MIND, BRAIN, AND EDUCATION

# The Neuroscience of PowerPoint™

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**ABSTRACT**— Many concepts have been published relevant to improving the design of PowerPoint™ (PP) presentations for didactic purposes, including the redundancy, modality, and signaling principles of multimedia learning. In this article, we review the recent neuroimaging findings that have emerged elucidating the neural structures involved in many of these concepts. First, we explore the research suggesting that the brain utilizes similar structures to process written text and oral speech leading to neural competition and impaired performance during dual linguistic text/audition tasks (redundancy principle). Next, we examine research that demonstrates that the brain processes visual images in a manner different from and parallel to oral speech leading to improved performance during dual nonlinguistic visual/audition tasks (modality principle). Finally, we look at how the brain responds to contextual and direct attention cues (signaling principle). We link this research to PP design and suggest a number of concrete ways to implement these findings to improve the didactic strength of slide-show presentations.

PowerPoint™ (PP): over the last two decades this once-popular business tool has extended its influence to academic classrooms and scientific labs around the world. In that time much behavioral and psychological research has been conducted exploring how best to utilize this tool for didactic purposes. Recently a wealth of neuroscientific data has been published that supports much of this research and elucidates the neural underpinnings of several key findings.

In this article, we explore neuroimaging findings from the fields of perception, comprehension, retention, and attention and apply these findings to the PP tool. Through this work, we hope not only to support several practical suggestions previously put forth in the multimedia learning literature, but also to take a step closer toward determining the mechanistic explanations for why said suggestions are effective.

## WHY WRITTEN TEXT WITH SPOKEN WORD DOES NOT WORK

A key concept in multimedia learning theory is the verbal redundancy principle. First outlined by Richard Mayer (2001), the verbal redundancy principle suggests that the presentation of concurrent aural and textual linguistic stimuli increases cognitive load which, in turn, impairs learning. With regards to PP, this often translates to the suggestion of eliminating much text from each slide presented during an oral presentation (see Pros, Tarrida, Martin, & Amores, 2013 for a review).

Although there are a number of behavioral studies supporting the verbal redundancy principle (see Toh, Munassar, & Yahaya, 2010 for a review), neural explanations have often been speculative and most often involve interference and/or resource competition within the visual working memory system (Toh et al., 2010). Interestingly, recent neuroimaging evidence suggests that this may not be the case.

To understand what neuroscience has to say about the verbal redundancy principle, it is necessary to look at the science of reading: more specifically, the *silent reading voice*. When silently reading text, most people "hear" an internal voice covertly pronouncing each word in turn. Although early cognitive theorists postulated that silently read text must be internally translated into and processed as aural speech, it was not until the proliferation of modern neuroimaging technology that this theory obtained strong empirical evidence. Currently, research suggests that, following primary visual and fisuform gyral (visual word form area) activation, silent reading activates neural areas commonly linked to pure audition (primary auditory cortex, secondary auditory cortex, etc.) and auditory speech perception (superior temporal sulcus [STS], right posterior temporal lobe, etc.; Bemis & Pylkkänen, 2012; Perrone-Bertolotti et al., 2012; Petkov & Belin, 2013).

This suggests that silent reading (the kind most often done by audience members attempting to decipher text presented on a PP slide) utilizes the same perceptual networks as the

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aural speech listening. As such, when reading text on a PP slide, it may be difficult to also listen to concurrent oration. Support for this supposition has recently been obtained by Wecker (2012) and Savoy, Proctor, and Salvendy (2009) who both reported large, significant decreases in recognition of orally presented information in the presence of text-based PP slides (as compared to orally presented information without accompanying slides or with minimally textual slides). These findings led Wecker to posit a "speech suppression effect" of text-based PP slides (p. 260).

Interestingly, several behavioral researchers attempting to elucidate the mechanisms of the verbal redundancy principle maintain it is not caused by split-attention effects (Sweller, Ayres, & Kalyuga, 2011). Whereas this may be true at the level of perception (as outlined above), recent neuroimaging evidence suggests that at the levels of comprehension and retention the verbal redundancy principle may, in fact, be caused by competition for attentional resources.

If the theory that text and speech are both processed via language-based auditory channels is correct, then the combination of these two stimuli becomes akin to a linguistic dichotic listening task (lDLT). During a typical lDLT, individuals are presented with two concurrent streams of auditory information. Several decades of behavioral research have shown that when a listener attends to only one of these auditory streams (selective attention), there is little to no comprehension or retention of the unattended stream. Perhaps more importantly, when a listener attempts to attend to *both* auditory streams (divided attention), comprehension and retention for both streams suffer (for review of DLT technique and findings, see Hugdahl, 2011; Hugdahl et al., 2009).

