The Effects of Text-Picture Integration and Auditory Distraction on Reading Comprehension in Adults: An Eye-tracking Study

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Abstract

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Many models of reading include cognitive components such as memory and attention in addition to the linguistic processing aspects; however, the particular effects of these other resources have yet to be clearly defined. The current study seeks to look at the effects of attentional resource manipulation on the reading process through the use of comic viewing, auditory distraction and dual-task paradigms. The study uses both behavioral measures (comprehension question performance) and eye-tracking measures (fixation time, revisits) to investigate the effects of increased cognitive load on the reading process in healthy, literate adults. The study found that healthy adults used the presence of comics to attenuate the effects of distraction and increased cognitive load on the comprehension process. Without the additional visual information of the comics, the participants showed a significant increase in the number of attempts to reread material (i.e. revisits) due to the distractor/dual-task presentation while still exhibiting notable decreases in comprehension. Furthermore, additional correlations were found between several cognitive testing measures and the participants’ performances in both the comprehension and eye-tracking measures across conditions. The results of this study provide valuable insight into future stages of this study, informing further research with both healthy adults and clinical populations such as people with aphasia or traumatic brain injuries.
# Table of Contents

I. List of Tables and Figures........................................................................................................ iii

II. Background ............................................................................................................................. 1
   i. Word-Level Models of Reading ......................................................................................... 3
   ii. Models of Sentence Processing ....................................................................................... 7
   iii. Discourse-Level Reading Comprehension ................................................................... 10
   iv. Cognition and Aging ...................................................................................................... 14
   v. Cognition and Aphasia ..................................................................................................... 17
   vi. Manifestation of Cognitive Differences in Reading ..................................................... 22
   vii. Eyetracking in Reading and Picture Viewing ................................................................. 26

III. Study 1 .................................................................................................................................. 30
   i. Research Questions ............................................................................................................ 30
   ii. Participants ....................................................................................................................... 35
   iii. Stimuli ............................................................................................................................... 36
   iv. Procedure .......................................................................................................................... 39
   v. Results ............................................................................................................................... 42
   vi. Discussion ......................................................................................................................... 48

IV. Study 2 .................................................................................................................................. 53
   i. Research Questions ............................................................................................................ 53
   ii. Design ............................................................................................................................... 59
   iii. Data Acquisition and Analysis ....................................................................................... 63
   iv. Results ............................................................................................................................... 64
   v. Discussion ......................................................................................................................... 79
vi. Limitations .................................................................................................................88
vii. Future Directions .......................................................................................................88

V. References......................................................................................................................91
VI. Appendix A - Example Story Stimuli for Eye-tracking Task.................................99
VII. Appendix B - Verbal Instructions to Participants for the Eye-tracking Task ..........115
VIII. Appendix C - IRB Approval for Dissertation Study....................................................116
List of Tables and Figures

Tables

1. Participant Demographics, Hearing and Vision Screening Results.................................35
2. ANOVA Results from Story Balancing between Blocks of Four Stories Each ..............37
3. Cognitive Testing Results for All Participants .............................................................43
4. Eye-tracking and Comprehension Question Scores for All Participants ....................44
5. T-Test Results for Comprehension Scores ..................................................................45
6. T-Test Results for Text Fixation Time in Seconds .........................................................46
7. T-Test Results for Total Reading Time in Seconds .......................................................47
8. Correlations between Comprehension Scores and Other Measures .........................48
9. Demographic and Cognitive Testing Results for All Participants ..............................65
10. Eye-tracking and Comprehension Question Scores for All Participants ..................67
11. ANCOVA Results for Comprehension Score ..............................................................69
12. ANCOVA Results for Time to First Response ...............................................................71
13. ANCOVA Results for Time to Final Submission ..........................................................71
14. ANCOVA Results for Question Subtypes .................................................................72
15. ANCOVA Results for Text Fixation Time .................................................................73
16. ANCOVA Results for Total Fixation Time .................................................................73
17. Correlations between Comprehension Scores and Cognitive Linguistic Measures ....76
18. Correlations between Text Fixation Time and Cognitive Linguistic Measures ..........77
19. Correlations between Total Fixation Time and Cognitive Linguistic Measures ..........78
Figures

1. Reading Processing via Dual Route Cascaded and Triangle Models .................................................. 6
2. A Sentence Processing Model Based on ACT-R Framework ......................................................... 10
3. Presentation of Sentence Stimuli in Comic and Text-Only Formats ................................................ 38
4. Presentation Order of a Story during Eye-tracking Task ................................................................. 41
5. Presentation Order of a Story during Eye-tracking Task ................................................................. 63
6. Mean Comprehension Score in Each Eye-tracking Condition ........................................................ 70
7. Mean Text Fixation and Total Fixation Times in Each Eye-tracking Condition ......................... 74
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Dedication

For Iomi, who kept me on track during the hardest parts of this journey.
**Background**

Despite the advancements of modern culture towards the mass distribution of television, film, and streaming video for a wide variety of purposes, reading continues to be a common and popular medium for entertainment, education and communication. According to a series of polls by the Pew Research Center, around 82% of Americans read books on a regular basis, 58% read newspapers, and 48% read magazines or journals (Rainie, Zickuhr, Purcell, Madden, & Brenner, 2012). Furthermore, older adults are using the Internet and electronic media for these purposes at a steadily growing rate, as 59% of Americans over 65 report browsing websites and using email (Smith, 2014). All of these methods of communication require both basic literacy skills and the ability to parse combinations of text and pictorial information.

While at its core reading is a linguistic process, it relies heavily on several other cognitive systems (e.g., attention, memory, executive function) to receive and integrate sufficient input for accurate processing (Perfetti, 2000). Once visual information is acquired, a successful attempt at reading comprehension beyond the word level requires processing beginning at the graphemic level which extends through discourse-level reading. If any of these ancillary cognitive systems becomes disrupted due to age or injury, downstream comprehension processing can be impaired. While normal aging does result in cognitive impairment, changes in processing speed and resource capacity have been observed, though typically at levels that have minimal bearing on reading comprehension in daily life (Borella, 2006).

On the other hand, adults who suffer neurological damage due to stroke, neurodegenerative disease, or traumatic brain injury can exhibit changes in language processing, especially if damage occurs in the left hemisphere. Aphasia is the subsequent, acquired impairment of receptive and/or expressive language processing that occurs in these cases, and can affect one or more modalities (e.g., speaking, listening, writing, reading). While originally
considered an isolated language impairment, aphasia frequently co-occurs with changes in other aspects of cognition (e.g., memory, attention) (Murray, 2012). If these cognitive-linguistic changes diminish the efficiency and accuracy of the reading process, (e.g., through impairments in graphemic input or lexical-semantic processing), a diagnosis of alexia may be given. Alexia, defined as an acquired reading impairment, has been detected in between 65% (Brookshire, et al., 2014) and 80% of people with aphasia (Wilson, 2008). The existence of more significant impairments to these other cognitive processes, when combined with the decrease in lexical access from aphasia itself, can lead to more severe presentations of alexia.

Depending on the severity of impairment, alexia can drastically alter a person’s ability to engage with both print and digital media due to impaired comprehension of written text. This disconnect from information can affect a person’s lifestyle, changing how they can communicate with others (e.g., via text or email) and the variety and depth of information sources available to them. This can lead to decreased quality of life from feelings of social isolation and lack of engagement in previously enjoyed activities and hobbies. The addition of pictures in the presence of text further increases the visual complexity presented to the reader, which may tax already impaired cognitive systems in some people with aphasia. If the reader cannot compensate for this distraction, it will further decrease their comprehension efficiency; however, if the reader is able to use the pictures to access semantic information that would otherwise be lost due to alexia, the pictures may potentially aid comprehension by providing context and non-linguistic semantic information. The studies described below measured the interactions between text-picture integration and cognitive performance on reading comprehension in healthy adults across the lifespan. As reading is a virtually automatic process in healthy, literate adults (LaBerge and Samuels, 1974), the reading task will not overburden the reader’s cognitive resources alone. An
auditory dual-task paradigm will be used to increase cognitive load in an attempt to overload attentional resources that are considered vital in a number of reading models (e.g., Lewis & Vasishth, 2005; Goldman, Varma, & Cote, 1996). This will allow for analysis of how increased cognitive burden can affect the reading process in a linguistically intact reader. The data collected in the current study will serve as initial normative data for the comprehension and eye-tracking measures used with future iterations of this line of study, exploring performance in people with aphasia and other adults with reading impairments.

**Word-Level Models of Reading**

In order to understand how other cognitive resources interact with language functions in the brain, this paper will explore theories and models of language processing, beginning at the single-word level and moving to sentence and longer-form, discourse levels. The two current prevailing theories of word-level reading comprehension are the Dual Route Cascaded (DRC) model (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001) and the latest iterations of the Triangle model (Harm & Seidenberg, 2004). The DRC model assumes that word reading, for both comprehension and pronunciation, are guided systematically by a set of lexical rules that allow the brain to decipher meaning and phonology from the orthography in a semi-hierarchical manner. The triangle model assumes that the different aspects of a word (orthography, semantics, phonology) all have mutual, simultaneous influence, creating “soft constraints” on the pronunciation and meaning of a word (Rayner & Reichle, 2010).

The concept of a dual-route process for reading was first suggested in the 1920s by de Saussure, who speculated that unknown words had to be read letter-by-letter whereas familiar words were read almost instantaneously (Coltheart, 2005). The current DRC model expands upon this concept further, featuring three routes, as shown in Figure 1 below. These routes
consist of a lexical-semantic route, a lexical-non-semantic route, and a grapheme-phoneme conversion route. The lexica found in the DRC model represent the idea that words are stored holistically and discretely and do not require compilation from a series of semantic features. This model is bidirectional within the lexical routes, suggesting that there is consistent feedback and feedforward between the different processing areas of both an excitatory and inhibitory nature, but unidirectional for grapheme-phoneme conversion (Coltheart, et al., 2001).

Figure 1 depicts the process of oral reading according to the DRC model; however, it should be noted that reading comprehension does not necessarily require the articulatory system for proper processing, though it may nonetheless have influence due to the feedback system displayed in this model. Reading comprehension, instead, would primarily be reliant upon accessing the semantic system for comprehension processing, which necessitates access through the lexical processing route. According to the DRC model, this begins when orthographic symbols are processed for visual features, which are then identified as specific patterns of letters (e.g., the word “cat” is analyzed as its constituent letters c, a, and t.). These letter units are sent to the orthographic input lexicon, where they are checked against known words. The orthographic input lexicon is the theoretical store of all known words in written or typed form within a person’s vocabulary, and as such, when these graphemes are first processed, there are likely to be multiple words with similar graphemes in nearby positions to the target that are activated within the lexicon (e.g., cat vs. cut vs. rat vs. scat). All of these patterns will begin to activate, with stronger activations for patterns which match more closely to the graphemes of the reading target (i.e., For “cat,” “cut” would activate more than “cute.”). As this is a bidirectional process, feedback is provided from the orthographic input lexicon to the letter identifying units and a feedforward response comes to the orthographic input lexicon in return until a singular response,
or several similar responses, achieve a sufficient activation threshold and are selected. As there are both excitatory and inhibitory connections between these two stages, this threshold is achieved by both heightening the activation of the target item in the lexicon (e.g., cat) and suppressing the similar competing items (e.g., cut, rat, scat) that would cause interference. During this process, there is additionally some cross-talk between the orthographic input lexicon and semantic systems, and the feedback between these two affects the speed and accuracy of target selection; however, once the target is selected, the orthographic input lexicon begins accessing features of the target word within the semantic system in earnest (e.g., has fur, four-legged, purrs and meows). The feedback from the semantic system to the orthographic input lexicon serves as a means of double-checking and cementing the activation of the singular target word (e.g., cat) in cases where a dominant activation level isn’t initially achieved. This semantic information is used downstream at the sentence and discourse level to construct the appropriate thematic roles and schema used in more complex levels of reading comprehension. Information is also fed forward to the phonological output lexicon, even when the task does not require oral output. It is known that people activate their phonological systems even when reading silently due to measurable levels of subvocalization during reading, and this has been shown to have an effect on comprehension (Slowiaczek & Clifton, 1980).

At the same time that this lexical-semantic route is being activated, the lexical-non-semantic route and the grapheme-phoneme conversion route are also activated; however, as stated above, their primary function is for oral reading, not reading comprehension. These paths use language-specific rules of letter-to-sound conversion to allow for oral reading without deeper semantic processing. While the grapheme-phoneme conversion route does not have any effect on semantic processing, there may still be residual feedback from the phonological output lexicon.
that has some influence on the orthographic input lexicon and semantic system during the process of reading internally, due to the aforementioned practice of subvocalization. Because each of the three routes processes orthographic information in parallel, the DRC model predicts that regular words are read and pronounced more rapidly than irregular words or nonwords because multiple routes will all arrive at the same conclusion and the feedback within the system will achieve its threshold more quickly.

![Diagram](image)

**Figure 1.** Reading processing via the (left) Dual Route Cascaded Model (Coltheart, et al., 2001) and (right) Triangle model (Harm & Seidenberg, 2004).

The other major model of word recognition, the Triangle model, is based on assumptions that contradict those found in the DRC model. There are several iterations of the Triangle model, the most frequently cited being Harm and Seidenberg (2004). The Triangle model predicts that a word’s pronunciation is determined by a unique set of connections and activations between orthographic input and phonological output while lexical information is represented as distributed across the connections and activation patterns within the model. Figure 1 depicts the Triangle model with larger ovals representing computational layers (i.e., the computer version of
a cluster of neurons) whose activation patterns represent the different forms of information (e.g., semantics, orthography, phonology). The small circles between each of these larger layers represent “hidden units” in the computational model, which allow modulation of the connection strength between each of the major processing groups (Seidenberg, 2005). These smaller circles do not represent any specific cognitive processes involved in reading, but theoretically their manipulation could be used to reflect developmental differences or acquired damage to connections within the language systems of the brain.

Whereas the DRC model handles the input and output lexica as discrete structural concepts, the Triangle model represents these as patterns of activation across the entirety of the linguistic processing network. The excitation and inhibition of a given word (e.g., “cat”) becomes a learned pattern that strengthens (i.e., induces a higher, more differentiated level of activation) with each iteration of exposure until it becomes a unique set of signals. Despite major differences in modeling the representation of the reading process, the Triangle model, like the DRC model, predicts that regular and more frequent words are read and pronounced more quickly than irregular and low-frequency words (Reyner & Reichle, 2010). The aforementioned models only handle single-word processing; however, reading is typically a sentence and discourse-level linguistic process. As such, these single words must feed into a larger system to build more holistic understanding of the text.

Models of Sentence Processing

While single-word models are important for understanding much of how lexical and semantic access works, those models do not predict how the brain interprets multiple words together to build context and relationships within a sentence. Regardless of whether the DRC, Triangle, or some yet-to-be-created model proves to be the most appropriate way to depict
single-word processing, the information gathered must be compiled to form more complex and coherent concepts. These sentence-level models take the information gained at the single-word level and build upon it to form syntactically accurate and thematically coherent schema. There are two major classes of sentence processing models, constraint-based models and garden-path models. The majority of early research focused on garden-path models (e.g., Ferreira & Clifton, 1986; Rayner & Frazier, 1987); however, later research has shifted towards constraint-based models, as they account for more factors than just syntactic complexity. These models have come to supplant garden-path models in modern research, and will be the primary focus of this section, after a description of their predecessor.

Garden-path models were first presented in the 1970s by Frazier and colleagues, and a number of variations have been described in the subsequent decades; however, all of the models share the same basic assumption about the order of processing. Garden-path models describe a system in which the reader constructs a singular interpretation of the sentence as they read, word-by-word, and this interpretation is only revised once the reader encounters a word or phrase that does not fit with the initial syntactic parsing of the sentence. For most, if not all, garden-path models, syntactic processing is the primary concern of processing, with semantic plausibility bearing little to no weight in parsing the sentence. These models get their name from garden-path sentences, which describe this phenomenon. For example, the classic garden path sentence, “The horse raced past the barn fell,” would be processed normally word-by-word until reaching the final word. Since “The horse raced past the barn,” is a syntactically plausible sentence, there would be no revisions until the reader happens upon the word “fell.” At this point, the reader would need to reanalyze the sentence and reinterpret it as “The horse [that was] raced past the barn fell” in order to make it syntactically coherent. This concept is known as a serial, depth-first
processing, because each word is analyzed in sequence (serially) for as many words as possible (depth) before revisions are made (Frazier, 1995).

Constraint-based models have recently replaced garden-path models as the prevailing system of sentence processing. These models suggest that syntax is but one of many aspects of the sentence being processed simultaneously, along with semantic plausibility, contextual constraints, appropriateness, and other factors (Rayner & Reichel, 2010). According to a review by Rayner and Clifton (2002), there are a number of factors in sentence processing, such as meaning and plausibility that can far exceed and obscure grammatical complexity’s effect on reading comprehension, and these factors are not fully accounted for by garden-path models.

Another advantage of these constraint-based models over the garden-path models is that they have been successfully implemented in computerized connectionist simulations; however, even these improved models cannot produce results fully consistent with the results seen in behavioral testing, and these simulations take far too many processing cycles to determine a single interpretation of a given sentence (McRae, et al., 1998).

One such model was created by Lewis and Vasishth (2005) based on the Adaptive Control of Thought – Rational (ACT-R) framework (Anderson & Lebiere, 1998); Figure 2 below depicts this model in five steps. First, after decoding the orthography of a word, resources for lexical (and theoretically semantic, though it is unstated) access are apportioned (1) and this lexical representation is held in the lexical buffer (2). Then, the syntactic category is determined after which, the concept tagged for retrieval for further processing (3). Space is made for the new word (4) within the working memory buffer where the rest of the sentence is held (5). Then the new word is attached to this memory structure (6) and the syntactic expectations are updated for the rest of the sentence (7). After this, attention moves to the next word (8).
Figure 2. A sentence processing model based on Adaptive Control of Thought – Rational (ACT-R) framework. (Lewis & Vasishth, 2005).

Models like this one provide a general idea of how sentence processing works with respect to working memory and other cognitive factors; however, they are not without limitations, as they do not accurately predict how differences in verb complexity, morphology and other factors affect behavioral aspects of reading, such as reading speed and accuracy of comprehension. Another limitation of these models is that they do not completely explain how information is integrated further into comprehensive schema required to understand long-form texts. For this, even broader-scope, discourse-level models are required.

