along with discussion of issues underlying passage comprehension, will be discussed in greater depth in the General Discussion.
GENERAL DISCUSSION

The purpose of this study was to examine how older adults utilize pictures when building an understanding of multimedia health documents, and whether attentional processes (as measured by eye-tracking) were related to differences in health-related cognitive resources and passage comprehension. To investigate these issues, we presented health-related text-picture passages to elders with hypertension. Three types of realistic passages were presented, addressing various aspects of self-care information. We collected eye movement data to measure readers’ looking behaviors, and utilized a reading/re-reading analysis paradigm novel to studying eye movements involved with multimedia comprehension. In studying how elders utilized pictures during different phases of comprehension processing, we hoped to reveal how older adults with varying cognitive resources actually achieve their level of comprehension.

Summary of Findings

Predictions 1a, 1b, and 1c: Relationships between comprehension and cognitive resources.

These predictions will be discussed with regard to the entire sample size, rather than the smaller samples of participants who contributed eye movement data. Prediction 1a, participants with higher levels of health literacy will better understand the multimedia passages, was supported by results from the Hypertension subexperiment but not the other two subexperiments. Prediction 1b, individuals with higher hypertension and general knowledge will better understand the passages, was supported by the Hypertension and Exercise subexperiments, but not by the Medication-taking subexperiment. Prediction 1c,
participants with higher fluid ability levels would better understand the passages, was not supported by any subexperiment.

The Medication-taking subexperiment may not have supported any of the predictions because of limitations of the comprehension questions and the testing situation. The Medication-taking passage comprehension results suggest that participants guessed in response to the questions. Poor performance on comprehension questions may have occurred because participants did not understand the passages. However, the Medication-taking passages were pulled directly from a study by Morrow et al. (1998), who found no indication that passage comprehension was poor. So, it seems more likely that participants did understand the passages, but performed poorly on comprehension questions because of the testing environment – questions were extremely similar from passage to passage (many asking about dosage values and times of day) and, unlike in Morrow et al. (1998), participants had to rely upon their memory to answer questions about very specific information (e.g., specific dosage values/times). Participants could very well have experienced interference with their recall for passage information, likely proactive (i.e., forgetting new information as a result of interference from previously-learned information) in nature (Reed, 2006). In sum, accuracy levels cannot be taken as reflective of participants’ understanding of the passages. Because of the poor comprehension performance, all other comprehension-related predictions for this study will not be addressed.

While the relationships between health literacy, hypertension knowledge, and Hypertension passage comprehension were in support of predictions 1a and 1b, the measures’ relationship with Exercise passage comprehension was surprising. We had
anticipated that individuals’ ability to understand health-related materials (i.e., their health literacy) would translate to all types of self-care information, while their hypertension knowledge would be irrelevant because the Exercise passages were unrelated to hypertension. The lack of relationship between comprehension of the Exercise passages and health literacy was likely due, at least in part, to the restricted range of health literacy levels in our sample and small sample size. However, both of these factors also held for the hypertension study, which did find evidence for the relationship between patient health literacy and passage comprehension. It is also possible, though, that Exercise performance was strongly related to participants’ spatial abilities, as the nature of the passages (a textual description of how to position one’s body, and a picture depicting it) likely placed a high demand on spatial aptitude. Though spatial ability is a facet of fluid ability, health literacy measures may not have captured it well enough to observe its impact on comprehension.

With regard to predictions 1a and 1b, which address relationships between comprehension and health literacy/crystallized abilities, I must also address the relationship between health literacy and those crystallized abilities (hypertension and general knowledge). In our sample, health literacy was related to both knowledge measures (hypertension and general/vocabulary), replicating the findings of previous studies (e.g., Chin et al., 2009; Gazmararian et al., 2003; etc.). The interrelationships between these various determinants of comprehension raise the question of whether health literacy and knowledge are equally important in their effect on comprehension. While this might be the case, knowledge may very well account for some of the health literacy-related variance in comprehension (e.g., Beier and Ackerman, 2005). Although the
present study did not involve breaking apart the specific components of health literacy that influenced comprehension (and could not, as our sample size was too small), we must recognize that health literacy and knowledge may have different levels of influence over comprehension of multimedia passages.