Although the precise mechanisms by which divided linguistic auditory attention interferes with information comprehension, and retention remain uncertain, several imaging studies have highlighted the important role of the left dorsal inferior frontal gyrus (ldIFG): a neural region linked to language-specific comprehension (for review see Costafreda et al., 2006). It has been reported that the ldIFG displays markedly *increased* activity during divided attention conditions than during selective attention conditions (likely reflective of increased processing demands) and has shown to be correlative with retention of presented information (Buchweitz, Keller, Meyler, & Just, 2012; Fernandes, Pacurar, Moscovitch, & Grady, 2006; Kensinger, Clarke, & Corkin, 2003). Of importance for this discussion is the fact that several researchers have noted a near identical hyperactivation of the ldIFG when participants undergo a dual text/speech task (Uncapher & Rugg, 2005, 2008) but no attenuated ldIFG activity when participants undergo *nonlinguistic* DLT or audiovisual tasks (Fernandes et al., 2006; Sigman & Dehaene, 2008; Uncapher & Wagner, 2009; Vohn et al., 2007). These findings support the notion that reading text and listening to speech rely on (at least in part) similar comprehension and retention networks.

The assumption can be made that, much like during lDLTs, dual text/speech tasks would lead to comprehension and retention impairment for information presented in both modalities due to divided attention. In fact, this is what research shows. Lin, Robertson, and Lee (2009) and Lin, Lee, and Robertson (2011) have twice explored attention and memory during simultaneous reading and listening tasks. Although neither study reported listening performance scores in isolation, both reported significant drops in reading performance scores during the concurrent listening task (as opposed to the pure reading or reading while ignoring auditory information conditions). The authors argued that these performance impairments were due to attention switching and re-orientation. In addition, Kalyuga, Chandler, and Sweller (2004) presented trade apprentices with purely text, purely auditory, or combined text/auditory instructions outlining varied technical processes (such as fusion soldering or drill speed measurement). Apprentices in the isolated instruction conditions learned faster and performed better (with the exception of a final multiple choice quiz) than apprentices in the dual condition due to, the authors argued, split attention effects (for additional behavioral research exploring linguistic text/audition interference, see Fernandes, Craik, Bialystok, & Kreuger, 2007; Fernandes & Moscovitch, 2003; Naveh-Benjamin, Kilb, & Fisher, 2006).

With regards to PP, if, during a text-based presentation, the audience is attempting to attend to *both* the slides and the speaker (via switching attention back and forth between the two), we would expect comprehension and retention for both the aural and written information to suffer due to divided-attention. In fact, beyond reporting a strong decrease in orally presented material in the presence of text-based PP slides, Wecker (2012, discussed above) also noted an *overall* decrease in informational retention which means that the audience displayed impaired retention for both orally and textually presented information. Through the implementation of self-report questionnaires, Wecker argued these impairments occurred due to divided and dysfunctional allocation of attention (rather than cognitive overload effects). Similarly, Yue, Bjork, and Bjork (2013) recently presented college students with varied PP presentations exploring the life cycle of a star. In this study, students presented with oral narration performed better on a post-presentation exam than students presented with identical oral and text narration (unfortunately, a purely text-based narrative condition was not explored).

These findings raise an important question: How can we use the knowledge that speech and text vie for the same neural perception, comprehension, and retention resources to enhance PP presentations? One answer put forth in the multimedia learning literature is to replace large passages of text (on PP slides) with images.

## WHY VISUAL IMAGES WITH SPOKEN WORD WORKS

A second key concept in multimedia learning theory is the modality principle. The modality principle suggests that learning can be enhanced when oration is combined with relevant visual images (rather than text; Mayer, 2009). With regards to PP, this often translates to the suggestion of placing relevant images on slides presented during an oral presentation (see Pros et al., 2013 for review). Although this principle has been demonstrated behaviorally, the neural structures involved were largely unelucidated until recently.

Unlike text, visual images have not been shown to utilize auditory processing regions during the perceptual stage. Rather, following primary visual activation, images activate various structures dependent upon the unique form of optical stimuli; such as the parahippocampal place area for scenic imagery, the extrastriate body area for body part imagery, the fusiform face gyrus for facial imagery, and the lateral occipital complex for object imagery (see Werner & Chalupa, 2013 for review). This means that, at the perceptual stage, pure images and spoken words will not typically converge on the same neural mechanisms and will, instead, be processed in parallel.