Discourse-Level Reading Comprehension

Many of the holistic models of reading comprehension are computational models, and while they have some relation to the physiological and cognitive processes displayed in actual reading, much of the focus is devoted towards the accuracy of the computations behind the scenes, rather than their correlation with actual cognition. As a result, there are many
computational models which can mimic the test results seen in practice, but do not do a sufficient job of explaining how they work.

The earliest model to describe reading at the discourse level more in terms of cognitive processes is the Construction-Integration (CI) model, which emerged in the 1970s. This model, created by Kintsch and Van Dijk (1978), is primarily driven by limitations in working memory. The model is based on the assumption that the reading of written language is built around three separate representations of the text as it is read. There is a lexical (i.e., word-level) representation which is then compacted into a semantic representation of the text’s meaning and a conceptual, situational model.

According to the CI model, only one sentence at a time can be represented as a word-for-word copy in working memory, due to the limited resources for such storage. Once this sentence is analyzed and the next sentence is targeted to process, the information from the current sentence is stored as an abstracted, semantic representation of the information provided, and the lexical and syntactic representations are discarded. The remaining concepts are stored as a series of propositions. Once these new propositions are organized, they are joined with any pre-existing propositions from earlier text to check for and maintain coherence of the overall narrative as it is presented. Meanwhile, the reader also develops a situational model related to the concepts expressed in the text. The situational model is a reader-constructed representation of the world described by the given text as understood by the reader. As the reader processes the text, they effectively create an imaginary depiction of the characters and events as they follow the rules of the world in the text. According to Kintsch, this is how the reader gauges his or her understanding of the text because, if the reader cannot develop an appropriate situational model,
they likely will not understand more than the surface level of the text, if anything at all (Kintsch, 1988).

Another model with similarities to the CI model was developed by Gernsbacher, Varner, and Faust (1990). Called the Structure Building Model, it relies on the incoming information being grouped into relevant conceptual schema by the reader. When a reader begins analyzing a text, they create a foundation for comprehension based on the first few words and sentences. Other information is then analyzed to see if it is related to this first conceptual structure, and if it is, it is then integrated. If it is not, a new structure is created to hold that information. As the reader progresses and more structures are built, the reader must begin suppressing less relevant structures due to the finite capacity of the reader’s cognitive resources. Readers who are able to integrate information better as they read will have fewer independent structures to manage, which theoretically frees up more cognitive resources for further comprehension. Conversely, readers who have more limited cognitive resources (e.g., lower working memory capacities), are more likely to have to suppress tangentially relevant information or fail to integrate it properly in the first place, decreasing their overall comprehension of the text.

A third model, created by Goldman, Varma, and Cote (1996), builds upon the ideas laid out by Kintsch and combines them with some of the ideas found in Just and Carpenter’s Constrained Capacity READER model (1992). Compared to Kintsch’s model, the Constrained Capacity READER model assumes more information needs to be manipulable during reading, meaning it resides longer in working memory, making working memory capacity the largest constraint on reading comprehension at the sentence level. The model assumes that at each hierarchical level (word, phrase, etc.) there is an activation threshold that determines whether it is included in the comprehension process. If a target achieves the required level of activation, it
is brought into working memory. The computerized version of this model is able to simulate comprehension effects due to differences in working memory that result from age-related effects and differences in comprehension level when comparing lower- and higher-skilled readers with respect to resolving lexical ambiguity and properly comprehending embedded sentences; however, it is more of a sentence-level processing model because there are limitations in its ability to create larger schemata across larger chunks of information (e.g., multiple paragraphs or pages).

Goldman and colleagues’ version is called the Capacity-Constrained Construction-Integration (CCCI) model. Because it introduces further memory limitations on the CI model, this model must parse the text more quickly and move things towards integration with the situational model (or be discarded) so that they can be removed from the working memory buffer. In order to account for the differences in memory capacity and cognitive processes, they propose an additional mechanism over and above those seen in the original CI and CC READER programs, called the Strategy Competition Module (Goldman & Saul, 1990). This conceptual module would contain certain aspects of metalinguistic knowledge that would allow for shortcuts in the comprehension process: knowledge of rhetorical devices that signal changes in topic, tone, etc.; knowledge of common discourse schemes (e.g., paragraph arrangements with thesis sentence first and conclusion last); monitoring processes for comprehension; and repair processes to fix apparent errors in comprehension. By having access to this outside knowledge, it decreases the amount of these structural concepts that need to be rebuilt with each new attempt at reading (Goldman, Varma, & Cote, 1996).

Overall, there are many similarities between these models, which give us some clues as to how cognition is likely tied to reading comprehension due to the common reliance upon aspects
of attention, memory and executive function. While there is demonstrably a wide range of normal function in each of these areas among healthy adults, these resources can change with age and neurological damage, which can thus affect reading comprehension in older populations as well as people with aphasia, who often demonstrate other cognitive impairments.

_Cognition and Aging_

It has been shown that many otherwise healthy older adults show mildly decreased cognitive speed and resource capacities which affect cognitive and linguistic processing in laboratory settings, even when activities of daily life are generally unaffected. Decreased grey matter volume across many cortical and subcortical areas (e.g., frontal cortex, hippocampus, cerebellum, etc.) as well as a concurrent thinning of white matter connections correlate with these decreases in processing speed and capacity (Reuter-Lorenz & Lustig, 2005). Additionally, there are many task-specific changes to activation patterns in the brain, with over-activations and under-activations shown in older adults on tasks which place high demands on executive functions and attention (Madden, Whiting, & Huettel, 2004) as well as working memory (Reuter-Lorenz & Sylvester, 2004). The decreases in available cognitive resources and processing speed that have been observed in these studies should theoretically have downstream effects on more complex processes such as reading.

Beyond the physical changes that occur to the eye with age (e.g., crystallization of the lens) (Scialfa, 2002), which can decrease the fidelity of visual input, and thus impair downstream processing of visual information, the anatomical and physiological changes within the brain also result in decreased visual attention and processing, especially dividing and switching attention (Madden, Whiting, & Huettel, 2004). It is theorized that these changes to attention may be in part
due to changes in working memory processing and executive functions that are commonly seen in healthy aging, which put further stress on attentional resources (Miyake, et al., 2000; MacPherson, Phillips, & Della Sala, 2002).

A meta-analysis of attention testing in older adults found that whenever the amount of time provided per step was extended or extra steps were added to tasks, the effects of age-related attention deficits arose. There were little-to-no effects seen in Stroop tests or negative priming tasks (i.e., tasks of focused and selective attention), but age-related effects emerged in dual-task methodologies (e.g., simultaneous visual and auditory reaction time tasks) or those that required a frequent and significant amount of attention switching between two information sources or modalities. In these cases, older adults showed longer reaction times; however no decrease in accuracy was reported. Many of these more complex tasks are also closely tied to executive functioning abilities due to the executive control over attention allocation, inhibition, and other complex functions (Verhaeghen & Cerella, 2002). This may be suggestive of an age-related decrease of executive functioning resources, as the simpler and shorter tasks do not overburden the available resources while the longer and more complex tasks show an additive slowing effect as processing reaches a bottleneck due to the limited resources.

Like the results found in the analysis above found, MacPherson, Phillips and Della Sala (2002) also found that the age-related changes to executive functions were task-specific. Comparing results from younger, middle-aged, and older adults, the researchers found that there were more age related effects on the Wisconsin Card Sorting Test, Self-Ordered Pointing Task, a shape-based delayed-response task, and an emotion identification task. They did not find age-related effects on a gambling task or a social faux pas detection task. Three of the four tasks with significant findings are associated with processing in the dorsolateral prefrontal cortex, while the
two non-significant findings, plus the emotion identification task, are considered to have more ventromedial processing. These age-related changes to executive functions correlate with anatomical findings which state that the loss of cortical volume is not uniform—while the dorsolateral and orbitofrontal areas of the cortex often lose volume at similar rates, the more medial portions (e.g., the anterior cingulate) seem to be more resistant to age-related degeneration (Raz, et al., 1997).

These changes to attention and executive functions can cause functional impairments to working memory, even when memory capacity and speed are not otherwise affected (Reuter-Lorenz & Sylvester, 2004). As a result, both verbal and visuospatial working memory spans show an effective decrease in older populations (Myerson, et al., 1999). Impairments to inhibitory control and attention can lead to interference during memory tasks by allowing extraneous information to encode into memory, which then interferes with retention and retrieval (i.e., retroactive interference) (West, 1996). Alternatively, material previously encoded on other tasks or trials may not be erased adequately and cause interference on subsequent trials (i.e., proactive interference) (Reuter-Lorenz & Sylvester, 2004). It has been shown that older adults have notably more difficulty with selective attention, which contributes to retroactive interference. This means that distractor tasks and stimuli tend to be more effective with older populations (West, 1999; Connelly, Hasher, Zacks, 1991).

There have been a number of explanations as to how these cognitive changes manifest in older adults, such as the Hemispheric Asymmetry Reduction in Older Adults model (Cabeza, 2002; HAROLD), Posterior-Anterior Shift in Aging model (Davis, et al., 2008; PASA), and Compensation-Related Utilization of Neural Circuits Hypothesis (Reuter-Lorenz & Lustig, 2005; Reuter-Lorenz & Cappell, 2008; CRUNCH). However, despite anatomical and physiological
changes within the brain, it should be noted that typical, healthy, older adults who exhibit any and all of these changes in testing show no significant effects on their ability to perform basic or instrumental activities of daily living. The mild decreases in attention and memory resources that occur with age are not apparent until the person is taxed in ways that are usually only observed in research settings. As such, reading comprehension at the level required for performance of activities of daily living is relatively preserved. Therefore, by manipulating the available cognitive resources through distraction or a dual-task paradigm, age-related changes to reading performance may emerge in older, healthy adults that may not be observed in younger groups. While not a perfect representation of the changes to cognition observed in people with aphasia, the differences in performance between a healthy adult with access to full versus partial resources may provide information about what to expect during later studies, which will include people with aphasia.

**Cognition and Aphasia**

While we do not have a unified model of the interplay between cognition and aphasia, our current evidence suggests that deficits of attention, memory and executive function can have definitive impacts on language processing in people with aphasia, which can amplify difficulties in complex processes such as reading.

While the traditional definition of aphasia is a loss of previously acquired language skill, both receptive and expressive, it is exceedingly rare that this loss occurs in isolation (Murray, 2012). Depending upon the size and location of the injury, a person with aphasia may experience deficits in a number of other areas including attention, executive function, and working memory, which can further impair language processing and lead to variability in language performance in
many people with aphasia (Hula & McNeil, 2008). Attention, working memory and executive functions all have cortical processing areas housed in and around the prefrontal cortex, making them susceptible to concurrent damage with Broca’s area in strokes or diffuse traumatic brain injuries. Likewise, attention and working memory also have more posterior processing and control areas that can be concurrently damaged with Wernicke’s area (Gazzaley & Nobre, 2012). Furthermore, due to the number of white matter tracts running between all of these processing and control areas, they are susceptible to interruption and impairment from subcortical stroke or brain injury even if the cortical areas themselves remain intact. This anatomical proximity is a major contributing factor to the comorbid cognitive changes seen in aphasia.

Due to the wide range of functions involved (e.g., inhibition, initiation, planning), executive functions can have significant effects on communication in people with aphasia. These cognitive processes have often been researched for their effects on communication (Frankel, Penn, & Ormond-Brown, 2007) or for their role in determining treatment effectiveness (Lambon Ralph, et al., 2010). Research has also shown that people with aphasia who have retained better executive function post-stroke have more successful attempts at communication than those with equal language skills and worse executive functioning (Miyake, Emerson, & Friedman, 2000; Ramsberger & Rende, 2002). However, explicit research on executive functions in people with aphasia is relatively sparse.

One example is a 2002 study in which Purdy compared the accuracy, speed and efficiency of people with and without aphasia on a series of cognitive tasks: Wisconsin Card Sorting Test, Porteus Maze Test, Tower of London, and Tower of Hanoi. Purdy found that there was no significant difference in the accuracy of attempts between the two groups on all tasks; however, the people with aphasia were found to be slower and less efficient on all of the tasks as
compared to the control group. As these were not primarily language-based, outside of the explanation of instructions and any internalized thought processes that the person used themselves, this suggests that there are other cognitive factors at play which affect processing speed and efficiency. These tasks are primarily considered to be tests of executive functioning, but it is difficult to fully dissociate executive function from other aspects of cognition (Miyake, et al., 2000).

Dissociating executive functions from other aspects of cognition is difficult because executive functions are also closely related to resource allocation for other cognitive processes, including attention. Many studies of attentional deficits in aphasia have been limited to one or two of the subtypes at a time; however, aggregation of the research findings shows that all forms of attention can be impaired in people with aphasia (Murray, 2012). When attentional resources are taxed in people with aphasia (e.g., through a dual-task paradigm), it has been shown that this has a direct, detrimental effect on language function, both for comprehension (Murray, 2000; Tseng, McNeil, & Milenkovic, 1993) and production tasks (Murray, 2000; Hula, McNeil, & Sung, 2007).

Murray (2012) is one of the few researchers who investigated multiple aspects of attention in a single comprehensive study. This study evaluated visual and auditory forms of attention switching, divided attention, sustained attention, and selective attention along with neglect, working memory and executive functions in people with and without aphasia. The study found that participants with aphasia were significantly more impaired on most of the attentional tasks from the Test of Everyday Attention (TEA; Ward, Ridgeway, & Nimmo-Smith, 1994), despite requiring little to no language processing to perform the tasks themselves. It should be noted that they are not completely non-linguistic tasks, however, as some require responses (e.g.,
the number of tones heard) and directions are still given verbally. Nonetheless, despite the significant group difference, not all of the attentional deficits shown were universal. Only 15% of people with aphasia scored as impaired on all subtests, with 64% scoring as impaired on half of the subtests and 85% as impaired on at least one subtest. The study also found that people with aphasia performed worse on the Behavioral Inattention Test than comparison participants, where 12% showed some level of visual neglect, as well as the Wechsler Visual Memory Span task and the Ruff Figure Fluency Test. Further analysis showed that several subtests of the TEA were significant predictors of auditory comprehension and communication independence. These significant levels of impairment to attention processing are consistent with theories of aphasia that posit that aphasia is not entirely a language-processing disorder and that other aspects of cognition can weaken or compensate for the remaining language function after damage to the brain occurs. This is more consistent with weak cognitive resource models of aphasia (e.g., McNeil, Odell, & Tseng, 1991; Hula & McNeil, 2008) as opposed to a strong model, which would attribute all language deficits to attention, memory and/or executive function (e.g., Murray, 1999).

Changes to executive function in aphasia can also influence successful transactions within working memory, over and above any impairment the working memory system (e.g., decreased capacity) itself may have suffered. Impairments to executive function can affect proper allocation of cognitive resources in complex tasks. Tasks which demand significant attention (i.e., require a heavy cognitive load) stress the central executive within Baddeley’s model of working memory (Baddeley, 2012). If attentional and executive resources are also impaired, this can disrupt the efficiency of working memory storage and recall, effectively making it appear more impaired than if those other systems were intact.
Using a series of n-back tasks, Christensen and Wright (2010) also showed how impaired language functions can influence working memory performance. During computerized 1-back and 2-back tests, people with and without aphasia were asked to keep track of either varieties of fruit, three-dimensional block formations, or “fribbles” (a set of indistinct three-dimensional shapes which look somewhat similar to real objects). In the 1-back task, the healthy adults performed significantly better on the fruit than fribbles, while there was no significant effect within the group with aphasia. On the 2-back task, both groups showed higher performance on the fruit task than fribbles or blocks. Additionally, the healthy adults also showed a higher performance on the fribbles than the blocks, while no such effect was demonstrated in the aphasia group. The researchers postulated that the healthy group’s ability to assign temporary names to the fribbles improved their ability to remember them, giving them an advantage as compared to the impaired language function of the group with aphasia. This lack of efficient labeling ability forced the participants with aphasia to perform the task purely using the visuospatial sketchpad, rather than recruiting the phonological loop.

These working memory deficits have also been shown to cause some downstream effects on comprehension in people with aphasia. Sung and colleagues (2009) investigated how working memory affected both auditory and reading comprehension in people with aphasia. The researchers divided the participants into high and low working memory groups based on performance on a modified sentence span task. Then the participants were given subtests of the computerized version of the Revised Token Test (McNeil & Prescott, 1978) in both auditory and reading forms. The reading forms were varied with either a full sentence being shown at once, the sentence being shown one word at a time with the previous word disappearing, or a condition where the next word appeared on screen and all previous words remained. The study found that
working memory was a factor on comprehension only when directly taxed (i.e., the auditory comprehension task and single-word presentation reading task), but there were no differences during more traditional reading presentations.

The studies above illustrate the deficits of attention, memory and executive function observed in people with aphasia. Given the importance of these cognitive resources to discourse-level reading (e.g., Goldman, Varma, & Cote, 1996), these additional cognitive deficits will further worsen the speed and accuracy of language processing. However, it is important to remember the variable severity and locus of impairment shown across people with aphasia. As such, the decrease in a particular cognitive resource (e.g., attention) in one person with aphasia can differ widely from another; thus, it is important to understand how the differences in performance may manifest during the reading process.

**Manifestation of Cognitive Differences in Reading**

It is evident that while both normal aging and brain injuries which lead to aphasia have the potential to cause changes in cognition, the severity of these differences are highly variable. Furthermore, while people with aphasia show difficulty with lexical-semantic access, healthy older adults show little-to-no change in semantic processing ability (Burke, MacKay, & James, 2000), suggesting that any reading difficulties for this group are more likely to come from non-linguistic processing deficits.

Sentence-level and discourse-level models of reading, discussed above, show that coordination between cognitive and language processing is vital to reading comprehension. The Construction-Integration model (Kintsch & Van Dijk, 1978) requires words to be held in memory for processing, then a semantic representation is extracted and held in its own memory.
while attention is shifted to the next word or phrase. Meanwhile executive function processes help guide the shift of attention, inhibition of distractors and unnecessary textual information. This basic reliance on other cognitive processes also holds for the Constrained Capacity READER model (Just & Carpenter, 1992), Structure Building Model (Gersbacher, Varner, & Faust, 1990), and the Capacity-Constrained Construction-Integration model (Goldman, Varma, & Cote, 1996), though each model utilizes memory, attention and executive function to varying degrees and in different ways. This means that, regardless of which model one subscribes to, the importance of well-preserved general cognition for reading is readily apparent.