None of the subexperiments provided evidence supporting prediction 1c, that participants with higher fluid abilities (i.e., working memory, processing speed) better understood the multimedia passages. The lack of relationship is surprising, as fluid abilities are components of the health literacy construct, and should therefore have been related both health literacy and any health literacy-related comprehension levels. In all likelihood, the lack of relationships between processing speed, health literacy, and comprehension stem from issues with processing speed task administration. As was explained in the Method section, inconsistently administered Identical Picture Tasks (our measure of processing speed) probably resulted in unreliable/inconsistent processing speed scores across participants. Absence of working memory correlations may simply have stemmed from our relatively small sample size (as compared to previous studies, e.g., Chin et al., 2009).

Predictions 2a and 2b: Relationships between initial reading/re-reading behaviors, cognitive resources, and comprehension.

Predictions 2a and 2b address why the relationships in predictions 1a and 1b occur; in other words, how participants with higher health-related abilities build their better comprehension of the multimedia passages. Prediction 2a states that during the first pass of reading a text, elders with higher health literacy and hypertension knowledge will allocate more of their time/attention to reading text than looking at pictures, compared to elders with lower levels of both abilities. Prediction 2b states that after the first pass of
reading, older adults with higher health literacy and hypertension knowledge will allocate
more time/attention to pictures than text.

**Medication-taking subexperiment: Summary and interpretation of findings.** The
Medication-taking subexperiment did not provide support for either 2a or 2b. When
viewing the medication-taking passages, readers did not follow any discernable reading
patterns/strategies, with regard to how they used pictures when building their
understanding. The lack of any ability-related reading/re-reading processing patterns
could have been an artifact of our comprehension questions. Questions targeted specific
aspects of the passages (e.g., dosage amounts/times, purpose of medication). As a result,
readers may have recognized what information they needed to attend and changed reading
patterns accordingly, subsequently inducing a non-normal multimedia reading process. A
factor that may have influenced the analysis of Medication-taking data was the smaller
sample size available for eye movement analysis within this subexperiment. The smaller
amount of usable data likely resulted from fatigue, as participants had to complete various
cognitive measures as well as both other subexperiments (and several rounds of eye
tracker calibration), all of which puts strain on the eyes and makes tracking more difficult.

**Hypertension and Exercise subexperiments: Summary of findings.** The phase-based
processing analysis of the Hypertension and Exercise text-picture passages provided
partial support for predictions 2a and 2b. However, the analysis revealed various allocation
strategies, characterized by shifts in looking behaviors across reading phases, which
predicted better comprehension and were often used by the participants with higher
cognitive resources. When reading of hypertension passages, compared to participants
with lower hypertension knowledge, higher knowledge elders devoted more of their
time/attention (e.g., time allocation variables, looks from text to picture, etc.) to reading text than looking at pictures during their first pass of reading. These higher hypertension knowledge elders allocated more time/attention to looking at pictures than reading text after the first pass, and these participants also tended to better understood the texts.

When reading exercise passages, participants with higher health literacy and better passage comprehension devoted more time/attention to looking at pictures than reading text during their first pass of reading, compared to participants with lower health literacy/comprehension. After their first read, higher health literacy readers allocated more time/attention to reading text than viewing pictures, compared to participants with lower health literacy.