Also unlike text, visual images have not been shown to utilize the same neural comprehension and retention regions as auditory stimuli. Whereas linguistic auditory attention/memory has been shown to reflect attenuated activation in the ldIFG, visual attention/memory effects have been correlated with attenuated activity in bilateral fusiform, hippocampal, and posterior parietal cortices (Kim, 2011). In addition, under dual-task auditory/visual conditions, research has revealed increased activity within bilateral STS (Holle, Obleser, Rueschemeyer, & Gunter, 2010; Werner & Noppeney, 2010a, 2010b). As these regions typically do not show activation during unimodal focused attention tasks, linguistic DLTs, dual-linguistic text/speech tasks, or dual visual tasks, it has been argued that the STS plays a role (in part) in audiovisual integration and later memory formation (see Koelewijn, Bronkhorst, & Theeuwes, 2010 for review).

What these findings suggest is that, whereas (as outlined above) dividing attention between text and speech typically impairs comprehension and retention for both stimuli streams, dividing attention between nonlinguistic visual and linguistic auditory tasks should engender little to no impairment for either stream: in fact, sensory integration may improve overall comprehension and retention. Indeed, this is what much research has shown. At the perceptual level, Alais, Morrone, and Burr (2006) found that, whereas participants' auditory (pitch) and visual (contrast) thresholds increased when measured during a concurrent task utilizing the same sensory modality, thresholds were unaffected when measured during concurrent task utilizing the opposing sensory modality. At the comprehension level, Schumacher, Elston, and D'Esposito (2003) reported that participants were able to perform equally well on simultaneous auditory and visual choice reaction time tasks as they could on each task in isolation (interestingly, when these dual reaction time tasks are performed with a short interstimulus-interval between modalities rather than simultaneously—per the psychological refractory period procedure—performance on the secondarily presented task suffered: for discussion of the psychological refractory period, see Pashler, 1994). At the retention level, Johnson and Zatorre (2006) asked participants to attempt to memorize stimuli in either one modality (while ignoring the other: selective) or both modalities simultaneously (divided). Results showed recognition memory performance was no different for both forms of stimuli in the divided condition when compared to each selective stimulus condition (for additional audiovisual divided attention behavioral research, see Arrighi, Lunardi, & Burr, 2011; Mishra & Gazzaley, 2012; Talsma, Doty, Strowd, & Woldorff, 2006).

Concerning PP, this research suggests that audiences may comprehend and retain more information when an oral presentation is accompanied by relevant image-based slides than when it is accompanied by text-based slides. This is what several researchers have found. For instance, Hallett and Faria (2006) presented undergraduate students with identical oral lectures, each accompanied by a different forms of PP: in one, PP slides contained bullet point text, in the second PP slides contained images, animations, and/or other nontext-based multimedia features. These authors report that students recalled more information both immediately following and 3 weeks after lectures utilizing image/multimedia-based PP slides. Similarly, Jamet and Le Bohec (2007) reported that students performed better on exams following lectures that combined oral presentation with image based slides as compared to lectures that combined oral presentation with text and/or combined text- and image-based PP slides (for additional research, see Kühl, Scheiter, Gerjets, & Edelmann, 2011; Liu, Lai, & Chuang, 2011; Yang, Chang, Jien, Jien, & Tseng, 2012; Yue et al., 2013).

## UTILIZING THE "POINT" IN PP

A third key concept in multimedia learning theory is the signaling principle. This principle suggests that learning can be enhanced when attentional cues are used to highlight relevant or essential information during learning (Mayer, 2009). With regards to PP, this often translates into using spatial or visual features to guide attention to relevant images or parts-of-images during a presentation. To understand how and why this works, it is important to explore the fields of contextual and spatial cueing.

First studied by Chun and Jiang (1998), contextual cueing is a concept that refers to the way in which people analyze and come to comprehend visual scenes. Specifically, contextual cueing suggests that visual attention can be beneficially guided and enhanced by the utilization of implicit regularities within a shifting visual scene. This means that if a shifting visual object appears repeatedly in the same location and/or surrounded by the same visual information over time, people will be quicker to locate and attend to the object than if it appears in random locations or surrounded by ever-shifting visual information over time (Chun & Jiang, 1998). In psychology, the guidance of attention via contextual cueing, which has been explored and confirmed time and again utilizing varied visual search paradigms (see Kristjánsson & Campana, 2010; Summerfield & Egner, 2009 for review), has been explained via unconscious learning; namely, without explicit instruction, people come to learn the unique visual layout and relationship in a manner that allows them to (correctly) predict future visual layout and relationship allowing for enhanced attention and comprehension.