Behaviorally, Radavansky and colleagues (1990) found differences between younger and older adults in the ability to store text information verbatim; however, they showed no differences in the ability to construct a situational model, which is heavily reliant on abstraction and semantic processing rather than strict memorization. This means that depending on the method of testing comprehension, the reading performance of older adults may appear more or less compromised. Tasks that tap into word-for-word retention or recognition and specific detail are likely to show older adults as more impaired than tasks that look at the ability to describe main concepts and generalities about the text. Memory differences are a driving force for the change in comprehension due to aging, as the elimination of the memory aspect in such reading tasks resulted in no significant difference between age groups (Borella, 2006).

Keeping this issue in mind, research has also revealed that older adults show decreased comprehension of texts that contain complex syntax (Kemtes & Kemper, 1997). More complex syntactic structures tax working memory (Kemper, 1987), and, as discussed above, older adults have decreased working memory efficiency. Older adults also require more time to process text segments (Stine & Hindman, 1994), meaning that those segments already in memory must be
maintained for longer before processing completes, which puts that information at risk of degradation.

For healthy adults, these effects are not typically severe enough to be debilitating in daily life. As De Beni and colleagues (2007) showed, there are minimal differences in comprehension between younger and older adults with respect to reading narrative texts. The study did find differences in comprehension of expository texts, which once again were correlated with working memory, likely due to the detailed nature of the reading. This recurring theme of memory as the gatekeeper of successful comprehension is intriguing; however, few if any studies that have explicitly investigated this correlation have looked to differentiate whether these are pure working memory capacity constraints or the interplay between changes in memory, attention and executive function due to aging which drive the differences in comprehension.

While causing mild changes to reading comprehension in healthy adults, impairments in these three processes seem to serve as an exacerbating factor for people with aphasia, who exhibit all the same effects as healthy adults but with greater severity and more complications. Due to the impairment of the lexical-semantic system, as well as the ancillary cognitive processes of reading, as many as 80% of people with aphasia are also diagnosed with alexia (Brookshire, et al., 2014; Wilson, 2008). These impairments at the word level work directly against the ability to construct a textbase or situational model that can be used to comprehend written information when presented. When combined with executive dysfunction (Barbey, Colom, & Grafman, 2014) and decreased working memory (Mayer & Murray, 2012), reading comprehension can be severely impaired in aphasia.

Furthermore, while it is clear from the healthy older studies that working memory impairments can have detrimental effects on reading, other studies have shown that impairments
to attention are also common among people with disordered reading (Steinman, Steinman, & Garzia, 1998). In fact, treatment of these deficits in attention has been shown to improve reading comprehension on a case-by-case basis for people with aphasia. Coelho (2005) administered a treatment regimen based on Attention Process Training II in a case study, leading to improvement on several reading tests including the Reading Comprehension Battery for Aphasia (La Pointe & Horner, 1998) and Gray Oral Reading Tests (Wiederholt & Bryant, 2001). The tasks target different aspects of attention and working memory without directly training reading, despite the improved reading outcome. Similar results were found for a second person with aphasia in a follow-up study (Sinotte & Coelho, 2007).

It should be noted, however, that many of these manifestations of age-related differences have been shown to be attenuated by education level. Education has frequently been shown to mitigate many age-related cognitive changes in healthy older adults and even lessens the impact of neuropathologies in people with neurodegenerative disorders or stroke damage (Brayne, et al., 2010). Hultsch and colleagues (1990) found better comprehension performance in healthy older adults with at least a high school education as compared to less than 12 years of schooling. Education is also often correlated with vocabulary level, and having a wider vocabulary has been shown to limit the negative effects of aging on comprehension (Johnson, 2003). As a result, controlling for education level is a vital part of studies in this line of research.

In summary, there are a number of cognitive processes that are involved in reading comprehension, and even healthy, young adults display a considerable range of performance in these areas. Age-related changes to cognition can create further discrepancies in the level of cognitive function among healthy adults due to varying exposure to neuroprotective factors such as education, which can slow age-induced changes. It is the manifestation of these differences in
cognition during reading that the first study, discussed in the next section, and the second study, discussed later, seeks to investigate. The data collected in these studies will serve to inform expectations of how cognitive-linguistic impairments in people with aphasia can impact the reading process, and dictate future studies in this line of research.

*Eyetracking in Reading and Picture Viewing*

The current study utilizes eye-tracking during both traditional text-only reading paradigms and in the presence of static picture scenes (i.e., comic strips) to obtain information about on-line processing during reading. The number and duration of fixations on a particular piece of text or object as well as the direction and distance of saccades between these fixation points can provide valuable information about how quickly and efficiently the reader is processing information. However, average fixation duration and saccade distance during reading is notably different from what is observed in scene viewing or visual search (Rayner, 2009; Rayner, Li, Williams, Cave, & Well, 2007).

In a review of available literature, Rayner (2009) collected and analyzed a number of eye-tracking measures in normal reading of English. The average fixation duration during reading was found to be around 250 ms during English language reading; however, fixations can range from 50 ms to 600 ms. Differences in fixation time can relate to both differences in cognitive speed between people as well as psycholinguistic factors (e.g., word frequency, imageability, etc.) (Rayner, 1998). Revisits, also sometimes called regressions, which are saccades that move backwards across text, occur in 10-15% of eye movements for literate, skilled readers of English. According to the Selective Reanalysis hypothesis, these revisits attempt to move the focus back to the point at which linguistic processing failed (Frazier &
Rayner, 1982), while the Time Out hypothesis explains these revisits as a means of postponing new input while the downstream cognitiving-linguistic systems are still processing the current input (Mitchell, Shen, Green, & Hodgson, 2008).

Scene viewing allows for the processing of more complexity of visual stimuli as compared to text-only presentations. This complexity allows for insight into other aspects of cognition that are not as accessible (e.g., whether the viewer is capable of inhibiting irrelevant visual stimuli in order to focus on the comprehension task). It can also be used to increase semantic activation of certain concepts by activating associated items and contexts, though this also can increase activation of associated competitors.

Studies involving scene viewing are often used to find the optimal organization and balance of items within a given display, which can inform the design of testing and treatment items, as well. For example, according to Wedel and Pieters (2008) (as the work was only available in German), Leven (1991) found that when allowed to view a series of advertisements with a mixture of pictures and text at their own pace, people concentrated mostly on the central visual area for information, with the lowest fixation time occurring in the upper right corner of each scene. They found that after an initial central fixation, the scan path followed a Z-shaped path similar to the way that we read English - beginning in the upper left, and ending in the lower right, despite not being an entirely text-based display. A preference for this same Z-path was also found in comic reading both within a singular panel and across a page containing multiple panels laid out in a linear or grid shape (Cohn & Campbell, 2015). Rayner and colleagues (2001) found that while each individual fixation was longer on average on objects shown in a scene, there were significantly more fixations on any accompanying text. This resulted in approximately 70 percent of all fixation time being spent on the text rather than the objects and scenes pictured.
Investigating the effects of picture presence on text viewing in a different way, Pan and colleagues (2004) looked at webpage viewing through the lens of a memorization task. This mixture of picture and text information makes it similar to the types of advertisements used as stimuli above; however, the stimuli here convey a more narrative, discourse-like information as compared to a standard print advertisement. In this study, participants were asked to either just look at the webpages given or to memorize the content shown on each page. Multiple pages from each site were shown together, in the typical manner one would read a multi-page article or search result. Among the results found by the study, it was shown that as people were familiarized with the site layout, their fixation times decreased, especially on repeated data, and the scan paths varied from the first page to the next, mostly as repeated data was ignored. Due to the repetitive nature of many of the pictures in the storybook and comic formats, this may suggest that during the later panels, less fixation time will be spent on the pictures themselves, and a greater percentage of the time may be spent on reading the text.

Kinzer and colleagues (2012) used eye-tracking to investigate differences in reading and comprehension in sixth-graders in a static scene (i.e., comic strip) and dynamic one (i.e., video game). In this study, one complete arc of narrative was taken from the game Trace Memory and converted into a comic style format. Trace Memory is a “visual novel” style game, which is similar to a digital version of a storybook. One group was given the comic format of the story while the other played the original game version. Both groups were allowed to read at their own pace. After completing the reading, participants were asked 15 multiple choice and seven short answer questions to test comprehension. The participants were then given a visual recall task where they had to indicate the location of several items that were seen in the room during the story. They found that the group who received the more storybook-like game content scored
higher on the multiple choice comprehension questions, but not the short answer questions. The group exposed to the more dynamic and interactive game content also performed significantly better than the comic group on the visual recall task. In this study, the comic group spent significantly less time on the reading task overall, but the proportion of fixation time spent on text versus pictorial information was not significantly different. This suggests that the game group’s higher comprehension may have come simply from spending more time reading and looking at the pictures presented.

Based on the currently available eyetracking research of integrated text-picture systems, it seems that the presence of text in a picture scene provides heavy influence on the overall approach to viewing the whole item. Given that each panel of a comic is essentially an integration of scene viewing and text reading similar to the advertisements used above, it is likely that there will be similar trends as well, with more time spent on the text than the pictures and an overall scan path mimicking the pattern displayed during text reading. It should be noted, however that none of these studies investigated differences in reading with the presence of a distractor or secondary task, which may influence the reader’s modality preference for receiving information (i.e., spending more time on the text versus the picture). The studies below will explore the effects of additional cognitive load on the more traditional experimental paradigm.
**Study 1**

In order to gather information on the viability of the larger study, a preliminary, first study was run with ten healthy normal adults. This study was designed to test the design and presentation of the visual and auditory stimuli and to test the basic hypotheses for use in the later study. Because the first study was performed with only 10 participants, there is not sufficient power to reach significance in most measures; however, this small data set still provides useful information for several aspects of the second study.

**Research Questions**

**Research Question 1**: Does the inclusion of integrated pictures (e.g., comic strips) and auditory distractions influence reading comprehension in healthy adults as compared to a distractorless, text-only presentation?

**Hypothesis**: The addition of pictures to a text comprehension task supplies an additional route of access to semantic information about a written story via the non-linguistic, visual pathway. The ability to recruit visuospatial processes otherwise not engaged by the phonological and graphemic processing pathways offers the chance to utilize resources not available in text-only conditions. However, adding an auditory distraction task will recruit attentional and processing resources away from the text comprehension task, increasing cognitive load and impairing comprehension. Based on sentence-level (e.g., Lewis & Vasishth, 2005) and discourse-level models (e.g., Goldman, Varma, & Cote, 1996), attentional and executive function resources will be occupied with inhibiting the auditory distraction, decreasing the cognitive resources available for processing during the reading comprehension task. Hence auditory
distraction conditions will be associated with a decrease in efficiency of schemata creation and detail organization during reading.

Based on this hypothesis, it is predicted that healthy adults will be able to efficiently process both the text and comic conditions. Because this study is investigating healthy, literate adults, it is assumed that basic reading comprehension skills are intact in all individuals involved in this study. Therefore, without the presence of a distraction to increase cognitive load and impair comprehension processing, there will be no difference between the distractorless, text-only and distractorless, comic conditions due to attenuation effects. It is only with the introduction of the distraction condition that cognition will be taxed to a degree that leads to decreased comprehension performance during reading. Comprehension scores in the two distraction conditions will be lower than those in the distractorless conditions, but adding visual information (the comic conditions) will supplement some of the information lost due to the presence of the distraction, resulting in higher scores in the distracted comic condition as compared to the distracted text-only condition.

**Research Question 2:** Does the inclusion of integrated pictures (e.g., comic strips) and auditory distractions influence eye movements during reading in healthy adults as compared to a distractorless, text-only presentation?

**Hypothesis:** When reading in the text-only conditions, there are no visual distractors to detract from the reading process. In the comic condition, however, reading and viewing pictures are both inherently visual processes that will compete for both visual and attentional focus. As the processing of the picture scene and the text are mutually exclusive, the focus of the eyes will have to shift from the text to the pictures to process all presented information in the integrated
conditions, even without the presence of an auditory distraction. In healthy, literate adults, the reading of text is a virtually automatized function (LaBerge and Samuels, 1974), which will cause the reader to prioritize the text processing before the picture viewing. When presented with a sufficient auditory distraction, this auditory task will increase overall cognitive load and impair comprehension. According to models of reading comprehension, (e.g., Lewis & Vasishth, 2005; Goldman, Varma, & Cote, 1996) attentional and executive function resources will be occupied with inhibiting the auditory distraction, decreasing the cognitive resources available during the reading comprehension task. As a result, the auditory distraction conditions will be associated with a decrease in efficiency of schemata creation and detail organization during reading.

Based on this hypothesis, it is predicted that healthy adults will be able to efficiently process both the text and comic conditions. Because this study is investigating healthy, literate adults, it is assumed that basic reading comprehension skills are intact in all individuals involved in this study. Therefore, without the presence of a distraction to increase cognitive load and impair comprehension processing, it is expected that there will be no difference in text fixation times between the distractorless text and comic conditions. As the presence of the comic provides novel visual stimuli for the participants to engage with in addition to the text, this will lead to extra time looking at the screen in order to process the people, objects and environment. Therefore, it is expected that participants will have longer aggregate fixation times on the screen in the comic condition compared to the text condition.

It is only with the introduction of the distraction condition that cognition will be taxed to a degree that leads to decreased comprehension performance during reading. In these conditions, automatic error-checking processes or downstream metacomprehension processes will cause the participant to re-read the text, resulting in increased text fixation time in both of the distracted
conditions. These failures in the text comprehension process may also drive the reader to use non-linguistic information in the comic format, therefore the distracted comic format will have the longest aggregate fixation time.

**Research Question 3:** Does performance on standardized cognitive and linguistic testing correlate with differences in reading comprehension due to the presentation of integrated pictures (e.g., comic strips) and auditory distractions?

**Hypothesis:** Reading is a complex linguistic process that is mediated and supported by several sets of cognitive resources. Models of reading comprehension (e.g., Lewis & Vasishth, 2005; Goldman, Varma, & Cote, 1996) and behavioral studies indicate that reading comprehension is mediated by the efficiency and capacity of working memory, attention, and executive function processes. Increased availability and capacity of these resources will allow for better comprehension of longer or more complex reading passages. The effects of these cognitive resources have been shown to be augmented by metacomprehension skills introduced via education (Hultsch, et al., 1990) as readers are trained to be more efficient and effective with the mental organization of schemata and details (Borella, 2006). Additionally, it has been shown that older adults perform more poorly on comprehension of specific details due to reductions in processing efficiency and metacomprehension skills (Borella, 2006). In situations where reading itself is not sufficient to achieve comprehension, the presence of the visual depiction of actions and items in the story will allow for semantic information to be gathered via a visual, non-lexical route to further support the comprehension process (e.g., PALPA model; Kay, Coltheart, & Lesser, 1992).
Based on this hypothesis, overall comprehension performance is expected to correlate positively with years of education as well as measures of attention, language, working memory, and executive function. Due to the effects of aging, however, it is expected that age will show a negative correlation with overall cognitive performance.

With regard to comparisons of the comic versus text-only conditions in healthy, literate adults, many are expected to score at ceiling without distraction. Those who do not achieve a attenuation effect in the text-only condition will benefit from the additional visual information that is provided by the comic condition. Such a result will correlate negatively with memory, attention, and/or language performance on the cognitive testing battery as these are the measures that dictate success in the text-only condition, and sufficient amount and efficiency of these resources would result in a attenuation effect. As age is associated with lower comprehension performance on details in text-only experiments (Borella, 2006), there will be a positive correlation between age and improvement seen in the comic condition.

Finally, differences between the conditions with and without auditory distraction are expected to be driven primarily by attentional and executive function performance. Participants with sufficient executive function and attention capacity will successfully inhibit the distraction, resulting in little to no difference in comprehension performance between conditions. Those who cannot effectively ignore the distraction will suffer impairment to the comprehension process and lower scores on the comprehension questions. Therefore, attention and executive function scores will correlate positively with performance in the distraction condition, due to the excess of resources for processing. Furthermore, older adults have been shown to have minor decreases in these cognitive resources as part of otherwise healthy aging, leading to a higher susceptibility to
distraction (West, 1999). Thus, it is expected that older adults will do worse in the distraction condition, leading to a negative correlation between age and performance.

Participants

Ten neurotypical adults with no history of neurological disorder or learning disability were recruited for this study. All participants were monolingual English speakers with ages ranging from 18 to 55, with six participants identifying as female. Neurotypical participants were recruited from the greater New York City area using fliers and personal referrals.

Table 1
Participant Demographics, Hearing and Vision Screening Results

<table>
<thead>
<tr>
<th>Participant ID</th>
<th>Gender</th>
<th>Age</th>
<th>Education</th>
<th>Average dB HL</th>
<th>Visual Acuity</th>
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<tbody>
<tr>
<td>P203</td>
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<td>18</td>
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<td>20/20</td>
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<tr>
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<td>18</td>
<td>12</td>
<td>0</td>
<td>20/20</td>
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<tr>
<td>P209</td>
<td>M</td>
<td>31</td>
<td>20</td>
<td>10</td>
<td>20/20</td>
</tr>
<tr>
<td>P212</td>
<td>F</td>
<td>23</td>
<td>11</td>
<td>0</td>
<td>20/25</td>
</tr>
<tr>
<td>P215</td>
<td>M</td>
<td>30</td>
<td>13</td>
<td>15</td>
<td>20/25</td>
</tr>
<tr>
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<td>33</td>
<td>18</td>
<td>10</td>
<td>20/20</td>
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<td>10</td>
<td>20/18</td>
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<td>11</td>
<td>15</td>
<td>20/25</td>
</tr>
<tr>
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<td>13</td>
<td>15</td>
<td>20/20</td>
</tr>
<tr>
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<td>F</td>
<td>52</td>
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<td>10</td>
<td>20/20</td>
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<td>Mean</td>
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<td>15.60</td>
<td>8.50</td>
<td>20/21.30</td>
</tr>
<tr>
<td>SD</td>
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<td>13.05</td>
<td>4.03</td>
<td>6.26</td>
<td>2.62</td>
</tr>
</tbody>
</table>

Prior to the start of any testing or experiments, all participants were given a consent form and provided an explanation of the study by the researcher. The researcher answered any questions and provided further explanation of the tasks as necessary prior to signing of the consent form and throughout the experiment. All participants were asked a self-reported history covering age, education, language use, handedness and neurological history. Age and education responses, along with the results of hearing and vision screenings can be seen above in Table 1. Cognitive testing administered during this study was not used as an exclusionary measure, and
all participants tested were included in the analysis. All recruitment and informed consent procedures and documents, and all experimental procedures, were approved by the Teachers College Institutional Review Board.