_Hypertension subexperiment: Interpretation of findings_ When elders constructed an initial representation of hypertension-related passages (during the first read of a text), higher levels of hypertension knowledge were associated with an increased focus on reading text rather than utilizing pictures during. These findings support predictions 2a and 2b and are consistent with, and extend, previous literature on impact of knowledge and pictures on comprehension (Gyselinck & Tardieu, 1999; Hegarty & Just, 1993; Mayer, 2001, 2005; Schnottz, 2005). More knowledgeable elders’ heightened focus on text during their read-through may have occurred for two main reasons (which are not mutually exclusive). First, they may have needed to focus more on text because of the additional time needed to use knowledge to integrate/organize concepts into a situation model (Miller, Stine Morrow et al., 2004). Second, higher domain-knowledge participants are thought to have less difficulty building initial representations (situation model, textbase, or both) primarily
from text, while those with lower knowledge attempt to use pictures to help build their initial understanding (Hegarty & Just, 1993).

After the first read of the text in the hypertension passages, as readers confirmed and elaborated initial text-based representations into a situation model, higher levels of health knowledge and comprehension were associated with reading behavior shifts to focusing on pictorial information. Again, these findings support predictions 2a and 2b. After constructing a mainly text-based understanding during the first pass, higher knowledge participants appear to focus on pictures – mainly, relevant pictures – as a means of “wrapping up” their understanding of the passage. This strategy seems consistent with two types of previous findings. First, pictures and text provide qualitatively different, highly complementary, types of information (i.e., text describes broad abstract topics; pictures can depict the relationships between textual concepts, ease inference processes) (Mayer, 2005; Schnitz, 2005). As a result, pairing text with pictures can benefit comprehension regardless of readers’ ability level by facilitating the development of situation models (e.g., Glenberg & Langston). Second, to the extent that readers shift their language comprehension focus as they move from initial reading to re-reading, pictures’ involvement with situation model processing might occur more during re-reading. Younger adults typically shift from textbase to situation model processing after their initial read of a text (Millis et al., 2004). Hegarty & Just (1993) found results compatible with this pattern, as their participants exhibited text/picture looking behaviors seemingly similar to situation model-level processing (i.e., behaviors reflecting readers’ confirmation/elaboration upon their initial representation of the information) towards the end of studying a multimedia passage, as readers used pictures to tie together initial representations of the information. In addition,
they found that high ability participants made just as many of these types of looks at pictures as did lower ability participants, after building their initial representations mainly from text (Hegarty & Just, 1993). However, elders may give more focus to situation model development during the initial read of text than do younger individuals (Stine-Morrow et al., 2004). These two types of findings suggest that knowledgeable older adults will likely strive to take advantage of pictures as they build/confirm/elaborate a situation model of the read information, and that such processing may occur after the first read of text, because they can use their knowledge to build initial representations using only text. These patterns seemingly help explain the processing behind the after-first-pass reading behaviors we observed in this subexperiment.

High knowledge participants’ focus on relevant pictures suggests that they create a situation model that integrated information from text and meaningful pictures. This follows Hegarty and Just’s (1993) finding that higher ability adults utilized pictures to elaborate initial representations of into a situation model, rather than using them to actually structure the initial representations. Since the lower knowledge individuals used pictures a great deal in their initial model construction, they may need to continue putting stress on textual information when wrapping up their existing model.

*Exercise subexperiment: Interpretation of findings.* Contrasting the Hypertension subexperiment findings, when elders constructed an initial representation of the exercise-related passages, higher levels of health literacy and comprehension were associated with an increased focus on utilizing pictures rather than reading text. After the first read of exercise passages, higher health literacy readers shifted their reading behavior to focus on reading text rather than looking to pictures. These findings conflict with predictions 2a and
2b, as well as the Hypertension subexperiment findings and the aforementioned existing literature.

**Reconciling findings of Hypertension and Exercise subexperiments.** Across the Exercise and Hypertension subexperiments, readers utilized pictures in opposite ways: pictures benefitted the building comprehension during the initial read of exercise passages, but were most helpful for comprehension of hypertension passages after the first pass of reading. Although the pattern of findings were different in the two experiments, in both cases the *overall* looking behavior (characterized by a shift in focus from one type of media to the other) was associated (though sometimes only marginally) with high ability and comprehension, confirming that both initial read and re-reading processes can play a part in overall understanding. Greater shifts in reading behaviors were associated with higher abilities and better understanding of passages in both experiments.