The precise neural mechanisms which reflect contextual cueing are currently under debate. Whereas several researchers have suggested the hippocampus proper plays a role in implicit contextual cueing (Giesbrecht, Sy, & Guerin, 2012; Hannula & Ranganath, 2009), several others have argued that the hippocampus only plays a role when explicit learning occurs; rather, parahippocampal and other medial temporal lobe structures play a role in implicit contextual cueing (Dennis & Cabeza, 2011; Westerberg, Miller, Reber, Cohen, & Paller, 2011). Regardless of precise location, these imaging studies concur on one important point: following repeated viewing of a predictable visual scene, neural activity *decreases*. This functional deactivation of specific neural regions has been theorized to mean it requires less effort for the brain to analyze and comprehend repeated, predictable visual scenes than novel, unpredictable scenes.

Apropos of PP, what these findings allude to is that images presented in a consistent, predictable manner will not overly tax the audience's attention and engender to quick and easy recognition. More concretely, contextual cueing effects suggests that, rather than dozens of scatter-shot images (Figure 1a), each slide should contain a small and predictable number of images which occur at the same location/s and are of similar size/s across slides. In addition, a simple delineation of the spatial layout (such as outlining the area where images will appear) will create spatial relationships which will enhance the contextual cueing effect (Figure 1b and c).

Although the effect of this type of predictable layout on PP slides has not been studied, per se, Ragan, Endert, Bowman, and Quek (2012) recently asked students to study a picture-story where each image was presented in succession at either one location (a single computer monitor) or across a diverse set of locations (across 10 computer screens). It was reported that students performed significantly better on a post-story exam when images were presented at a single, predictable location, leading the authors to conclude "…increasing the spatial variance of (sequentially presented) information locations does not necessarily support cognitive processing" (p. 97).

Beyond contextual cueing, spatial cueing can also be used as a form of signaling principle. Arguably first elucidated in detail by Michael Posner (1980), spatial cueing argues that attentional alignment can be initiated in response to "cues" about the probable location of impending targets of interest. Although these cues can come in a variety of forms (visual, auditory, symbolic, etc.) one class of cues specific for our interests is called *direct*; whereby attention shift is initiated by the appearance or flicker of a visual signal (such as an outline box, circle, or dot) which appears at or near the location of a target within 250 ms of target appearance. Several decades of research have consistently found that valid direct cues lead to faster response and accuracy to the cued target (see Rai & Singh, 2009 for review), due likely to a combination of an

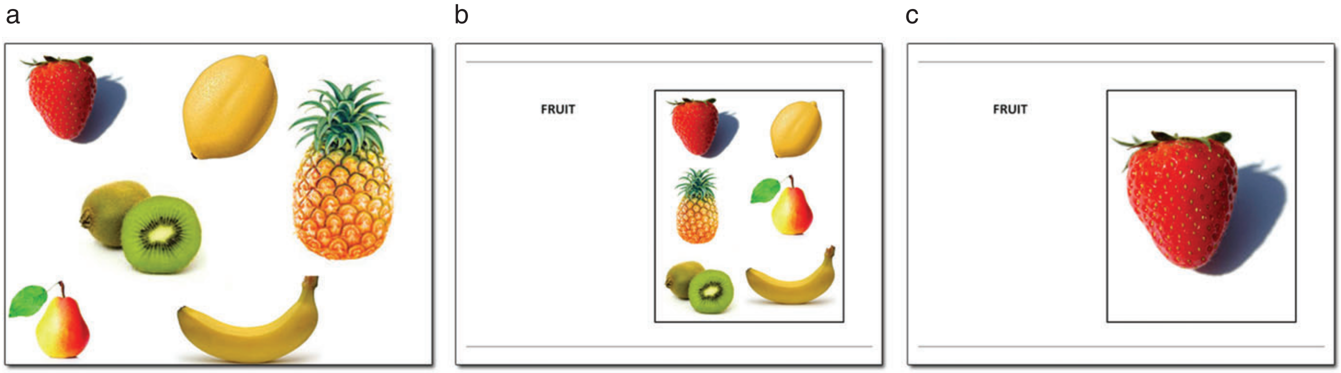
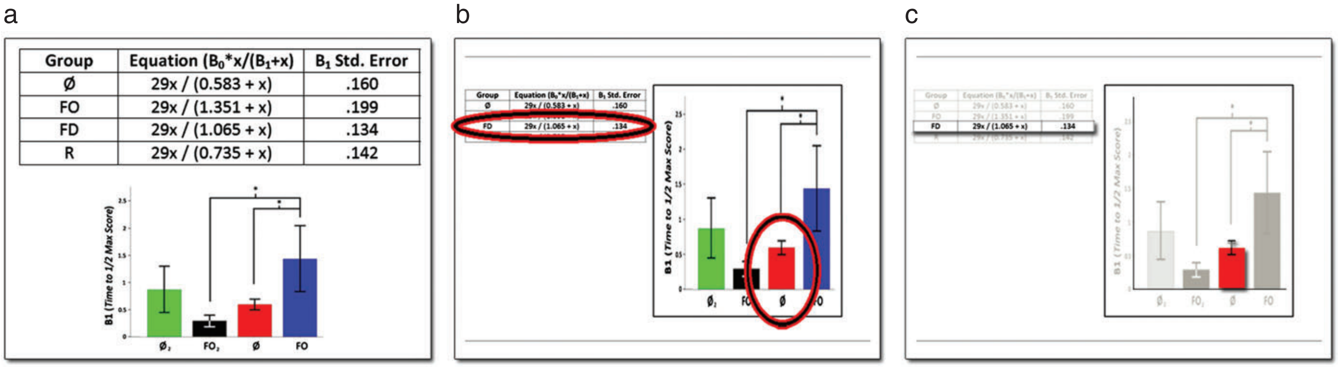