**Stimuli**

**Story development**

Seventeen stories were written by the researcher and a research assistant. Each story was written to be seven lines long and designed to follow a similar narrative structure (see Appendix A for all stories and questions). Each sentence was limited to 95 characters to ensure that it appeared on a single line during the text-only eye-tracking task. The font used for the text-only format was a 48-point Arial font. The Pixton comics were created using an unnamed, sans-serif font as customization of fonts is limited in Pixton. All stimuli were shown on a 19” Dell laptop screen running at a resolution of 1920 x 1080.

Each story was measured for average word frequency from the Subtlex-US (i.e., Zipf frequency) (Brysbaert & New, 2009), average word imageability from the MRC database (Coltheart, 1981), Flesch-Kincaid grade level (Kincaid, Fishburne, Rogers, & Chissom, 1975), Flesch readability (Flesch, 1948), average word length and total number of words.

One story was selected for use as a practice item; the remaining sixteen stories were divided into blocks of four stories each. Averages were taken for each measure across the four stories in a block. Each of the four story blocks used during the eye-tracking task were balanced for all of these measures as shown in Table 2 below.
Table 2
ANOVA Results from Story Balancing between Blocks of Four Stories Each

<table>
<thead>
<tr>
<th>Measure</th>
<th>df</th>
<th>F</th>
<th>Mean Square</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zipf Frequency</td>
<td>3</td>
<td>0.490</td>
<td>0.010</td>
<td>0.696</td>
</tr>
<tr>
<td>Imageability</td>
<td>3</td>
<td>1.991</td>
<td>320.313</td>
<td>0.169</td>
</tr>
<tr>
<td>Grade Level</td>
<td>3</td>
<td>1.014</td>
<td>0.088</td>
<td>0.420</td>
</tr>
<tr>
<td>Readability</td>
<td>3</td>
<td>0.686</td>
<td>7.512</td>
<td>0.578</td>
</tr>
<tr>
<td>Average Word Length</td>
<td>3</td>
<td>0.533</td>
<td>0.018</td>
<td>0.668</td>
</tr>
<tr>
<td>Total Words</td>
<td>3</td>
<td>0.236</td>
<td>22.500</td>
<td>0.870</td>
</tr>
</tbody>
</table>

Note: No significant between-groups differences found at the p < 0.05 level.

Comprehension questions

Four comprehension questions for each story (68 total) were developed: one regarding a stated main idea, one stated detail, one implied main idea, and one implied detail. These four types of questions were chosen to test recognition memory of main ideas versus details that have been shown to be sensitive to age-related differences in recall in other studies of reading across the lifespan (Radavansky, et al., 1990; Borella, 2006). Each question has four answer choices: the correct answer, a phonemic foil, a semantic foil and an irrelevant foil.

Two additional researchers reviewed the story questions for accuracy, clarity, balance and appropriateness prior to use in this study. Four questions and one story were altered for clarity after review by the researchers prior to the final grouping of stories.

Picture development

Pictures were developed using the Pixton comic creation software (Goodinson & Goodinson, 2015). Each story was divided into seven panels, one panel per sentence. The Pixton software includes a customizable character creator with a number of settings and objects all presented in a consistent style, allowing for a constant level of complexity on all objects. All text
in the comics presented were standardized to the same size, and each picture was sized to be 945 x 908 pixels. A comparison of the comic and text-only formats can be seen in Figure 3.

![Figure 3. Presentation of the same sentence in (left) comic form and (right) text-only form.](image)

**Auditory Distraction**

To create the auditory distraction four young adult, native English speakers, two male and two female, were recorded using an Audio Technica AT2020 microphone and Audacity® recording and editing software, Version 2.1.0 (Audacity, 2015). Each speaker read a book spanning four different genres and topics to vary the linguistic information and structure presented. Each reader was asked to record about 15 minutes of reading at their normal pace. Afterwards, these audio files were edited using Audacity® (Audacity, 2015), to remove pauses, line noise, disruptions in fluency (e.g., self-corrections), and to normalize the level of audio to a maximum of 90 dB. The four tracks were then overlaid to ensure no fewer than three speakers were heard at any given time. The resulting track was approximately 10 minutes long. The track was then subdivided into four segments of 2.5 minutes, creating four starting points in the audio file to ensure that the participants were not hearing the same starting point every time the audio was played. This was done to decrease the likelihood of habituation to the distraction recording. The audio that preceded each starting point was then appended to the end of the file, effectively creating a 10-minute audio loop.
Procedure

Behavioral Testing

All testing and experimental tasks occurred during a single one-and-a-half-to-two-hour session. After receiving informed consent, a testing battery was administered to the participants. First, participants were screened for visual acuity using a Snellen chart at a distance of 10 feet, with acuity of 20/30 or better required. Then they were tested for hearing acuity at 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz, using a Maico MA27 portable audiometer, with no more than 15 dB hearing loss allowed. All participants scored within normal limits on both acuity tests. As the hearing screening was not performed in an isolation booth, sound levels in the room were measured using the SoundMeter app, version 8.4.3 for iOS (Faber Acoustical, 2016), which was found to be “the app best suited for occupational and general purpose noise measurements” (p. EL191, Karous & Shaw, 2014). Running this application on a second generation iPad, the room was found to have between 10 and 15 dB of ambient noise primarily below 1000Hz. As such, 10 dB were subtracted from all measurements below 1000Hz for eligibility purposes.

After completion of the hearing and vision screenings, a cognitive-linguistic testing battery was administered. This testing battery consisted of Cognitive Linguistic Quick Test (CLQT; Helm-Estabrooks, 2001), as well as the Elevator line bisection task from the Comprehensive Aphasia Test (CAT; Swinburn, Porter, & Howard, 2004), logical memory subtests from the Wechsler Memory Scale IV (WMS; Wechsler, 2009) and Elevator Counting, Elevator Counting with Distraction, Visual Phone Search, and Dual Task Phone Search and Counting subtests subtests from the Test of Everyday Attention (TEA; Ward, Ridgeway, & Nimmo-Smith, 1994) to screen for overall cognitive and linguistic function. The “Elevator Counting” task is an auditory attention task where the participant must count a series of tones
and provide the number after the set. In the “Elevator Counting with Distraction” subtest participants must discriminate between high and low frequency tones and only count the low tones. In the “Phone Search” subtest, participants perform a visual search for pairs of matching symbols on a page that contains text, numbers and symbols. The dual task subtest of the TEA combines the initial Elevator Counting paradigm and the Phone Search paradigm into one simultaneous task. Participants who did not score within normal limits were not excluded from participation and analysis, as this study is investigating how differences in cognition may affect reading comprehension. Afterwards, participants were seated at the computer for the eye-tracking task described below.

Eye-tracking Experiment

Prior to the start of the task, the researcher explained the task to the participant, with an opportunity to ask questions. These instructions are provided in Appendix B. Then, participants were shown a summary of the instructions on the computer screen once more and then one practice item in both text-only and comic format to introduce the task, with the accompanying comprehension questions following the text-only version.

Afterwards, the participants read four blocks of four stories each. As shown in Figure 4, prior to the start of each story, participants were asked to look at a fixation cross at the center of the screen for 2000ms to ensure all participants were attending to the same area of the screen before each story begins. The story reading task was self-paced with the participants moving from one sentence to the next by pressing the spacebar on the laptop keyboard. In the two text-only blocks, the participants were asked to read a story one sentence at a time with no picture support. In the two comic strip blocks, the text of the story was integrated into these pictures. In
all conditions, participants could not return to previous sentences once they advanced. Upon completion of each story, the participants were tested using the set of four comprehension questions as described above. Participants were offered a short break between each block if desired.

**Figure 4.** Presentation order of a story. A) Fixation cross shown for 2000ms. B) Seven slides shown each with one sentence/panel. C) Four comprehension questions shown, one at a time, with four multiple choice answer options.

The order of the four blocks (text-only without distraction, text-only with distraction, comic without distraction, and comic with distraction) were counterbalanced across participants. The presentation order was quasi-randomized such that a roughly equivalent number of participants received text-only blocks vs. comic blocks in each position and distracted blocks vs. distractorless blocks in each position. Additionally the groups of stories were also balanced such that roughly equivalent participants received the four story groups in each possible order. As an example, one participant may have received the distracted text version of story group 1 first, followed by non-distracted comic group 2, non-distracted text group 3, and then distracted comic group 4 while another participant would receive the non-distracted comic version of group 4 first, followed by distracted comic group 1, non-distracted text group 2, and then distracted comic group 3. The blocks with distraction included an auditory distraction of four-talker babble
played at 60-70 dB above hearing level, based on the results of the hearing screening. This dB level was chosen because it has been shown that an irrelevant speech stream, played at approximately 70dB is sufficient for decreasing reading comprehension in healthy young adults (Sorqvist, Halin, & Hygge, 2010).

Results

Participants ranged in age from 18 to 55 years with 11 to 22 years of education. Across all cognitive-linguistic testing, one participant scored below normal on the TEA Dual Task subtest, two other participants scored below normal on the TEA Phone Search subtest, and one other participant scored below normal on the TEA Distracted elevator subtest. Three of these participants and one other participant also scored below the 50th percentile in the WMS Logical subtasks. All other scores and participants were found to be within normal limits. Table 3 below contains testing data for all individuals and Table 4 contains eye-tracking data and comprehension scores for each condition and participant.

Because this is a first study with a small number of participants, there are several instances where paired sample t-tests will be used to examine group effects. Were this a larger sample, a 2 x 2 Repeated Measures ANOVA would be run instead to investigate interaction effects and include covariates; however, this first study does not have sufficient power to reach significance with such a test, and the small sample size and distribution violates some of the assumptions of the ANOVA. As shown in Tables 6 and 7, while there may be a pattern of differences in Text Fixation Time and Total Fixation Time that are dependent upon the
Table 3
Cognitive Testing Results for All Participants in Study 1

<table>
<thead>
<tr>
<th>ID</th>
<th>Logical I</th>
<th>Logical II</th>
<th>Comprehension</th>
<th>Elevator</th>
<th>Distracted Elevator</th>
<th>Phone Search</th>
<th>Dual Task</th>
<th>Attention</th>
<th>Memory</th>
<th>Exec. Fxn.</th>
<th>Language</th>
<th>Visuospatial</th>
</tr>
</thead>
<tbody>
<tr>
<td>P203</td>
<td>32</td>
<td>33</td>
<td>27</td>
<td>7</td>
<td>10</td>
<td>2.05</td>
<td>0.16</td>
<td>210</td>
<td>185</td>
<td>37</td>
<td>37</td>
<td>101</td>
</tr>
<tr>
<td>P206</td>
<td>41</td>
<td>42</td>
<td>30</td>
<td>7</td>
<td>9</td>
<td>2.74</td>
<td>0.47</td>
<td>211</td>
<td>185</td>
<td>36</td>
<td>37</td>
<td>101</td>
</tr>
<tr>
<td>P209</td>
<td>20*</td>
<td>20*</td>
<td>22*</td>
<td>7</td>
<td>10</td>
<td>2.75</td>
<td>-0.10</td>
<td>208</td>
<td>170</td>
<td>34</td>
<td>32</td>
<td>102</td>
</tr>
<tr>
<td>P212</td>
<td>18*</td>
<td>9*</td>
<td>19*</td>
<td>7</td>
<td>8</td>
<td>2.35</td>
<td><strong>3.97</strong></td>
<td>208</td>
<td>179</td>
<td>35</td>
<td>36</td>
<td>100</td>
</tr>
<tr>
<td>P215</td>
<td>23*</td>
<td>21*</td>
<td>26</td>
<td>7</td>
<td>10</td>
<td><strong>4.80</strong></td>
<td>0.35</td>
<td>205</td>
<td>163</td>
<td>36</td>
<td>35</td>
<td>97</td>
</tr>
<tr>
<td>P218</td>
<td>30</td>
<td>31</td>
<td>27</td>
<td>7</td>
<td>10</td>
<td><strong>5.50</strong></td>
<td>2.82</td>
<td>207</td>
<td>177</td>
<td>35</td>
<td>34</td>
<td>100</td>
</tr>
<tr>
<td>P403</td>
<td>45</td>
<td>41</td>
<td>30</td>
<td>7</td>
<td>9</td>
<td>2.20</td>
<td>0.35</td>
<td>206</td>
<td>175</td>
<td>35</td>
<td>37</td>
<td>95</td>
</tr>
<tr>
<td>P406</td>
<td>14*</td>
<td>4*</td>
<td>15*</td>
<td>6</td>
<td>3**</td>
<td>3.93</td>
<td>1.85</td>
<td>195</td>
<td>155</td>
<td>32</td>
<td>32</td>
<td>92</td>
</tr>
<tr>
<td>P409</td>
<td>25</td>
<td>22</td>
<td>22</td>
<td>7</td>
<td>10</td>
<td>2.55</td>
<td>0.19</td>
<td>210</td>
<td>179</td>
<td>37</td>
<td>36</td>
<td>102</td>
</tr>
<tr>
<td>P412</td>
<td>35</td>
<td>27</td>
<td>28</td>
<td>7</td>
<td>10</td>
<td>3.30</td>
<td>0.53</td>
<td>213</td>
<td>184</td>
<td>37</td>
<td>36</td>
<td>103</td>
</tr>
</tbody>
</table>

Note: * Indicates below 50th percentile on subtest of WMS ** Indicates a below-normal/impaired score on TEA subtest
Table 4  
**Eye-tracking and Comprehension Question Scores for All Participants in Study 1**

<table>
<thead>
<tr>
<th>ID</th>
<th>Total Text Fixation Time (ms)</th>
<th>Total Reading Time (ms)</th>
<th>Comprehension Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>P203</td>
<td>46239</td>
<td>52729</td>
<td>44776</td>
</tr>
<tr>
<td>P206</td>
<td>18287</td>
<td>27838</td>
<td>24601</td>
</tr>
<tr>
<td>P209</td>
<td>47844</td>
<td>*</td>
<td>23941</td>
</tr>
<tr>
<td>P212</td>
<td>54574</td>
<td>52297</td>
<td>47135</td>
</tr>
<tr>
<td>P215</td>
<td>76347</td>
<td>47293</td>
<td>72392</td>
</tr>
<tr>
<td>P218</td>
<td>48753</td>
<td>81994</td>
<td>72558</td>
</tr>
<tr>
<td>P403</td>
<td>7722</td>
<td>26893</td>
<td>5827</td>
</tr>
<tr>
<td>P406</td>
<td>69613</td>
<td>72653</td>
<td>94820</td>
</tr>
<tr>
<td>P409</td>
<td>39181</td>
<td>70363</td>
<td>37101</td>
</tr>
<tr>
<td>P412</td>
<td>28950</td>
<td>30444</td>
<td>32922</td>
</tr>
<tr>
<td>Mean</td>
<td>43751</td>
<td>51389</td>
<td>45607</td>
</tr>
<tr>
<td>SD</td>
<td>21299</td>
<td>20499</td>
<td>27070</td>
</tr>
</tbody>
</table>

Note: * Eye-tracking data failed to collect properly for part of the non-distracted comic portion of P209's task, the incomplete data has been excluded from the study.
condition, the considerable between-subject variability impedes the effectiveness of the ANOVA at this time.

In order to address Research Question 1, a series of paired-sample t-tests, shown in Table 5, were conducted to compare the effect of picture integration and auditory distraction presence on comprehension performance. No significant differences were found based on presentation type; however, there are indications that comprehension may be impaired in the distracted text condition as compared to the no-distraction comic condition (p = 0.108).

Table 5

<table>
<thead>
<tr>
<th>Measure</th>
<th>Mean Difference</th>
<th>SD</th>
<th>t</th>
<th>df</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Text – Normal Comic</td>
<td>-0.556</td>
<td>1.878</td>
<td>-0.887</td>
<td>8</td>
<td>0.401</td>
</tr>
<tr>
<td>Normal Text – Distracted Text</td>
<td>0.500</td>
<td>1.716</td>
<td>0.921</td>
<td>9</td>
<td>0.381</td>
</tr>
<tr>
<td>Normal Text – Distracted Comic</td>
<td>-0.200</td>
<td>1.229</td>
<td>-0.514</td>
<td>9</td>
<td>0.619</td>
</tr>
<tr>
<td>Normal Comic – Distracted Text</td>
<td>1.000</td>
<td>1.658</td>
<td>1.809</td>
<td>8</td>
<td>0.108</td>
</tr>
<tr>
<td>Normal Comic – Distracted Comic</td>
<td>0.222</td>
<td>2.048</td>
<td>0.326</td>
<td>8</td>
<td>0.753</td>
</tr>
<tr>
<td>Distracted Text – Distracted Comic</td>
<td>-0.700</td>
<td>2.058</td>
<td>-1.076</td>
<td>9</td>
<td>0.310</td>
</tr>
</tbody>
</table>

A post-hoc analysis was performed on the comprehension questions by subdividing the comprehension scores by question type (i.e., stated vs implied and main idea vs. detail). Because there was no overall effect of presentation on comprehension performance, this analysis was done to see if any pairs of conditions were near significance, as these details may inform the hypotheses for the second study. For this analysis, a series of paired-sample t-tests were performed comparing the same question type (e.g., stated detail) across presentation conditions (e.g., distracted comic vs. distracted text). There was only a single significant result, as scores on questions of stated details were higher in the no-distraction comic condition than in the distracted text-only condition (t (8) = 3.162, p = 0.013). Three other results showed patterns that may lead
to effects in a larger study, as well: stated details in no-distraction text were higher than in distracted text \( (t (9) = 2.250, p = 0.051) \), and stated main ideas were higher in no distraction comic condition than no distracted text condition \( (t (8) = 2.000, p = 0.081) \) and higher in the distracted text condition than the no-distraction text condition \( (t (9) = 1.964, p = 0.081) \).

An additional post-hoc analysis was performed within each presentation condition (e.g., distracted comic vs. comic without distraction) comparing comprehension question accuracy across question type (e.g., stated details vs. implied main ideas). Again, a series of paired-sample t-tests were used for this analysis. There was a single significant result in the distracted text-only condition, where participants scored higher on stated main ideas than stated details \( (t (9) = 4.583, p = 0.001) \). Only one other comparison resulted in a p-value less than 0.100, in which participants scored higher on implied details as compared to stated details \( (t (9) = 2.236, p = 0.052) \).