In addition, in both subexperiments, the only phase-specific processing patterns associated with better comprehension were higher ability participants’ reading behaviors during the reading phase in which they more heavily utilized pictures (i.e., looking to pictures more frequently, for more of the phase). These results suggest that pictures will not be useful if readers simply look at them during any point of processing multimedia. Rather, a crucial aspect of multimedia processing appears to be knowing both *how* to take advantage of pictures (i.e., integrate pictorial and textual information by looking more/less frequently to pictures) and *when* to do so (i.e., during initial construction of a representation or when confirming/elaborating upon it) to take advantage of pictures or to focus on text as comprehension is developed.
The differences in when pictures were used during the Hypertension and Exercise subexperiments suggests that different types of pictures (e.g., more vs. less diagrammatic) may be more useful to different aspects of comprehension processing (i.e., creating an initial representation vs. confirming/elaborating upon that representation). Another possible reason for the differing picture viewing could be the greater semantic overlap between text and picture in the exercise passages (compared to hypertension passages). Every phrase within the exercise texts clearly overlapped with the picture, whereas only chunks of hypertension text overlapped with only one of the available pictures (relevant picture). This greater, more obvious overlap in exercise passages, combined with the clear usefulness of the stretch diagram, might have presented more opportunity for the exercise picture to be used as a text comprehension support right away (during the initial read). Perhaps within hypertension passages, in which far more information was contained in text than in pictures, and pictures were far less diagrammatic than the stretch pictures, readers had to (or were encouraged to) develop an initial understanding of the textual information before recognizing the points at which pictures could support model development.

A remaining issue is the fact that our Exercise subexperiment findings directly contrast those of Hegarty & Just (1993), who studied how individuals varying in cognitive abilities integrate text and pictures over the course of reading multimedia. The authors suggested that compared to lower domain-ability individuals, higher ability individuals interrupted reading to integrate diagrams with text less frequently because they are able to construct an initial representation (not yet situation model-level) from text, without needing the support of pictures. Their explanation implies that during the initial read of a
text, integrative looks between text and pictures reflect readers’ difficulty in building representations purely from the text. We replicated this finding with our hypertension passages (though we found no indication that looking behaviors during the first pass related to comprehension). However, we found that higher health literacy individuals (we did not directly measure spatial ability) utilized pictures more than the lower literacy participants when constructing an initial representation of exercise passages, and that participants with better comprehension looked more frequently, and for longer times, to pictures when reading. In this case, one might draw the conclusion that integration of pictorial information with text is a sign of effective representation-building, rather than difficulty doing so. Our finding of correlations between initial representation construction processes and comprehension supports this idea. So although processing patterns varied, both within our subexperiments and with regard to Hegarty & Just (1993), I draw the conclusion that looking between text and picture during early stages of processing does not necessarily indicate difficulty with processing. Higher ability individuals appear to be simply better at effectively integrating pictorial and textual information, and do so at a phase of processing (perhaps determined by the type of pictures/passages) that most benefits their overall understanding.

Health literacy and its associated abilities (e.g., health knowledge) appear to have an interesting impact on elders’ processing of multimedia health documents, influencing the strategy individuals take as they work to understand multimedia passages. Not only do older adults with higher health literacy rely upon pictures when developing their understanding, using pictures at different points of processing the material, they also tended to use a more effective (in terms of benefitting comprehension) phase-based
looking strategy than did lower health literacy elders. However, the nature of the strategy itself likely depends upon the nature of the multimedia materials being read.