**Fig. 1.** Contextual Cueing in PowerPoint$^{TM}$. (a) Although no text is being utilized, images are unorganized and will require the audience to locate each prior to attending. (b) A simple box outlining where images will consistently appear between slides will largely eliminate the need to locate prior to attending. (c) Using a single, simple image in a well-defined area will ensure images are easy to locate and attend allowing for maximum attention to be spent on integrating the image with the commensurate oral presentation.



| Group | Equation ($B_0$*x/($B_1$+x) | $B_1$ Std. Error |
|---|---|---|
| Ø | 29x / (0.583 + x) | .160 |
| FO | 29x / (1.351 + x) | .199 |
| FD | 29x / (1.065 + x) | .134 |
| R | 29x / (0.735 + x) | .142 |

Fig. 2. Spatial cueing in PowerPoint$^{TM}$. (a) Busy charts and graphs often require large amounts of attention to decipher and are not always completely relevant to the presentation. (b) The appearance of simple circles can guide audience attention to those aspects relevant to the presentation. (c) A surround wash-out of irrelevant information can also guide audience attention to pertinent information.

exogenous attentional grab (whereby the sudden appearance of a cue on the peripheral externally attracts visual attention) and an endogenous attentional shift (whereby the sudden appearance of a cue on the peripheral is understood to symbolize something important so that attention is purposely switched to it). Imaging data have shown that this cued attentional shift, whether exogenous or endogenous, relies on a diffuse fronto-parietal cortical network (see Huang & Grossberg, 2010 for review).

Several recent studies have demonstrated enhanced learning effects from spatial cueing. For instance, Amadieu, Marine, and Laimay (2011) demonstrated that direct cueing (via zooming) each step in-turn during an animation exploring the process of long term potentiation enhanced learner comprehension and retention. In addition, Ozcelik, Arslan-Ari, and Cagiltay (2010) reported that direct cueing (via colored highlighting) of specific aspects within a static diagram of a turbojet engine during an accompanying oral narration of how the engine works led to enhanced performance on post-lesson transfer and matching exams (see also Boucheix, Lowe, Putri, & Groff, 2013; de Konin, Tabbers, Rikers, & Paas, 2007).

Regarding PP, spatial cueing is perhaps most appropriately utilized when displaying graphs or charts. Oftentimes, data displays contain much more information than is relevant to the commensurate oral discussion (Figure 2a). As such, when detailed graphs or charts are presented, learners must allocate attention to deciphering the slide and locating the few aspects pertinent to the presentation—a process likely to interfere with comprehension and retention of the accompanying speech. Using spatial cues, such as "appearing" circles or a surround washout (Figure 2b and c) will simply and easily guide the audience's attention to important, referenced information. Using this simple technique, a presenter can effectively "point" so that audience members can attend both to the important aspect of the complex image and the orally presented information.

## CONCLUSION

Through this review, we have explored the ideas that written text and spoken word conflict at the levels of perception, comprehension, and retention (largely due to neural overlap and competitive processing), whereas pure images and spoken word do not typically conflict (largely due to independent and parallel neural processing) and, oftentimes, integrate to enhance retention. We linked these findings to the multimedia learning principles of redundancy and modality (respectively). In addition, we explored ways in which common PP features can be used to cue and guide attention in a manner which will enhance material comprehension and retention, akin to the multimedia learning principle of signaling. Although the fields of neuroscience, psychology, and education are continually growing and integrating (a process which will no doubt add to and clarify many of the points discussed in this article), the findings made thus far serve as a solid conceptual foundation for the development of effective PP presentations and the guidance of future research exploring this matter.

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