In order to address Research Question 2, a series of paired-sample t-tests were run comparing total text fixation time across presentation conditions. There were no significant differences in text fixation time; however, there was a pattern that showed longer fixation times in comic conditions that did not rise to the level of significance in the first study. The full list of results can be seen in Table 6.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Mean Difference</th>
<th>SD</th>
<th>t</th>
<th>df</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Text – Normal Comic</td>
<td>-8.093</td>
<td>18.873</td>
<td>-1.286</td>
<td>8</td>
<td>0.234</td>
</tr>
<tr>
<td>Normal Text – Distracted Text</td>
<td>-1.856</td>
<td>14.436</td>
<td>-0.407</td>
<td>9</td>
<td>0.694</td>
</tr>
<tr>
<td>Normal Text – Distracted Comic</td>
<td>-11.847</td>
<td>22.691</td>
<td>-1.651</td>
<td>9</td>
<td>0.133</td>
</tr>
<tr>
<td>Normal Comic – Distracted Text</td>
<td>3.375</td>
<td>18.589</td>
<td>0.545</td>
<td>8</td>
<td>0.601</td>
</tr>
<tr>
<td>Normal Comic – Distracted Comic</td>
<td>-6.329</td>
<td>10.210</td>
<td>-1.860</td>
<td>8</td>
<td>0.100</td>
</tr>
<tr>
<td>Distracted Text – Distracted Comic</td>
<td>-9.991</td>
<td>17.840</td>
<td>-1.771</td>
<td>9</td>
<td>0.110</td>
</tr>
</tbody>
</table>
Additionally a series of paired-samples t-tests comparing total fixation time across condition found significant differences between four pairs of conditions. The comic condition without distraction was found to be significantly longer than the no-distraction text condition \((p = 0.003)\), distracted comic was found to be significantly longer than the no-distraction text condition \((p = 0.007)\), no-distraction comic was significantly longer than the distracted text \((p = 0.005)\), and distracted comic was significantly longer than the distracted text \((p = 0.002)\). The full list of results can be seen in Table 7.

Table 7

<table>
<thead>
<tr>
<th>Measure</th>
<th>Mean Difference</th>
<th>SD</th>
<th>t</th>
<th>df</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Text – Normal Comic</td>
<td>-35.987</td>
<td>24.960</td>
<td>-4.325</td>
<td>8</td>
<td>0.003*</td>
</tr>
<tr>
<td>Normal Text – Distracted Text</td>
<td>-1.856</td>
<td>14.436</td>
<td>-0.407</td>
<td>9</td>
<td>0.694</td>
</tr>
<tr>
<td>Normal Text – Distracted Comic</td>
<td>-31.767</td>
<td>29.088</td>
<td>-3.453</td>
<td>9</td>
<td>0.007*</td>
</tr>
<tr>
<td>Normal Comic – Distracted Text</td>
<td>31.269</td>
<td>24.733</td>
<td>3.793</td>
<td>8</td>
<td>0.005*</td>
</tr>
<tr>
<td>Normal Comic – Distracted Comic</td>
<td>0.395</td>
<td>13.690</td>
<td>0.087</td>
<td>8</td>
<td>0.933</td>
</tr>
<tr>
<td>Distracted Text – Distracted Comic</td>
<td>-29.911</td>
<td>21.547</td>
<td>-4.390</td>
<td>9</td>
<td>0.002*</td>
</tr>
</tbody>
</table>

Note: * Indicates significance at \(p < 0.05\) level

In order to address Research Question 3, an analysis of bivariate correlations in SPSS was performed. The full results are shown in Table 8. This analysis found a number of significant correlations at the \(p < 0.05\) level. Differences in comprehension performance between comic and text conditions were significantly correlated with CLQT Memory and Visuospatial Scores as well as TEA Elevator and Distracted Elevator scores. Additionally, CLQT Attention and age correlated mildly with this difference in performance. Only the TEA Dual Task score correlated with differences in performance between the distraction and non-distraction comprehension scores, though just above the \(p < 0.05\) level. Several measures also correlated strongly with overall comprehension score performance including CLQT Memory, Attention and Visuospatial subscores; all subtests of the WMS; the TEA Elevator and Distracted Elevator tasks; and education. Additionally, the CLQT Executive Function subscore showed a mild
correlation that did not rise to the level of significance. Table 8 below details all correlations and p-values, with tests arranged such that adjacent tests rely on similar cognitive processes.

Table 8
Correlations between Comprehension Scores and Cognitive-Linguistic Testing Measures

<table>
<thead>
<tr>
<th>Measure</th>
<th>Comic – Text-only</th>
<th>Distraction – No Distraction</th>
<th>Overall Comprehension Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Correlation (r)</td>
<td>p-value</td>
<td>Correlation (r)</td>
</tr>
<tr>
<td>Age</td>
<td>0.553*</td>
<td>0.097*</td>
<td>-0.149</td>
</tr>
<tr>
<td>Education</td>
<td>-0.390</td>
<td>0.266</td>
<td>-0.079</td>
</tr>
<tr>
<td>CLQT Language</td>
<td>-0.366</td>
<td>0.299</td>
<td>0.146</td>
</tr>
<tr>
<td>WMS Logical I</td>
<td>-0.336</td>
<td>0.342</td>
<td>-0.343</td>
</tr>
<tr>
<td>WMS Logical II</td>
<td>-0.423</td>
<td>0.223</td>
<td>-0.389</td>
</tr>
<tr>
<td>WMS Comprehension</td>
<td>-0.378</td>
<td>0.282</td>
<td>-0.250</td>
</tr>
<tr>
<td>CLQT Memory</td>
<td>-0.783*</td>
<td>0.007*</td>
<td>0.065</td>
</tr>
<tr>
<td>TEA Elevator</td>
<td>-0.771*</td>
<td>0.009*</td>
<td>0.232</td>
</tr>
<tr>
<td>TEA Distracted Elevator</td>
<td>-0.658*</td>
<td>0.038*</td>
<td>0.118</td>
</tr>
<tr>
<td>CLQT Attention</td>
<td>-0.778*</td>
<td>0.053*</td>
<td>0.042</td>
</tr>
<tr>
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Note: * Bold results indicate significance at p < 0.05 level. Italicized results indicate significance at p < 0.10 level.

Discussion

The purpose of this first study was to collect preliminary data and to test the viability of the picture, auditory and comprehension question stimuli as well as the eye-tracking measures.

To this end, the study proved quite informative. The text and picture stimuli, along with the comprehension questions functioned as intended in the first study. No participants reported any difficulty reading the stimuli as provided, and all stimuli will all be maintained in their current form for the subsequent, larger study. A greater number of participants in the study would also likely abate some of the effect of any outliers in the current data set that result in large standard
deviations. Because reading speed can vary widely between people, the variability of fixation times in small groups influences the statistics greatly.

While there were no significant differences in overall comprehension performance across presentation type, as hypothesized in Research Question 1, they may emerge with a larger contingent of participants. The preliminary study showed a possible effect on comprehension when comparing the no-distraction comic condition to the distracted text condition (p = 0.108), which is in line with the presented hypothesis. The comic presentation without a distraction provides the most possible information for the reader, allowing for maximum comprehension of the narrative, whereas, in the distracted text condition, the reader is put in the most difficult position, with a more limited set of cognitive resources and the most limited means of acquiring information (i.e., text only). This difference seemed to be driven by lower performance on the stated detail questions in these conditions, which was the lone significant result (p = 0.013) when questions were broken down by type. This also is consistent with expectations, as the comic allows for visual representation of stated, detailed information, allowing for visual processing of details alongside the linguistic presentation of the information.

With regard to Research Question 2, the study also found no significant differences in text fixation times across presentation conditions. For the comic-to-text comparisons, this suggests that the visual complexity of the comics is not so distracting that it causes participants to lose focus while reading, suggesting that the design is sufficiently balanced. However, the lack of an effect across distraction conditions suggests that the distraction is not effective enough to cause impairment of reading comprehension during the task, which would lead to longer fixation times as participants would need to regress and repair during failed reading attempts.
Analysis of total task time on each story found a significant difference across the picture conditions (i.e., text versus comic), which is a result of the presence of pictures. Since text fixation time did not differ in these comparisons, the additional time spent in the comic condition was used to search the pictures for any additional information that may assist with comprehension. Again the lack of distraction effect informs the idea that 4-talker babble may not be a sufficient level of distraction for healthy adults.

Despite a limited number of significant statistical results in the comprehension and eye-tracking measures, a number of significant correlations emerged in the data, as hypothesized in Research Question 3. This further indicates that the underlying foundations of the current line of research are solid. Overall comprehension performance correlated positively with education, which is consistent with numerous studies across the last several decades. It also correlated positively with performance on several measures of memory and attention, both of which are required for adequate reading comprehension processing. The lack of correlation between comprehension outcomes and language measures suggests that the reading level of the stories and questions is not taxing language processing systems at a high level in healthy adults. This is a positive in this study, as it is seeking to manipulate attention and other cognitive processing rather than language in and of itself.

By examining differences in performance on the comic condition versus the text condition, four other correlations emerged. The CLQT memory and visuospatial subscores and two TEA attention subtests correlated negatively with differences in comic-text performance. Because of a attenuation effect on the comprehension scores for this group of participants, the negative correlation is less an indicator that the participants did worse in the comic condition, but that they did the same in the comic and text conditions. This is because participants who scored
highly on these cognitive measures did not require information from the comics to answer all the questions correctly, whereas participants who scored lower were more likely to do worse in the text condition as compared to the comic. Because the task was self-paced, the participants who needed more information were able to spend time in the comic condition gathering additional visual information that could then be used to inform their answers on the comprehension questions. If the task were time-limited, these participants would likely have scored on par or lower in the comic condition as compared to the text, which is consistent with the negative correlations seen.

A similar analysis of differences in comprehension performance with and without distraction showed no significant correlations, with only one correlation approaching significance. Performance on the TEA dual task subtest was positively correlated with performance in the distraction task, but not significantly (p = 0.053). This suggests that the auditory distraction was having a mild effect on performance but not enough to make a difference for most of the participants.

Overall, the auditory distraction proved to be ineffective at creating an effect in both the eye-tracking measures and comprehension questions, indicating that a more difficult task is required to generate differences in the data. It should, however, be noted that, due to the study recruitment occurring in the greater New York City area, the participants may be more effective at inhibiting external noise than non-city residents. Also, while making more difficult stories or comprehension questions is an option, these stories and questions are designed to also be used with people with aphasia. More linguistically difficult stories and more challenging comprehension questions will result in a floor effect in the aphasia group, rendering the data uninterpretable. The first study also did not include any adults in the range of 60 – 80 years of
age, where changes in cognition are more likely to affect performance in the baseline reading task (Borella, 2006) and the distracted task. As a result, a more difficult distraction task seems to be the optimal solution at this time.

Given the results of this first study, which are mostly in line with the stated hypotheses and expectations of the line of research, an expanded participant pool and improved distraction task are likely to generate more informative outcomes.
Study 2

The small group tested in the first study yielded promising, but inconclusive results on the effects of picture integration and auditory distraction. While mild effects were seen in fixation time as a result of picture condition, there did not seem to be a significant effect of the auditory distraction during the first study, and as a result, the distraction task was modified to become a dual-task paradigm for the second study. In order to do this, tones were added to the same four-talker babble audio file used for the first study. This enabled a dual task paradigm, where participants were asked to press a button when they hear a certain tone and to ignore all the other tones and the speech they heard while reading. Beyond this change, the gathering of a larger group of results will shed a more certain light on the effects of picture and distraction presentation on reading comprehension in healthy adults. This information can then be used to inform future studies involving people with aphasia and other cognitive-linguistic disorders. As such, the current study seeks to further investigate differences in comprehension and eye-tracking measures in healthy adults based on text-picture integration and the presence of a dual task which taxes vigilance and divided attention as its primary focus.

Research Questions

Research Question 1: Does the inclusion of integrated pictures (e.g., comic strips) and a tone-based secondary task influence reading comprehension in healthy adults as compared to a distractorless, text-only presentation with respect to both response accuracy and response time?

Hypothesis: The addition of pictures to a text comprehension task supplies an additional route of access to semantic information about a written story via the non-linguistic, visual pathway. The ability to recruit visuospatial processes otherwise not engaged by the phonological and graphemic processing pathways offers the chance to utilize resources not available in text-
only conditions. However, adding an auditory distraction task will recruit attentional and processing resources away from the text comprehension task, increasing cognitive load and impairing comprehension. Based on sentence-level (e.g., Lewis & Vasishth, 2005) and discourse-level models (e.g., Goldman, Varma, & Cote, 1996), attentional and executive function resources will be occupied with inhibiting the auditory distraction, decreasing the cognitive resources available for processing during the reading comprehension task. Hence auditory distraction conditions will be associated with a decrease in efficiency of schemata creation and detail organization during reading.

Based on this hypothesis, it is predicted that healthy adults will be able to efficiently process both the text and comic conditions. Because this study is investigating healthy, literate adults, it is assumed that basic reading comprehension skills are intact in all individuals involved in this study. Therefore, without the presence of a distraction or dual-task to increase cognitive load and impair comprehension processing, there will be no difference in accuracy or response time between the distractorless, text-only and distractorless, comic conditions due to attenuation effects. It is only with the introduction of the dual-task paradigm that cognition will be taxed to a degree that leads to decreased comprehension performance during reading. Comprehension scores in the two distraction conditions will be lower than those in the equivalent distractorless conditions while response times will increase. Adding visual information (the comic conditions) will supplement some of the information lost due to the distraction via the non-linguistic pathways, resulting in higher scores in the distracted comic condition as compared to the distracted text-only condition with lower response times than the distracted, text-only condition.

With respect to response accuracy by question type, due to availability of both direct recall and recall via the schema created during reading, participants will perform better on stated
information over implied information, and better on main ideas than on details; however these gaps will be much smaller in the comic conditions as there is additional visual information to help with recall. There is an age-related decline in recall of specific details during reading comprehension task, but the ability to create adequate schema during the reading process may allow older adults to perform at the level of younger counterparts when asked about main ideas (Borella, 2006).

Participants will also respond more slowly when they are uncertain of the answers to the comprehension questions, creating longer response times. When there is uncertainty, they are more likely to deliberate when responding or to change an answer after first selection. Given these expectations, the pattern of response times will mirror response accuracy. Thus, participants will take longest to respond after the distracted conditions, with the undistracted comic being the quickest response condition.

In order to answer this question, 2x2 repeated-measures ANOVA will be performed comparing comprehension question response accuracy overall and between question types (e.g., stated details, implied main ideas), as well as differences in response time in the four experimental conditions, including interaction effects.

**Research Question 2:** Does the inclusion of integrated pictures (e.g., comic strips) and a tone-based secondary task influence eye movements (e.g., fixation times, number of revisits) during reading in healthy adults as compared to a distractorless, text-only presentation?

**Hypothesis:** When reading in the text-only conditions, there are no visual distractions to detract from the reading process. In the comic condition, however, reading and viewing pictures are both inherently visual processes that will compete for both visual and attentional focus. As the processing of the picture scene and the text are mutually exclusive, the focus of the eyes will
have to shift from the text to the pictures to process all presented information in the integrated conditions, even without the presence of an auditory distraction. In healthy, literate adults, the reading of text is a virtually automatized function (LaBerge and Samuels, 1974), which will cause the reader to prioritize the text processing before the picture viewing. When presented with a sufficient auditory distraction, this auditory task will increase overall cognitive load and impair comprehension. According to models of reading comprehension, (e.g., Lewis & Vasishth, 2005; Goldman, Varma, & Cote, 1996) attentional and executive function resources will be occupied with inhibiting the auditory distraction, decreasing the cognitive resources available during the reading comprehension task. As a result, the auditory distraction conditions will be associated with a decrease in efficiency of schemata creation and detail organization during reading.

Based on this hypothesis, it is predicted that healthy adults will be able to efficiently process both the text and comic conditions. Because this study is investigating healthy, literate adults, it is assumed that basic reading comprehension skills are intact in all individuals involved in this study. Therefore, without the presence of a distraction to increase cognitive load and impair comprehension processing, it is expected that there will be no difference in text fixation times between the distractorless text and comic conditions. As the presence of the comic provides novel visual stimuli for the participants to engage with in addition to the text, this will lead to extra time looking at the screen in order to process the people, objects and environment. Therefore, it is expected that participants will have longer aggregate fixation times on the screen in the comic condition compared to the text condition.

It is only with the introduction of the dual-task condition that cognition will be taxed to a degree that leads to decreased comprehension performance during reading. The audio file contains both spoken word and text. This tests the participants’ ability to inhibit the influence of
the verbal audio stream while still reacting to the tones and focusing attention on the reading task. This requires significant amounts of attentional, memory, and executive function resources to prevent the auditory distraction from having a detrimental effect on comprehension. Failing inhibition and attentional management at this level, the participant has to expend further resources to differentiate the auditory linguistic data from the visual linguistic information, which will additionally tax the linguistic and working memory systems until the undesirable information is purged. This increase in cognitive load should, theoretically, negatively affect the comprehension of the stories in the distracted condition. In this case, automatic error-checking processes or downstream metacomprehension processes will cause the participant to re-read the text at a micro or macro level. **This may manifest in the eye-tracking information as an increased number of revisits, slower overall reading speed (i.e. total task time and text fixation time).**

These failures in the text comprehension process may also drive the reader to use non-linguistic information in the comic format, therefore the distracted comic format will have the longest aggregate fixation time.

In order to answer this question, a 2x2 repeated-measures ANOVA will be performed analyzing differences in total screen fixation time, fixation time on text, and number of revisits within text in the four experimental conditions, including interaction effects.

**Research Question 3:** Does performance on standardized cognitive and linguistic testing correlate with differences in reading comprehension due to the presentation of integrated pictures (e.g., comic strips) and a tone-based secondary task?

**Hypothesis:** Reading is a complex linguistic process that is mediated and supported by several sets of cognitive resources. Models of reading comprehension (e.g., Lewis & Vasishth, 2005; Goldman, Varma, & Cote, 1996) and behavioral studies indicate that reading
comprehension is mediated by the efficiency and capacity of working memory, attention, and executive function processes. Increased availability and capacity of these resources will allow for better comprehension of longer or more complex reading passages. The effects of these cognitive resources have been shown to be augmented by metacomprehension skills introduced via education (Hultsch, et al., 1990) as readers are trained to be more efficient and effective with the mental organization of schemata and details (Borella, 2006). Additionally, it has been shown that older adults perform more poorly on comprehension of specific details due to decreases in processing efficiency and metacomprehension skills (Borella, 2006). In situations where reading itself is not sufficient to achieve comprehension, the presence of the visual depiction of actions and items in the story will allow for semantic information to be gathered via a visual, non-lexical route to further support the comprehension process (e.g., PALPA model; Kay, Coltheart, & Lesser, 1992).