**Limitations of the study**

Our study was limited in several ways. In our Hypertension subexperiment, pictures were not specifically designed to organize the comprehension of text. Even relevant pictures were not optimal, overlapping with only a portion of textual information and unrelated to many concepts mentioned in the text, and multimedia learning theory argues that effective pictures should both overlap with text (Mayer, 2001; Schnottz, 2005) and explicitly depict relationships between textual concepts (Gyselinck & Tardieu, 1999; Glenberg & Langston, 1987). Though this allowed us to examine multimedia processing of realistic hypertension materials, older adults with lower knowledge and/or health literacy might benefit from better-designed pictures. The study also did not include a text-only condition. As a result, we can only address whether less knowledgeable participants relied more upon pictures than those with more knowledge, not whether they benefitted more from the presence of pictures.

Due to our small sample size, we can only draw tentative conclusions regarding the exact relationship between process variables, knowledge, and comprehension accuracy. A larger sample size would also enable us to separate effects of verbal ability (measured by vocabulary) and domain knowledge. We also did not measure spatial ability, which plays a part in readers’ ability to understand text that describes spatial relations (i.e., our exercise texts). Our comprehension questions within the Medication-taking subexperiment were
not optimal, and as a result we could not take question accuracy as a measure of readers’ understanding of the texts.

Lastly, because our findings are correlational, any interpretation related to causation (e.g., a certain re-reading strategy improves comprehension) is speculation that must be addressed with more controlled studies, and with a larger sample size that allows us to tease apart the separate impacts of health literacy and knowledge.

**Implications**

This study's most valuable contribution has been the adaptation of a reading/re-reading paradigm for application to the processing of multimedia, introducing a new technique for investigating the processing of text and pictures at the level of eye movements. Past work on multimedia processing has typically focused on global, overall reading patterns rather than breaking down reading into discrete phases of situation model development. Despite the methodological limitations of our study, and the fact that we did not definitively support one particular phase-based processing strategy, our analysis paradigm helped us move past simply analyzing global looking behaviors (e.g., more time spent on text than pictures; fixation duration longer on pictures than text) to breaking down the reading process itself. With the paradigm we were able to reveal that individuals of varying health knowledge and health literacy levels appear to have different approaches to processing multimedia health information across two phases of situation model construction, and that these strategies are related to comprehension. Based upon their ability levels, readers used pictures differently and at different points of processing. We also found indications that higher knowledge individuals were better able to
differentiate between relevant and irrelevant pictorial information (see Hypertension subexperiment).

Despite the value of our analysis strategy, the practical implications of this study are not as clear-cut, though the findings may have implications for training and the general design of multimedia documents. With regard to training, the existence of ability- and comprehension-related multimedia reading strategies presents the possibility that lower ability individuals, or those who struggle to understand the material, might learn how to implement effective processing strategies. Given the different processing patterns found in the Hypertension and Exercise subexperiments, any learning strategies would have to be sensitive to the type of picture-text material in question. But, if researchers revealed the optimal way for readers to process the material – for example, if comprehension is strongly linked to focusing almost entirely on text during the first read, and using pictures to supplement understanding during re-reading – perhaps lower-ability individuals could be trained to treat the material in this manner.

In terms of multimedia design, this study essentially provides further rationale for existing design recommendations. For instance, current multimedia design suggestions include directions to avoid placing pictures within a block of text that should not be broken up, place pictures close together to ease integration processes/working memory load, not include overly redundant or extraneous pictures, and so forth (examples of design principles can be found in Holsanova et al., 2008; Mayer, 2001; Mayer & Moreno, 2003; etc.), to avoid issues such as cognitive overload and split-attention effects. The current study provides evidence that if such design recommendations are ignored, the consequence could be a disruption in readers’ situation model processing. Pictures can lose their value if
they are not used at appropriate points in processing. Arranging pictures/text in a confusing or cognitively-stressful manner may not only negate any benefits that pictures could otherwise provide, but may negatively impact readers’ ability to effectively process text into a situation model. In addition, using pictures that are unrelated to the text is not an effective means of supporting comprehension, and less knowledgeable/health-literate readers are more likely to try to process these pictures. This behavior indicates that including extraneous, decorative pictures can lead to distraction, potentially harming comprehension rather than supporting it.
REFERENCES