Based on this hypothesis, overall comprehension performance is expected to correlate positively with years of education as well as measures of attention, language, working memory, and executive function. Due to the effects of aging, however, it is expected that age will show a negative correlation with overall comprehension performance due to age-related changes in cognition.

With regard to comparisons of the comic versus text-only conditions in healthy, literate adults, many are expected to score at ceiling without distraction. Those who do not achieve a attenuation effect in the text-only condition will benefit from the additional visual information that is provided by the comic condition. Such a result will correlate negatively with memory, attention, and/or language performance on the cognitive testing battery as these are the measures that dictate success in the text-only condition, and sufficient amount and efficiency of these
resources would result in a attenuation effect. As age is associated with lower comprehension performance on details in text-only experiments (Borella, 2006), there will be a positive correlation between age and improvement seen in the comic condition.

Finally, differences between the conditions with and without auditory distraction are expected to be driven primarily by attentional and executive function performance. Participants with sufficient executive function and attention capacity will successfully inhibit the distraction, resulting in little to no difference in comprehension performance between conditions. Those who cannot effectively ignore the distraction will suffer impairment to the comprehension process and lower scores on the comprehension questions. Therefore, attention and executive function scores will correlate positively with performance in the distraction condition, due to the excess of resources for processing. Furthermore, older adults have been shown to have minor decreases in these cognitive resources as part of otherwise healthy aging, leading to a higher susceptibility to distraction (West, 1999). Thus, it is expected that older adults will do worse in the distraction condition, leading to a negative correlation between age and performance.

In order to answer this question, correlations will be calculated between the cognitive test scores (e.g., Wechsler Memory Scale), and comprehension question response accuracy, total time reading, fixation time spent on text, and number of revisits within and between AOIs.

**Design**

**Participants**

For this study, 33 participants were tested, ranging in age from 18 to 75 (M: 43.31, SD: 17.08) with 10 to 22 years of education (M: 16.25, SD: 2.46), with 15 (46.9%) identifying as female. Of the participants, 24 (75.0%) identified as Caucasian/White, six (18.8%) as African-
American/Black, and two (6.3%) as Asian. No participants identified as Native American, Pacific Islander, or Hispanic. One participant failed the hearing screening and was excluded from the results of this study. Additionally, two participants’ eyetracking information failed to collect completely, resulting in partial data sets. All participants were native English speakers with no history of learning disability, stroke or neurological impairment. Participants were considered monolingual if they had no more than a self-rated intermediate familiarity with a second language and did not use that language on a regular basis (i.e., learned a language in college but has since fallen into disuse). All participants were recruited from the greater New York City area using fliers posted around the community and by referrals.

Prior to the start of any testing or experiments, all participants were given a consent form and provided an explanation of the study by the researcher. The researcher answered any questions and provided further explanation of the tasks as necessary prior to signing of the consent form and throughout the experiment. All participants were then asked a self-reported history covering age, education, language use, handedness and neurological history.

All recruitment and informed consent procedures and documents, and all experimental procedures were approved by the Teachers College Institutional Review Board prior to the start of the study.

**Stimuli**

The same text and visual stimuli used in the first study were used in the current study. All information regarding stimuli development was discussed above in the data section of Study 1.

As there did not seem to be a significant effect of the auditory distraction during the first study, the task has been modified for this study to become a dual-task setup with tone counting.
The same base audio file containing a four-talker, irrelevant speech stream was overlaid with a series of pure tones. The pure tones were generated and inserted into the audio file using Audacity®, version 2.1.0, (Audacity, 2015). Pure tones at a frequency of 1000 Hz and 1500 Hz were played for 500 ms at 20 dB over the sound level of the four-talker babble. Tones were interspersed at quasi-random intervals such that between 12 and 16 tones played in a 60 second interval, with interstimulus wait times ranging from 2000 ms to 6000 ms. Participants were instructed to respond to the high tones only while reading by pressing the F or J key. These keys were chosen so that the participant could rest their hand on the home row comfortably, as if they were touch-typing, as the key used to advance the stories is the space bar. Furthermore, the bumps on F and J keys provide tactile feedback to the participant in case they move their hand during the task and find themselves searching for the appropriate key again.

Procedure

Testing for all participants

All testing and experimental tasks for neurotypical participants occurred in a single, approximately two-hour session. No changes were made to the consent process, exclusion criteria screening or cognitive linguistic testing after Study 1 and all the same procedures were followed as described above. The eye-tracking task was altered and the new protocol is described below.

Eye-tracking task

Prior to the start of the task, the researcher or an assistant verbally explained the task to the participant. Then, the participant was given an opportunity to ask questions. After this, the
eye-tracking system was calibrated for the participant using SMI’s built-in five-point calibration task prior to the start of the practice items. The participant was then shown a summary of the instructions on the computer screen once more and then one set of practice items to introduce the task. The first practice task introduced the auditory distraction task in isolation. The participant was asked to listen to the babble and pure tones and press the F or J key without reading. This could be repeated multiple times until the participant was comfortable with operating the keys. After this, the participant was shown a practice story, which is not one of the 16 stories used in the main task, in text format and then in comic format with and without the auditory dual task. The accompanying comprehension questions were shown only after the text version and not after the subsequent comic.

Afterwards, the participants read four blocks of four stories each. Prior to the start of each story, participants were shown a fixation cross at the center of the screen for 2000ms to ensure all participants were attending to the same area of the screen before each story began. The story reading task was self-paced with the participants moving from one sentence to the next by pressing the spacebar on the laptop keyboard. In the two text-only blocks, the participants were asked to read a story one sentence at a time with no picture support. In the two comic strip blocks, the text of the story was integrated into these pictures. In all conditions, participants could not return to previous sentences once they advanced. Upon completion of each story, the participants were tested using the set of four comprehension questions described previously. The sequence is shown below in Figure 5. Participants were offered a short break between each block, if desired.
Figure 5. Presentation order of a story. A) Fixation cross was shown for 2000ms. B) Seven slides shown, each with one sentence or comic panel. These were read in silence or concurrent with tone task. C) Four comprehension questions were presented, one at a time, with four multiple choice answer options each.

Participants received the four blocks in an order counterbalanced across participants, with two blocks including an auditory distraction of four-talker babble played at 40-50 dB above hearing level, with the pure tones played at 60-70 dB above hearing level, based on the results of the hearing screening. The participants were asked to press either the F or J key when they heard a high tone and to ignore the low tones as they read the stories.

Data Acquisition and Analysis

All eye-tracking data, comprehension response time data, and comprehension question responses were recorded by the SMI BeGaze and Experiment Center software. Eye movement information during the story reading task were recorded by the SMI Red250 Mobile system, which records 250 measurements per second. SMI reading analysis software automatically assigns a region of interest (ROI) to each word and sentence in the text-only conditions. The sentence-level ROI was used for text fixation time measures while word-level ROI measures were used to calculate number of revisits. For the comic task, ROIs were set around each picture in general as well as each actor in the picture and objects pertinent to the story. The relevant
dependent variables are total task time, total fixation time on text, total number of revisits, and number of fixations. All of these measures were compared across testing conditions (e.g., with/without distraction, visual presentation style) and group.

The aforementioned measures were retrieved from the SMI software, which outputs the data into a Comma-separated Variable (.csv) file. This file was loaded into Microsoft Excel file where other relevant data was added (e.g., distraction presence, story block number) and then transferred to SPSS for analysis.

Data was analyzed in SPSS between conditions (with and without distraction, with and without picture) and groups using a series of repeated measures, 2 x 2 ANCOVAs comparing the comprehension performance and eye-tracking results across conditions. Then a series of correlations was run comparing cognitive testing performance, comprehension scores, response times, and eye-tracking measures. Then bivariate correlations were taken, comparing cognitive testing and demographic data with the behavioral and eye-tracking measures taken during the reading task.

Results

Across all cognitive-linguistic testing, several participants scored within the impaired range on one or more subtests. One participant scored a standard score of 5 or below (borderline impaired as per Donders, 2016) on all three Wechsler Memory Scale measures. One participant
Table 9

*Demographic and Cognitive Testing Results for All Participants in Study 2*

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Note: *Indicates below 10\textsuperscript{th} percentile (borderline impairment) on subtest of WMS ** Indicates an impaired score on TEA or CLQT
### Table 10
Eye-tracking and Comprehension Question Scores for All Participants in Study 2

<table>
<thead>
<tr>
<th>ID</th>
<th>Total Reading Time (ms)</th>
<th>Total Text Fixation Time (ms)</th>
<th>Comprehension Score (max. = 16)</th>
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<td>SD</td>
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Note: * Eye-tracking data failed to collect properly for portions of P1129’s and P1139’s reading patterns and responses.
scored as impaired on the Elevator Counting subtest (auditory attention) of the Test of Everyday Attention, two on the Elevator Counting with Distraction (more difficult auditory attention) subtest, seven on the Phone Search (visual attention) subtest, and two on the Dual Task Counting (auditory and visual attention) subtests. Two scored below normal limits on the Cognitive Linguistic Quick Test’s Attention subscore, two on the Memory subscore, and two on the Visuospatial subscore. As stated in the methods above, this was not an exclusionary criterion, and all participants who scored below normal continued in the study. Table 9 contains all testing data for all individuals and Table 10 contains the raw eye-tracking data and comprehension scores for each condition and participant.

In order to address Research Question 1, which asks whether picture and auditory conditions affect reading comprehension, a 2 x 2 repeated measures ANCOVA was conducted. The results, shown in Table 11, compare the effect of picture integration and auditory distraction presence on comprehension question response accuracy, and Figure 6 shows the means and standard deviations for these groups. Using age and years of education as covariates, no significant differences were found based on presentation type. Age (F(1, 28) = 2.809, p = 0.105) was not a statistically significant covariate; however, education (F(1, 28) = 4.822, p = 0.037) resulted in significant between-subject effects.

Table 11

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Df</th>
<th>df error</th>
<th>Mean Square</th>
<th>F</th>
<th>p</th>
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<tbody>
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<td>Distraction</td>
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<td>0.005</td>
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</table>
Figure 6. A bar graph displaying mean comprehension scores across all participants in each of the four eye-tracking conditions.

An additional 2 x 2 repeated measures ANCOVA was run to analyze whether there was an effect of distraction and comic presence on time to first answer selection and answer submission during the comprehension questions. Age was found to have a significant between-subject effect as a covariate on both time to first click ($F(1, 28) = 14.392, p = 0.001$) and answer submission ($F(1, 28) = 10.966, p = 0.003$), while education showed no such effects ($F(1, 28) = 1.337, p = 0.257$) and ($F(1, 28) = 1.190, p = 0.285$ respectively). There were no significant within subject effects found. The statistical results for this test can be found in Tables 12 and 13.

An analysis of effects of the dual task and comic presence was performed using a 2 x 2 repeated measures ANCOVA on each of the four subtypes of questions: implied details, stated details, implied main ideas, and stated main ideas, as previous studies have shown performance differences on different question types due to age (Borella, 2006). There were no significant
effects of comic or dual task on performance in any of the question types, as shown in Table 14. However, education was shown as having a significant effect on performance of implied detail questions (F(1, 28) = 6.929, p = 0.014) and age was found to have an effect on stated main ideas (F(1, 28) = 4.293, p = 0.048).

Table 12
**ANCOVA Results for Time to First Response across All Eye-tracking Conditions**

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<tr>
<th>Dependent Variable</th>
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Table 13
**ANCOVA Results for Time to Answer Submission across All Eye-tracking Conditions**

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<th>df error</th>
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In order to address the second research question, about the effects of comic and distraction presence on eye-tracking data, again a 2 x 2 repeated measures ANCOVA was used. The outcome measures for this analysis were total text fixation time and total time on task. Age and education were not found to be significant between-subject effects on text fixation (Age:
Table 14

**ANCOVA Results for Question Subtypes across All Eye-tracking Conditions**

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<td>0.803</td>
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<td>0.012</td>
<td>0.050</td>
<td>0.825</td>
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<td>0.001</td>
<td>0.003</td>
<td>0.985</td>
</tr>
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</table>
F(1, 28) = 0.003, p = 0.959; Education: F(1, 28) = 3.649, p = 0.067), nor on total task time (Age: F(1, 27) = 0.051, p=0.823; Education: F(1, 27) = 3.624, p = 0.068), and there were no main or interaction effects found when the covariates were introduced for text fixation time. A significant interaction effect between age and presence of the dual task was seen in total task time (F(1, 27) = 5.123, p = 0.032). The complete results can be seen in tables 15 and 16, and the means are displayed in the charts shown in Figure 7.

Table 15

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Df</th>
<th>df error</th>
<th>Mean Square</th>
<th>F</th>
<th>p</th>
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<tbody>
<tr>
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<td>9684377.96</td>
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<td>1.962</td>
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<tr>
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<td>122983811.2</td>
<td>0.237</td>
<td>0.630</td>
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<tr>
<td>Comic</td>
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<td>30728950.23</td>
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<td>Comic * Age</td>
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<td>172845.241</td>
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<td>0.985</td>
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<td>0.871</td>
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<tr>
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<td>5058014.275</td>
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<td>0.897</td>
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</table>

Table 16

<table>
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<th>Dependent Variable</th>
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<th>Mean Square</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
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<td>0.032</td>
</tr>
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<td>27</td>
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<td>0.057</td>
<td>0.813</td>
</tr>
<tr>
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<td>979530726.3</td>
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<td>0.218</td>
</tr>
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<td>186941915.5</td>
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<td>0.586</td>
</tr>
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<td>27</td>
<td>60258731.42</td>
<td>0.098</td>
<td>0.757</td>
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<td>1673527.673</td>
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<td>27</td>
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<tr>
<td>Distraction * Comic * Education</td>
<td>1</td>
<td>27</td>
<td>13310663.99</td>
<td>0.040</td>
<td>0.842</td>
</tr>
</tbody>
</table>

In addition, the total number of revisits in the two text-only conditions was compared using a paired samples t-test. Because revisits are an online, error-checking process during
Figure 7. A graph displaying mean text fixation time in milliseconds (left) and mean total task time (right) across all participants in each of the four eye-tracking conditions.

Automatized reading, higher level cognitive processes are not necessarily involved. As such, the effects of education and age should be limited by comparison to comprehension question answering and thus were not considered covariates. Number of revisits per stimulus were calculated automatically by the SMI reading software on the text-only data. The paired sample t-test found that total number of revisits were significantly higher in the distracted condition ($t(30) = -2.201, p = 0.036$).

As a correlate to the number of revisits in the text-only formats, the number of revisits to the AOIs around the text bubbles were compared using a paired sample t-test. This counts the number of times a participant fixated on the text box, fixated on the comic panel, then returned to the text box and fixated again. That is to say, this is effectively a measurement of how many times a participant read a portion of the text, then looked at the pictures in the comic panel, and then returned to the text to either complete the reading or to reread the text. There was not a significant effect of distraction on the number of revisits in the comic condition ($t(30) = -1.565, p = 0.128$).
In order to answer the third research question, which deals with correlations between the cognitive testing data and the comprehension and eye-tracking measures, a series of bivariate correlations were used. These correlation results can be seen in Tables 17, 18, and 19.

Overall comprehension score performance correlated positively with education (r = 0.408, p = 0.023), WMS Logical II (i.e., delayed story retelling) (r = 0.392, p = 0.029), WMS Comprehension Questions (r = 0.465, p = 0.008), and four subscores of the CLQT: Memory (r = 0.527, p = 0.002), Executive Functioning (r = 0.473, p = 0.007), Language (r = 0.470, p = 0.008) and Visuospatial Processing (r = 0.532, p = 0.002). There was also a negative correlation with the TEA Phone Search task (r = -0.441, p = 0.013). In addition to this analysis, comprehension scores were evaluated according to dual-task and comic presence and correlated with the testing data. Performance in the base condition (i.e., no distraction and text only) correlated negatively with age (p = 0.041) and positively with the CLQT Executive Function subscore (r = 0.370, p = 0.041). Comprehension question score in the non-distracted comic condition correlated positively with two CLQT subscores: Memory (r = 0.428, p = 0.015) and Language (r = 0.402, p = 0.023). Response accuracy in the distracted text condition correlated negatively with the TEA Phone Search (r = -0.375, p = 0.035) and positively with CLQT visuospatial subscore (r = 0.378, p = 0.033). Finally, performance in the distracted comic condition correlated positively with the WMS Logical II score (i.e., delayed story retelling) (r = 0.417, p = 0.017), and the CLQT Memory (r = 0.542, p = 0.001) and Visuospatial Processing (r = 0.380, p = 0.032) subscores. The complete correlation results for comprehension data can be seen in Table 17.

Bivariate correlations were also run between the cognitive testing data and the eyetracking data. There were two significant correlations between text fixation time and the cognitive testing data. The first, a positive correlation between the baseline (i.e., text only, no
Table 17
Correlations between Comprehension Scores and Cognitive Linguistic Measures

<table>
<thead>
<tr>
<th>Measure</th>
<th>Overall Comprehension</th>
<th>No Distraction Text</th>
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<th>Distracted Text</th>
<th>Distracted Comic</th>
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<tbody>
<tr>
<td></td>
<td>Correlation (r)</td>
<td>p-value</td>
<td>Correlation (r)</td>
<td>p-value</td>
<td>Correlation (r)</td>
</tr>
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<td>0.232</td>
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<tr>
<td>CLQT Language</td>
<td>0.470</td>
<td>0.008</td>
<td>0.331</td>
<td>0.069</td>
<td>0.402</td>
</tr>
<tr>
<td>WMS Logical I</td>
<td>0.351</td>
<td>0.053</td>
<td>0.298</td>
<td>0.104</td>
<td>0.081</td>
</tr>
<tr>
<td>WMS Logical II</td>
<td>0.392</td>
<td>0.029</td>
<td>0.266</td>
<td>0.148</td>
<td>0.176</td>
</tr>
<tr>
<td>WMS Comprehension</td>
<td>0.465</td>
<td>0.008</td>
<td>0.206</td>
<td>0.267</td>
<td>0.240</td>
</tr>
<tr>
<td>CLQT Memory</td>
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<td>0.002</td>
<td>0.265</td>
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<tr>
<td>TEA Elevator</td>
<td>0.153</td>
<td>0.411</td>
<td>0.151</td>
<td>0.419</td>
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<tr>
<td>TEA Distracted Elevator</td>
<td>0.325</td>
<td>0.074</td>
<td>0.232</td>
<td>0.0210</td>
<td>0.079</td>
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<tr>
<td>CLQT Attention</td>
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<td>0.154</td>
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<td>TEA Dual Task</td>
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<td>0.124</td>
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Note: *Bold results indicate significance at p < 0.05 level
Table 18
*Correlations between Text Fixation Time and Cognitive Linguistic Measures*

<table>
<thead>
<tr>
<th>Measure</th>
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<th>Distracted Text</th>
<th>Distracted Comic</th>
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<td>Correlation (r)</td>
<td>p-value</td>
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<td>0.186</td>
<td>0.309</td>
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<td>-0.213</td>
<td>0.242</td>
</tr>
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<td>0.417</td>
<td>-0.143</td>
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</tr>
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<td>0.465</td>
<td>0.113</td>
<td>0.536</td>
</tr>
<tr>
<td>TEA Distracted Elevator</td>
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<td>-0.243</td>
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<td>0.543</td>
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<tr>
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<td>-0.252</td>
<td>0.165</td>
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Note: *Bold results indicate significance at p < 0.05 level*
Table 19
*Correlations between Total Fixation Time and Cognitive Linguistic Measures*

<table>
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<th>No Distraction Comic</th>
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<td>p-value</td>
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<td>0.169</td>
</tr>
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<td>0.200</td>
<td>0.280</td>
<td>0.067</td>
<td>0.717</td>
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<td>0.417</td>
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<td>0.759</td>
<td>0.228</td>
<td>0.218</td>
<td>0.182</td>
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<td>WMS Comprehension</td>
<td>-0.221</td>
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<td>-0.285</td>
<td>0.115</td>
<td>0.060</td>
<td>0.747</td>
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<td>CLQT Memory</td>
<td>-0.204</td>
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<td>-0.046</td>
<td>0.802</td>
<td>0.261</td>
<td>0.156</td>
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<td>TEA Elevator</td>
<td>0.139</td>
<td>0.465</td>
<td>0.110</td>
<td>0.548</td>
<td>0.277</td>
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<td>0.064</td>
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<td>Elevator</td>
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<td>0.205</td>
<td>-0.229</td>
<td>0.207</td>
<td>0.171</td>
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<td>CLQT Attention</td>
<td>0.042</td>
<td>0.824</td>
<td>-0.227</td>
<td>0.211</td>
<td>0.159</td>
<td>0.394</td>
<td>0.009</td>
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<tr>
<td>TEA Dual Task</td>
<td><strong>0.478</strong></td>
<td><strong>0.008</strong></td>
<td>0.108</td>
<td>0.556</td>
<td>0.277</td>
<td>0.131</td>
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<tr>
<td>TEA Phone Search</td>
<td>-0.265</td>
<td>0.158</td>
<td>-0.154</td>
<td>0.400</td>
<td>-0.270</td>
<td>0.141</td>
<td>-0.148</td>
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<td>CLQT Visuospatial</td>
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<td>-0.166</td>
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<td>0.252</td>
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<td>CLQT Exec. Fxn.</td>
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<td>0.545</td>
<td>0.193</td>
<td>0.299</td>
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Note: *Bold results indicate significance at p < 0.05 level*
distraction) condition and the TEA Dual Task ($r = 0.478, p = 0.008$). This same correlation was seen in the total fixation time correlation ($r = 0.478, p = 0.008$). The second is a negative correlation between the WMS comprehension score and the non-distracted comic condition ($r = -0.405, p = 0.021$). The full correlation results for the eyetracking data can be seen in Table 18 for text fixation time and Table 19 for total fixation time.

Discussion

This study sought to build upon the results of the first study above using an auditory dual-task paradigm to further tax the cognitive resources of the participants during the reading task in lieu of the auditory distraction used in the initial study. This, in conjunction with the comic versus text conditions while setting the stage for future experiments comparing performance across groups (e.g., people with aphasia) or further stimuli manipulations (e.g., more complex reading passages). To this end, the current study showed many similar trends with the original study with some differences that will be discussed below.

With respect to the first Research Question, investigating the effects of presentation type on story comprehension, and, as with the first study, the statistical analysis yielded no significant effects on comprehension score. While the overall differences in comprehension score did not rise to significance, this may be a result of a attenuation effect in the comprehension scores. The distracted conditions showed a larger range of scores (10-16) as compared to the non-distracted conditions (13-16), and fewer participants received perfect marks in the distracted text condition (18.8%) as compared to the distracted comic (28.1%), normal text (41.9%), and normal comic (53.1%) conditions. This pattern, in fact, parallels the hypothesized effects for this study, that the distracted text condition both limits the viable pathways of information ingress (i.e., text only)
and limits the available resources for processing this data (e.g., attentional resources) due to the dual-task paradigm. As a result, information is encoded for memory less efficiently, and thus is more likely to decay and be lost by the end of the story. The presence of a second information pathway in the comic formats allows the reader to supplement the linguistic data being processed with the parallel visuospatial processing of the pictorial information. As the healthy adults have enough cognitive resources to devote to both processes, even when asked to listen to a series of tones and press buttons while reading, they are still able to benefit from this second, complementary set of information to improve comprehension performance back to an equivalent level as compared to the non-distracted text condition. The non-distracted comic condition on the other hand presents the most ideal means of conveying information, presenting the story to be transmitted via both processing pathways without any distraction competing for cognitive resources. This situation theoretically results in the optimum opportunity for achieving perfect or near-perfect comprehension; however, while the statistics did show this pattern, they did not rise to significant levels of difference. This may be due to the attenuation effects discussed above, as 18% of all participants still achieved a perfect score in the most cognitively intense condition.

Looking at these results through the lens of cognitive load theory, it is clear that while the comic versions of the stories have more intrinsic cognitive load due to the interactivity of the picture and text elements depicted, as compared to the text-only versions of the stories, these comics also apply germane (or effective) cognitive load in that respect. The picture and text information both coincide and support each other, leading to improved schema development and acquisition for the story. Conversely, the dual-task paradigm provides extraneous (or ineffective) cognitive load, resulting in resources being taken away from the analysis and encoding that leads to downstream schema development (Sweller, Ayres, & Kalyuga, 2011). In
healthy adults with enough cognitive resources to handle both the increased cognitive load of the comic and the dual-task paradigm, little to no difference in comprehension performance occurs, whereas, in adults who do suffer decreased comprehension in the presence of the dual-task, the comic provides enough germane information without completely overloading the cognitive resources available. This is likely due to the comic being able to recruit resources for the visuospatial pathway of working memory, as opposed to the phonological pathway that is being monopolized by the dual-task audio in Baddeley’s model of working memory (Baddeley, 2012).

With respect to the covariates in this analysis, both age and education level showed to be significant factors. This is in line with previous research findings which show reading comprehension performance as inextricably linked to education, and that age has an effect on certain types of comprehension questions, with older adults performing worse when asked about specific details of the story (Borella, 2006).

Similar results showing significant effects of age and education were seen when comprehension performance was evaluated by question type with no significant effect of the experimental conditions on performance. Education was shown to have a significant impact on performance of implied details, which may pertain to how education results in improved metacomprehensive skills (Borella, 2006). These skills allow for more efficient and accurate building of the schema that are needed to fill in implied information that is not provided directly by the story. On the other hand, age was shown to have a significant negative impact of performance on the stated main idea questions. This likely has to do with a combination of decreased memory performance displayed in older adults and decreased efficiency of metacomprehensive processes that often go unpracticed in daily life outside of academia. As a
result, older adults are less efficient at recall of explicitly stated information on reading comprehension tasks (Borella, 2006).

Additional analyses were performed that examined time to first answer comprehension question click and time to final submission of each response. As there were not significant differences in the accuracy of responses across the different experimental conditions, response time offered a second avenue to investigate differences in performance. If participants were to take longer to answer in one condition, this would suggest they were having more difficulty with recall or recognition in that condition. This could be a byproduct of an insufficiently constructed schema during reading due to the differences in cognitive load between the distracted and non-distracted conditions or between the text and comic conditions. Again, there was not a significant difference across conditions, and age was seen to be a significant factor, likely due to the age-related effects of mild motor slowing often observed healthy older adults more so than any cognitive effects, as there was not any effect of response time based on cognitive load differences experienced in the different conditions.

While the tone-response dual-task condition certainly taxed the cognitive resources of the participants more than the simpler distraction of the first study, the simple nature of the stories did not place enough demands on the participants to overload their available cognitive resources. This is further evident in the statistical results aimed at answering Research Question 2, which examined the effects of the experimental conditions on fixation time and number of revisits. As with the first study, no significant differences in text fixation time were found across presentation conditions. Additionally, there were neither age nor educational effects observed on the text fixation time. Participants did not spend any less time reading the text present during the comic condition (i.e., using the pictorial display of the story to subvert the need for reading), nor
did they spend more time in the distracted condition to make up for the taxing of attentional resources, as hypothesized. It is highly likely that the lower reading level of the stories is not enough to sufficiently challenge these healthy adults in the distracted condition into consciously adjusting their reading patterns in a significant way.

The lack of reward for higher achievement, the exposure to the loud auditory task, and the simple format of the narratives may have affected motivation levels of some participants, which are shown to be an important factor in reading (Taboada, Tonks, Wigfield, & Guthrie, 2009). Lower levels of motivation may have resulted in less time spent than necessary to achieve better results. Without a measure of response certainty (i.e., how much a participant believed they knew the correct answer), it is difficult to know whether the lower performing participants were shirking the task or if they believe they knew the story sufficiently but failed to encode it accurately. However, as the revisits analysis below details, there are subconscious, automatic adjustments being made even without conscious adjustment by the reader.

With regard to total task time (i.e., total screen fixation time) during the reading segments, the introduction of age and education as covariates eliminated the significant difference seen in the comic-text comparison during the initial study. It should be noted that several participants had extremely low fixation times in this study (e.g., cumulative times under 2 seconds per story in some conditions), including P1115, who scored impaired on several cognitive measures. The data sets for these participants did not show any recording errors and thus were included in the analysis, though these fixation times undoubtedly had some effect on the ANCOVAs that were run.

As with text fixation time, age and education did not show any significant effects on total task time. However, there was a single, significant interaction between the presence of a
distraction and age. Overall, older adults spent less time reading text and/or looking at comics in the presence of the dual-task paradigm as opposed to the quiet conditions. Since older adults typically read at the same speed or slower than younger adults (Hartley, Stojack, Mushaney, Annon, & Lee, 1994), this suggests that the older adults were eschewing spending the necessary time reading in order to avoid the presence of the dual-task paradigm. Anecdotally, this is consistent with the fact that multiple older adults stated that the dual-task paradigm was much harder and less enjoyable than the silent reading conditions.

It is possible that such large variation in performance time between subjects, resulting in a very large standard deviation, may be masking some of the effects of the distracted condition on reader performance. This is indicated by the significant t-test comparing the number of revisits in the distracted and non-distracted text conditions. This result suggests that the distraction is having a mild effect on the participants at the lower levels of reading. These microsaccade revisits that were measured only take milliseconds to perform and are easily hidden within the variance of reading speeds; however the fact that the number of them does increase with the introduction of the dual task shows there is some latent effect occurring. Likely, these healthy adults have sufficiently intact error checking and correcting mechanisms early in their reading process that keeps these small errors in reading processing from affecting downstream processing, such as the error corrected processes seen in the SWIFT (Engbert, Nuthmann, Richter, & Kliegl, 2005) or E-Z Reader models (Reichle, Polatsek, Fisher, & Rayner, 1998). This limits the amount of large-scale sentence rereading, which would in significant increases to text fixation and task time, and prevents significant decreases in comprehension score performance, although there is the non-significant, but evident trend discussed above.
Furthermore, these participants were drawn primarily from the area around New York City, an expansive, urban environment. Studies have shown that adults who live in highly urbanized areas show stronger ability to switch attention between stimuli at the cost of sustained, focused attention on a singular task (Linnel, Caparos, de Fockert, & Davidoff, 2013). As such, if this study were replicated in a variety of environments spanning urban, suburban, and rural areas, there may be differences in susceptibility to distraction by the tone-response task that were not observed in this iteration of the study.

An additional post-hoc analysis was performed looking at correlations between performance on the comprehension measures and fixation time. A significant correlation was found in only the distracted text condition ($r = 0.418, p = 0.019$). This further substantiates that there is some mild effect of the distraction on the reading process for healthy, literate adults that is not being captured by the measures and analysis in this initial study.

The third Research Question seeks any correlational relationships between the cognitive testing data and participant performance on the comprehension and eye-tracking measures. A number of correlations emerged. The negative correlation of non-distracted, text-only comprehension performance with age echoes the finding seen in the ANCOVA discussed previously. When examining comprehension question accuracy across conditions, age was seen as a significant covariate contributor. The correlation with overall comprehension performance also showed a similar pattern ($r = -0.335; p = 0.066$); however it did not reach the level of significance. These correlations are also in line with past studies which established that older adults tend to perform worse when asked about specific details of a narrative (Borella, 2006), which reduces overall response accuracy on this task.
A positive correlation between education and overall comprehension is consistent with a number of studies which traditionally show a connection between higher education and better comprehension performance and with mitigating changes to comprehension with age (Johnson, 2003). This may be due to both neuroprotective factors of education on aging, but also to exposure to and practice of metacomprehensive skills in academic settings (Perfetti, Marron, & Foltz, 1996). However, because this study includes people with a Bachelor’s degree or higher at about twice the rate of the population, this effect is lessened through the attenuation effects observed.

The positive correlations between overall comprehension performance and the CLQT Memory subscore are unsurprising, as the recognition aspect of question answering is a memory-driven task, and the correlation with the CLQT visuospatial subscore is likely related to the level of success in image processing and retention in the comic subtests. The negative correlation between overall performance and the TEA phone search illustrates the need for attentional resources during reading. Lower scores on this task are suggestive of more efficient use of visual attention resources, which would also contribute to higher comprehension scores across the board, but especially in the presence of the dual task, as there are sufficient resources to keep reading despite the distraction of the audio and motor tasks.

There are also positive correlations between overall comprehension and the delayed recall and comprehension questions from the WMS. The comprehension question score is essentially similar task as the comprehension probes used in the eye-tracking task, but with a 20-minute delay. The ability to recall and recognize answers after a 20 minute delay is a more memory-intensive task than the one used in the experiment, so participants who perform well on the WMS should have sufficient cognitive resources for effective recall in a shorter amount of
time. Likewise, the delayed free recall of the story is also a more difficult and more resource intensive task than the comprehension question task used in the study.

Diving down into each of the four story conditions, there are a number of correlations that echo the overall comprehension performance correlations, the aforementioned negative correlation between age and the non-distracted, text-only condition notwithstanding. The other correlations again illustrate the multi-faceted nature of reading comprehension, as it draws upon resources from attention, memory, executive function, and visuospatial processing along with language.

There were far fewer correlations between the eyetracking data and the cognitive results. The eyetracking data varied widely from person to person, making any significant measurements (beyond the significant number of revisits discussed above) difficult to parse out. The negative correlation between WMS comprehension score and text fixation time in the non-distracted comic may be indicative of highly efficient encoding of language into memory such that they do not require more than one pass at reading the text to memorize or create the schema required for the story. This efficiency frees these people up to either spend more time looking at the comics to further reinforce the linguistic information or to move more quickly through the story, decreasing the amount of time the information has to decay in memory.

Overall, the theoretical underpinnings of the cognitive effects on reading comprehension (as seen in the differing score ranges) and eye movements during the reading process (as shown by the regressive fixations) and subsequent correlational data show patterns consistent with the hypotheses; however, many did not reach significance. With further data collection and expansion of the experimental manipulations (e.g., increased reading level), a number of informative observations may yet be discovered in this line of research.


Limitations

It is difficult to generalize the results of this study to the greater populace due to the small sample size. Reading rates are highly variable, and the differences between and within participants were quite large. For example, the differences in performance time due to the increase in number of regressive microsaccades was dwarfed by the differences in overall reading time across conditions and participants. A larger data set may be able to better account for this level of variability.

There are other aspects of this study which also limit the ability to generalize to the population as a whole, such as the lack of Hispanic participants, which make up around 16% of the United States population (Humes, Jones, & Ramirez, 2011), and the higher than average education – 75% of enrolled participants had at least a Bachelor’s degree, whereas the rate is 32.5% for the general populace (Ryan & Bauman, 2016). These issues mean that the sample collected is not an ideal representation of the United States’ population at-large.

This higher than average education is in conflict with the reading level of the stories, which was targeted at the fourth to fifth grade level. This level, while easy for most of the populace to read and comprehend, was selected with the intention of using these narratives for testing people with aphasia and other clinical populations down the line. More challenging structures and lower frequency words being used may generate stronger results from healthy adults.

Future Directions

Continuing to collect normal data on these stimuli will allow for further refining of the information available about neurotypical adult reading performance under these conditions. As there are trends to many aspects of this data which approached but failed to attain statistical
significance, adding more points of data with a more geographically, racially, ethnically, and educationally diverse sample will continue to bring the exact nature of these experimental effects into focus. Additionally, further manipulation of the stimuli using more complex grammatical formations, lower frequency words, longer passages, or other variables, in combination with the current distraction, should challenge neurotypical adults further and generate more clear differences in eye movement and fixation time during reading in healthy adults across the lifespan.

The current experiment design also seems to be suitable for testing adult clinical populations, and would allow for exploration of differences in performance among people with aphasia, including differentiation by subtype, as well as other groups who typically show signs of cognitive impairment (e.g. people with traumatic brain injury). Because the remaining capacity of cognitive resources is often decreased with these groups, it is likely unnecessary to induce further cognitive load with people with aphasia or traumatic brain injury to see differences in eye movement and fixations as compared to neurotypical adults; however, the effects of performance in non-ideal conditions can also be studied using the four-talker babble design from the first study or the dual-task paradigm to simulate reading in a public space, especially for those with more mild impairments who are seeking to re-enter the workforce.

As the data continues to build and the links between these aspects of cognition and reading performance become clearer, further steps can be taken to use this information to create improved diagnostic tools, including use of the eyetracker directly, for various clinical populations, and the creation and refinement of treatment materials for those groups who exhibit impaired reading comprehension. While the comics have shown to improve comprehension performance in healthy adults, it remains to be seen if they will be more of a semantic scaffold
for impaired populations or a distraction for their already-impaired language and cognitive processing systems.
References


Appendix A
Example Story Stimuli for Eye-tracking Task

Sally was driving down the highway to take her nephew Neil to the zoo.
Neil asked, “Aunt Sally, why are there flashing lights behind us?”
Sally checked her rearview mirror and realized she was being pulled over.
The officer approached and asked for her license, which she gave him.
The officer said, “Your brake light is out, and it seems your license is expired.”
Sally said, “I didn’t realize. Looks like we have to postpone our trip to the zoo.”
The officer looked at Neil sympathetically and said, “You have 30 days to fix it.”