APPENDIX A: EXAMPLES DISPLAYS FOR EACH SUBEXPERIMENT

Subexperiment 1: Hypertension passages

The cells of the body need oxygen and food to survive. Oxygen and nutrients are carried to all parts of the body through the blood. The heart pumps blood out of its chambers through blood vessels through arteries. Blood pressure is the force applied against the walls of the arteries as the heart pumps blood through the body. The pressure is determined by the force and amount of blood pumped and the size and flexibility of the arteries. This can lead to atherosclerosis, where fatty material and plaque are deposited in the wall of an artery, impairing blood flow.

Subexperiment 2: Exercise passages

Sit down and straighten your left leg. The sole of your right foot should rest next to the inside of your straightened leg. Lean forward from your hips and reach toward your foot. Keep your left foot upright with the ankle and toes relaxed. Repeat with right leg.
Subexperiment 3: Medication-taking passages

DIRECTIONS: Pills in the bottle with the blue label are Beta Blockers, and must be taken regularly – at the same time each day. Ask your doctor or pharmacist if you can take your beta blocker with food. If you forget to take your Beta Blocker on time, take it as soon as you remember. However, if it is almost time for your next dose, skip the dose you missed and go back to your regular schedule. DO NOT DOUBLE DOSE. Take 2 tablets at 6:00 a.m. and 2 tablets at 4:00 p.m.
APPENDIX B: EXAMPLE MAPS OF AREAS OF INTEREST (AOIs) FOR EACH SUBEXPERIMENT

Subexperiment 1: Hypertension passages

The cells of the body need oxygen and food to survive. Oxygen and nutrients are carried to all parts of the body through the blood. The heart pumps blood out of its chambers through blood vessels through arteries. Blood pressure is the force applied against the walls of the arteries as the heart pumps blood through the body. The pressure is determined by the force and amount of blood pumped and the size and flexibility of the arteries. This can lead to atherosclerosis, where fatty material and plaque are deposited in the wall of an artery, impairing blood flow.

Subexperiment 2: Exercise passages

Sit down and straighten your left leg. The sole of your right foot should rest next to the inside of your straightened leg. Lean forward from your hips and reach toward your foot. Keep your left foot upright with the ankle and toes relaxed. Repeat with right leg.
Subexperiment 3: Medication-taking passages

DIRECTIONS: Pills in the bottle with the blue label are Beta Blockers, and must be taken regularly – at the same time each day. Ask your doctor or pharmacist if you can take your beta blocker with food. If you forget to take your Beta Blocker on time, take it as soon as you remember. However, if it is almost time for your next dose, skip the dose you missed and go back to your regular schedule. DO NOT DOUBLE DOSE. Take 2 tablets at 6:00 a.m. and 2 tablets at 4:00 p.m.
APPENDIX C: EXAMPLE QUESTIONS FOR EACH SUBEXPERIMENT

*Note: all example questions were paired with the passages depicted in Appendix A

Subexperiment 1: Hypertension passages

Question 1: Does blood pressure apply force from the outside of the artery wall? [Correct response: No]

Question 2: Does the artery wall appear to have more than one layer? [Correct response: Yes]

Question 3: Is the size and flexibility of the arteries the only thing that determines blood pressure? [Correct response: No]

Subexperiment 2: Exercise passages

Question 1: Are both your legs straight? [Correct response: No]

Question 2: When doing this stretch, do you reach towards both feet at the same time? [Correct response: No]

Question 3: Do you first reach towards your foot, then point your toes? [Correct response: No]

Subexperiment 3: Medication-taking passages

Question 1: Should you consult your doctor before deciding to take this pill at mealtimes? [Correct response: Yes]

Question 2: Do you take 4 pills over the course of 24 hours? [Correct response: Yes]

Question 3: Do you take 1 pill at 4:00 p.m.? [Correct response: No]