Sally and Neil Questions
DETAIL IMPLIED: What will Neil see at the zoo?
Animals Arcade games
Sports Books

DETAIL STATED: Why does Sally get pulled over?
Brake light License
Blinker Bright lights

MAIN IDEA STATED: How does the officer feel toward Neil?
Sympathetic Angry
Sad Empathetic

MAIN IDEA IMPLIED: Why does the officer give Sally 30 days?
So Neil can go to the zoo So he doesn’t have to write a ticket
So Sally can get to work on time So the officer can take his kids to the zoo
Danielle was home Saturday morning and her dog, Jackson, was chewing on a tennis ball. All of a sudden she heard Jackson cough.

Danielle said, “What's the matter, Jackson?” and Jackson coughed again.

Then she realized the tennis ball was nowhere to be seen.

Danielle rushed Jackson to the vet for surgery.

The vet told her, “Jackson needs to stay overnight or longer to make sure he's okay.”

After two days, he returned home healthy, but he won’t be getting any more balls.

Danielle and Jackson Questions

MAIN IDEA STATED: What happened to Jackson at the vet?

Surgery X-ray
Shots Medicine

DETAIL STATED: What was Jackson playing with?

Tennis ball Rope
Baseball T-bone

MAIN IDEA IMPLIED: What happened to the tennis ball

Jackson hid it Jackson attacked it
Jackson lost it Jackson ate it

DETAIL IMPLIED: Why won’t Jackson get more tennis balls?

Danielle can’t afford them Danielle doesn’t like them
Danielle is allergic Danielle is worried
Jim stopped by the grocery store on his way home with a list of items to pick up. He hadn’t bought groceries in two weeks, so it took a while to get everything. After the clerk scanned everything she asked, “How will you be paying, sir?” Jim reached for his wallet and realized it wasn’t there. “It must be around here somewhere,” he panicked, searching frantically. He slapped his forehead and exclaimed, “Oh! I know where it must be.” Before the clerk could say anything, Jim ran to his car and sped back to work.

Jim and the Grocery Clerk Questions

MAIN IDEA STATED: What did Jim forget?
His keys
His checkbook
His Wallet
His watch

DETAIL IMPLIED: Where did Jim leave his wallet?
At home
At school
At work
In the car

MAIN IDEA IMPLIED: Why did Jim run out of the store?
He was scared
He was upset
He couldn’t pay
He forgot his keys

DETAIL STATED: How long has it been since Jim bought groceries?
1 week
2 weeks
1 day
2 days
Mary had been searching all day for the new pair of sunglasses she had just bought. When her roommate Cecile came in, Mary asked, “Have you seen my sunglasses?” Cecile shook her head and replied, “Nope, did you look in the bathroom?” Just then, Mary saw that Cecile had a very similar pair hanging from her shirt. “Are those my sunglasses?” Mary asked, as she pointed at them. “Oh these?” said Cecile sheepishly, “I must have grabbed them by mistake”. “I bet you did,” Mary said, annoyed, as she took them from Cecile.

Mary and Cecile Questions

MAIN IDEA STATED: What was Mary looking for?
- Keys
- Sunscreen
- Glasses
- Sunglasses

DETAIL STATED: Where did Cecile tell Mary to look?
- Kitchen
- Bathroom
- Bedroom
- Living room

DETAIL IMPLIED: Where does Mary find her sunglasses?
- In the bathroom
- In Mary’s purse
- On Cecile’s shirt
- In Cecile’s room

MAIN IDEA IMPLIED: Why is Mary mad?
- Cecile took her sunglasses
- Cecile took her glasses
- Cecile lost her sunglasses
- Cecile broke her glasses
Bill was very neat and was always nagging his roommate Greg about cleaning things.

One day, Bill returned from work to a sink full of dishes.

Bill angrily said, “Greg, you need to do these dishes! I am not doing a single one!”

Greg responded, “No problem, man, I will take care of them right away.”

The next morning, Bill was surprised the sink was empty until he opened the cabinet.

“Greg,” he yelled, “Did you just put the dirty dishes away?!”

“Well yeah,” said Greg, “It would have taken me forever if I had to clean them.”

Bill and Greg Questions

MAIN IDEA STATED: Who was upset in the story?

- Greg
- Bill
- No one
- Bill and Greg

MAIN IDEA IMPLIED: Why was Bill upset at Greg?

- Greg is lazy
- Greg is picky
- Greg is late
- Greg is loud

DETAIL IMPLIED: What did Bill find in the cabinet that made him upset?

- Dirty dishes
- Dirty clothes
- Clean dishes
- Cleaning supplies

DETAIL STATED: When did Bill open the cabinet?

- That night
- The next night
- The next morning
- That afternoon
Mike and Thomas were in the front yard playing baseball.

Mike pitched and Thomas knocked the ball over the neighbor’s fence.

"Oh no," Thomas yelled, as the brothers heard the crash of breaking glass.

They sprinted into their house, and Thomas slammed the door behind them.

"Shhh," Mike hissed, "Be quiet and maybe they will think nobody’s home!"

Suddenly, there was a knock, making the boys jump fearfully.

A deep voice bellowed, "Come out boys, I found your baseball!"

Mike and Thomas Questions

MAIN IDEA STATED: What are the boys doing outside?
- Playing baseball
- Playing basketball
- Playing football
- Playing hopscotch

MAIN IDEA IMPLIED: What happened to the ball after it was hit?
- It broke a window
- It was caught
- It went in the street
- It bounced away

DETAIL STATED: Why did Mike hush Tom?
- So their neighbor couldn’t find them
- So they could sneak up on the neighbor
- So their mom wouldn’t find them
- Because they were playing hide and seek

DETAIL IMPLIED: Who was the voice at the door?
- Thomas
- Mike
- Neighbor
- Mother
After a long day, Joanne and Alan were getting ready to leave work. 

Alan looked out the window and sighed. 

He said, "The weather outside looks terrible, and I forgot my umbrella." 

"No, you didn't," Joanne said with a laugh while Alan looked confused. 

She retrieved two umbrellas out of her bag and gave him one. 

Joanne said, "I just forgot to return it yesterday." 

Alan laughed and took the umbrella from her. 

Alan and Joanne questions 

DETAIL STATED: Who thought they forgot their umbrella? 

Joanne   Alan 
Anna       John 

MAIN IDEA STATED: What is Alan's problem? 

He forgot his umbrella  He forgot his keys 
He forgot his uniform  He forgot his gym clothes 

MAIN IDEA IMPLIED: Why did he not have his umbrella? 

He lost it  He lent it 
He left it at home  He broke it 

DETAIL IMPLIED: What was the weather like? 

Sunny       Storming 
Hot         Snowing
Haley knocked on the bedroom door and shouted, “It’s time for school!”

Ray rolled over and yawned, “Five more minutes, mom.”

Haley entered and pulled the sheet off Ray’s bed, annoyed.

Then, she responded, “No, time to get up. You do this every day!”

Ray yawned and realized something, “Wait, today’s Saturday!”

Haley looked at the calendar hanging nearby and laughed, “Oops, I’m sorry!”

She apologized again, tucked him back in and closed the door.

Haley and Ray questions

DETAIL STATED: Who was woken up?

Haley          Ray
Rachel         Henry

DETAIL IMPLIED: What time of day is it?

Morning       Afternoon
Evening       Midnight

MAIN IDEA IMPLIED: Why did Haley apologize?

She got the day wrong                  She broke Ray’s things
She missed Ray’s birthday              She woke Ray up too late

MAIN IDEA STATED: Why is Haley annoyed?

Ray won’t get up                        Ray won’t do his homework
Ray won’t clean up                      Ray won’t go to bed
Annie went to the dealership with her three children to buy a new vehicle. When she arrived, Naomi, the saleswoman, asked, “What kind of car do you want?” Annie thought for a moment and said, “I just need something small, please.” Naomi showed her a small, red car with two doors and asked “How about this?” Annie shook her head and said, “No, what about something with four doors?” Naomi showed Annie a larger, grey sedan, and she smiled. “It’s perfect!” Annie said and immediately rushed to sign the paperwork.

Annie and Naomi questions

DETAIL STATED: Where did Annie go?
Car wash Restaurant
Car dealer Restroom

MAIN IDEA IMPLIED: Why didn’t Annie like the first car?
Too big Too small
Wrong color Too expensive

DETAIL IMPLIED: Why does Annie want a four-door car?
She has three kids She has two kids
She has three kittens She has two kittens

MAIN IDEA STATED: Why did Annie go to the car dealership?
To get her car fixed To go see her friend
To sell her old car To buy a new car
Alisha and Steven decided they needed a vacation and planned a road trip.

As they were driving down the road, Steven asked, "Where is that smoke coming from?"

Alisha got out of the car, looked at the hood and saw the problem.

“Oh, no,” she cried, “I think we need to call a tow truck.”

Steven got his phone and called for assistance.

The tow truck driver hooked the car up and brought them to a nearby mechanic shop.

When they arrived at the mechanic, they paid the driver and thanked him for his help.

Alisha and Steven Questions

MAIN IDEA STATED: Why were Alisha and Steven driving?

To get groceries           To go on a vacation
To drive to the airport    To go to a veterinarian

DETAIL IMPLIED: Where was the smoke coming from?

Around the tire           In the trunk
Under the hood            From the heater

MAIN IDEA IMPLIED: Why did they call the tow truck?

They lost the keys         The engine was damaged
They ran out of gas        The tire was damaged

DETAIL STATED: Who looked under the hood?

Alisha                   Ally
Steven                   Sam
Lou was sitting at his desk, trying to write an article for the newspaper.

Nate walked over and asked, “It’s almost our deadline; how is your article?”

Lou looked at the blank computer screen, shook his head and frowned.

“It was almost done, but then my computer froze,” Lou replied.

Nate thought for a second and said, “Let me show you a trick!”

He grabbed Lou’s keyboard, pressed a few buttons, and suddenly it was back.

Lou smiled, “That’s a neat trick – I wish writing all my articles was that easy!”

Lou and Nate questions

MAIN IDEA IMPLIED: What happened to Lou’s article?
He deleted it
He never wrote it
He lost it
He copied it

DETAIL IMPLIED: What is Lou’s job?
Janitor
Journalist
Mailman
Photographer

MAIN IDEA STATED: Why was Nate asking about the article?
It was overdue
It was almost due
It was too short
It was too long

DETAIL STATED: Who fixed the computer problem?
No one
Nate
Lou
The boss

109
Lillian and Jason were about to fly across the country for a conference.

After parking at the airport, Lillian got out of the car.

“T’ll get the bags,” Jason said. “Can you get our briefcases out of the trunk?”

Lillian opened the trunk, then called to Jason. “Are the briefcases back there?”

Jason said. “No, didn’t you put them in the trunk before we left work today?”

After a moment, Lillian said, “I’m going to call the office. We need those plans.”

She called work, and the secretary said they would ship the briefcases overnight.

Lillian and Jason questions

MAIN IDEA IMPLIED: Why couldn’t Lillian get the briefcases?
They were in the back seat  They were in their office
They were in the trunk  They were in the parking lot

MAIN IDEA STATED: Where were Lillian and Jason headed?
Home  A Conference
Work  A Coffee shop

DETAIL IMPLIED: Who forgot to pack the briefcases?
Jason  Lillian
The Secretary  The boss

DETAIL STATED: Where were they parking the car?
At work  At home
At the airport  At the store
It had been raining for a few days, and Natalie's car was covered in dirt. She drove to the car wash. The attendant greeted her, "What'll it be?"

"Just a basic wash and shine, please!" Natalie answered and handed him money.

“It’ll be about half an hour, ma’am. You can wait inside until it’s ready,” the attendant said. Natalie waited inside with her book until the car was finished. Then she headed home. Driving home, she accidentally drove through a pothole filled with muddy water.

"At least it was clean for a minute," Natalie sighed. Then she drove back to the car wash.

Natalie and the car wash questions

MAIN IDEA IMPLIED: What did Natalie want?
A new car     A clean car
A new bike     A clean house

MAIN IDEA STATED: Why did Natalie go back to the car wash?
She forgot her purse     She drove through mud
She got lost     She forgot her house key

DETAIL IMPLIED: What did Natalie do while the car was being washed?
Read a book     Watch TV
Read a magazine     Fall asleep

DETAIL STATED: How did Natalie pay?
Credit card     Check
Cash     It was free
Ken woke up one morning, and, out of nowhere, his mouth hurt terribly. He made an emergency appointment to see his dentist and drove right over.

The dentist asked Ken, “Have you had this pain for a long time?”

Ken shook his head, “It’s new - I just woke up with it this morning.”

The dentist looked in his mouth and asked, “What did you eat for dinner last night?”

Ken said, “A big plate of cheesy nachos and a few drinks, like every Thursday.”

The dentist pulled a chip from Ken’s mouth, “You should eat better and brush better.”

Ken and the dentist questions

MAIN IDEA STATED: What was wrong with Ken when he woke up?
- His head hurt
- His mouth hurt
- He lost a tooth
- He lost his glasses

MAIN IDEA IMPLIED: What was making Ken’s mouth hurt?
- A loose tooth
- A piece of food
- A piece of glass
- A wisdom tooth

DETAIL STATED: What did Ken have for dinner?
- Nachos
- Tacos
- Lasagna
- Nuts

DETAIL IMPLIED: What day did Ken go to the dentist?
- Thursday
- Friday
- Wednesday
- Tuesday
Last week, Bonnie bought a new pair of shoes, but they didn’t quite fit.
She drove to the mall on Sunday so she could try to get a different size.
As she handed the manager the shoebox, she said, “I’d like to exchange these.”
The manager opened the box and said, “But these shoes are two different colors.”
Bonnie looked in the box and saw one brown shoe and one black shoe.
“That’s odd, “ she thought, “That one looks like the brown shoes I’m wearing today.”
She looked down and realized that only one of the shoes she was wearing was brown.

Bonnie and the manager questions

MAIN IDEA STATED: What did Bonnie want to do?
Buy shoes
Return shoes

Exchange shoes
Sell shoes

MAIN IDEA IMPLIED: Why couldn’t she exchange the shoes in the box?
They were too old
They didn’t match
She forgot the shoes
She forgot the receipt

DETAIL STATED: What color were the shoes in the box?
Black and blue
Brown and white

Black and brown
Black and white

DETAIL IMPLIED: Where was the other shoe she wanted to return?
At home
In the car

On her foot
On the counter
Liz and Sonya wanted new bikes, but their parents said they had to wait. “We’re going to need to buy them ourselves,” said Sonya, “but how?”

Using the computer, the two girls looked up ideas on how to make money. Eventually, Sonya found a lemonade recipe and gave it to Liz to make.

After a while, Liz came back with a glass. “Here, tell me what you think.” Sonya took a big drink and gagged, “This doesn’t taste like lemonade at all!”

Liz replied, “But the computer said that salt makes people thirstier!”

Liz and Sonya questions

MAIN IDEA IMPLIED: Why did Liz change the recipe?
To sell more lemonade   To make it taste better
To make it taste worse   To save money

MAIN IDEA STATED: Why did the girls want to make money?
To buy a car   To buy a bike
To fix a bike   To fix a car

DETAIL IMPLIED: What did Liz change about the recipe?
She added more sugar   She added salt
She used limes   She added honey

DETAIL STATED: How were the girls going to make money?
By selling fruit   By selling candy
By selling lemonade   By getting jobs
Appendix B

Verbal Instructions to Participants for the Eye-tracking Task

During this next task, you will be shown stories in either a text-only format, like a book, or a combination of text and pictures, like a comic. Read the story at your own pace, and at the end of each story, you will be asked a series of questions about the story you just read. During some of the stories, you may hear some sounds and talking being played in your headphones. Do your best to keep track of the story and not listen to the people speaking in the recording.

At the beginning of each story, you will see a small plus sign in the center of the screen. Please look this spot until the first part of the story appears. When you are done with one part of the story, press the spacebar to move to the next slide. Once you advance, you cannot go back to a previous part of the story. After you complete the story, the questions will appear on the screen automatically. Use the mouse to select the best answer for the question on screen, and then click continue to go to the next question. The computer will let you know when all questions are answered.

First, you will be shown a story to familiarize you with the task. This story is not scored, and is only to get you used to how the story, questions and tones will be presented. First you will be shown the story as just text, and then afterwards, you will see the questions for that story. After you answer the questions, you will see the same story, but as a comic.

In the main part of this task, you will see the stories in sets of four, with questions after each story. If you need a break, you may take one after each set of stories is completed, but not during the set of four stories.

I can answer questions about this task now and after the practice, but once the task starts, I cannot answer any questions for you. Do you have any questions as of right now?
Appendix C

IRB Approval for Dissertation Study

Teachers College IRB Expedited Approval Notification

To: Daniel Furnas
From: Amy Camilleri
Subject: IRB Approval: 17-090 Protocol
Date: 12/08/2016

Please be informed that as of the date of this letter, the Institutional Review Board for the Protection of Human Subjects at Teachers College, Columbia University has given full approval to your study, entitled "The Effects of Text-Picture Integration and Auditory Distraction on Reading Comprehension in People with Aphasia," under Expedited Review (Category (4) Collection of data through noninvasive procedures (6) Collection of data from voice, video, digital, or image recordings made for research purposes.) on 12/08/2016.

The approval is effective until 12/07/2017.

The IRB Committee must be contacted if there are any changes to the protocol during this period. Please note: If you are planning to continue your study, a Continuing Review report must be submitted to either close the protocol or request permission to continue for another year. Please submit your report by 11/09/2017 so that the IRB has time to review and approve your report if you wish to continue your study. The IRB number assigned to your protocol is 17-090. Feel free to contact the IRB Office (212-678-4105 or accamilleri@gmail.com) if you have any questions.

Please note that your Consent form bears an official IRB authorization stamp and is attached to this email. Copies of this form with the IRB stamp must be used for your research work. Further, all research recruitment materials must include the study’s IRB-approved protocol number. You can retrieve a PDF copy of this approval letter as well as the stamped consent(s) and recruitment materials from the IRB Mentor site.

When your study ends, please visit the IRB Mentor site. Go to the Continuing Review tab and select "terminate" from the drop-down menu.

Best wishes for your research work.

Sincerely,
Amy Camilleri
IRB Administrator
accamilleri@gmail.com

Attachments:
- Informed Consent - Aphasia (Final Version).pdf