HHS Public Access
Author manuscript
Curr Dir Psychol Sci. Author manuscript; available in PMC 2019 June 19.

Published in final edited form as:
Curr Dir Psychol Sci. 2019 February ; 28(1): 47–52. doi:10.1177/0963721418807725.

Insights From Crossing Research Silos on Visual and Auditory Attention

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Abstract

Many learning tasks that children encounter necessitate the ability to direct and sustain attention to key aspects of the environment while simultaneously tuning out irrelevant features. This is challenging for at least two reasons: (a) The ability to regulate and sustain attention follows a protracted developmental time course, and (b) children spend much of their time in environments not optimized for learning—homes and schools are often chaotic, cluttered, and noisy. Research on these issues is often siloed; that is, researchers tend to examine the relationship among attention, distraction, and learning in only the auditory or the visual domain, but not both together. We provide examples in which auditory and visual aspects of learning each have strong implications for the other. Research examining how visual information and auditory information are distracting can benefit from cross-fertilization. Integrating across research silos informs our understanding of attention and learning, yielding more efficacious guidance for caregivers, educators, developers, and policymakers.

Keywords

visual attention; auditory attention; selective sustained attention; distraction; learning; noise; clutter

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Children need to acquire knowledge from both informal and formal settings, but the world around them is filled with different sounds and sights all vying for attention. Research suggests that successful learning depends in part on the ability to selectively focus attention (Erickson, Thiessen, Godwin, Dickerson, & Fisher, 2015; Oakes, Kannass, & Shaddy, 2002), and this capacity develops slowly during childhood (Colombo, 2001). A growing body of research is focused on investigating the nature of children's auditory and visual environments and how these features impact learning (Fisher, Godwin, & Seltman, 2014; Pereira, Smith, & Yu, 2014; Tomalski et al., 2017).

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Declaration of Conflicting Interests
The author(s) declared that there were no conflicts of interest with respect to the authorship or the publication of this article.

Children have difficulty learning in chaotic environments containing visual or auditory distractors (Barr, Shuck, Salerno, Atkinson, & Linebarger, 2010; Chiong & DeLoache, 2013; Flack & Horst, 2017; Godwin et al., 2016; Parish-Morris, Mahajan, Hirsh-Pasek, Golinkoff, & Collins, 2013). Research on these issues tends to be siloed: Relatively little cross talk occurs among researchers with expertise in auditory and language development and researchers focusing on visual attention and learning.[1] We argue that each domain has important implications for the other, and considering visual and auditory distractions jointly may lead to new insights and recommendations for best practices for caregivers, educators, developers, and policymakers. Here, we provide an overview of attention, discuss areas of overlap between auditory and visual domains, and conclude by presenting relevant research on learning, focusing on how auditory and visual distraction may be fundamentally intertwined.

Attention, Auditory Processing, and Visual Processing

The environment contains many distinct sources of visual and auditory information; however, only a subset of this information may be relevant for a particular learning task. Thus, to learn, children must selectively attend to relevant features of the environment at the expense of others. Imagine a child sitting at the kitchen table listening to a caregiver read a story. This task might require the child to visually attend to the illustrations and carefully listen to the story. Simultaneously, the child needs to ignore the sights and sounds of a busy household that are irrelevant to the task at hand (e.g., an intricate tablecloth, the dishwasher humming, the dog walking past). We refer to this ability to attend to task-relevant information, inhibit irrelevant information, and maintain this state over time as *selective sustained attention*.

Attention regulation can be automatic, meaning that attention is captured by salient aspects of the environment— such as loud sounds, bright colors, and motion—or top- down and voluntary, based on an individual's goals and interests (Colombo & Cheatham, 2006; Ruff & Rothbart, 2001). Early in development, selective sustained attention is largely driven by stimulus properties such as brightness, contrast, and novelty (Bornstein, 1990; Ruff & Rothbart, 2001). As brain regions such as the prefrontal cortex mature, children acquire increasing ability to deploy attention voluntarily (Oakes et al., 2002). This dual model of attention regulation is a common framework in cognitive psychology; however, debate exists over precisely how to define attention, its components, and functions. A comprehensive treatment of the nature of attention is beyond the scope of the present article (for reviews, see Colombo, 2001; Ruff & Rothbart, 2001); nevertheless, there is general agreement that (a) attention is multifaceted, with distinct functions, and (b) selective sustained attention is critically important for complex processing.

Prior work has examined the relationship among attention, task performance, learning, and academic achievement (Choudhury & Gorman, 2000; Commodari, 2012; Dixon & Salley, 2007; Duncan et al., 2007). Although selective sustained attention is hypothesized to be

[1] We focus on attention with a specific emphasis on how auditory and visual distractions influence learning. Multimodal perception is a related but separate line of inquiry. We refer interested readers to Bremner, Lewkowicz, and Spence (2012) for more information on this important research area.

critical for learning in both the auditory and visual domains, a disproportionate amount of research on the development of attention has focused on visual attention. Additionally, research with infants and toddlers tends to focus on attention that is regulated automatically. These asymmetries are likely due to difficulties in measuring voluntary attention in children who are too young to understand or follow directions and because attention is often measured via behavioral indices such as eye gaze, which is more tightly linked to visual attention—although it is possible to shift the focus of attention without changing gaze (Duc, Bays, & Husain, 2008; Hoffman & Subramaniam, 1995).

Key Differences and Areas of Overlap

Many differences exist between the auditory and visual domains. For example, although sounds may be sustained over time, decay and transience are among their fundamental properties. Thus, auditory processing often involves making sense of rapidly changing or disappearing signals. In contrast, visual input is more stable and less likely to suddenly disappear or to disappear as quickly. Consequently, visual processing may be less fundamentally linked to temporal principles governing auditory processing. Research suggests that temporal dynamics favoring learning in the visual domain often differ from those of similar learning tasks presented in the auditory domain (Conway & Christiansen, 2009). In comparison, language processing occurs in both the auditory and visual domains (recognizing words within a speech stream and reading respectively); however, the transient nature of the auditory domain makes the task inherently different.

In the same way that temporal dynamics are critical to auditory processing, spatial factors are of greater importance to visual processing. To attend to a target among distracting objects, a viewer must localize it in space. At a physiological level, visual information is spatially distributed, such that information from different objects is processed by different receptors in the eye. In audition, all sounds are funneled down the ear canal to the tympanic membrane or eardrum; collective vibrations are transmitted to the cochlea and auditory receptors. The brain must reseparate the target and distracting signals prior to making sense of an attended signal (Bregman, 1990). In some respects, visual distractions may be easier to ignore than auditory distractions, especially if an individual can physically orient away from the distractions. For instance, desk dividers can shield against visual distractions and focus attention on instructional materials. In contrast, a physical shield (e.g., earplugs) can dampen all sound but cannot typically selectively reduce distracting sounds.

Another important difference relates to phenomena associated with increasing the number of auditory and visual objects. In vision, increasing the number of objects can produce clutter, possibly increasing the difficulty of maintaining attention to a target (Dixon & Salley, 2007; Fisher, Thiessen, Godwin, Kloos, & Dickerson, 2013). In contrast, increasing the number of auditory signals can fuse signals into a single noise that is more intense but also less variable and thus less likely to cause distraction; this is particularly true of voices (Brungart & Simpson, 2002). Consequentially, attentional effects based on the number of objects likely differ by domain. There are also differences in modality dominance: Infants and toddlers rely more on auditory information in contexts in which auditory and visual information compete. Around age 4, this preference evens out, and eventually visual information begins to dominate (Robinson & Sloutsky, 2004). The protracted developmental trajectory of attention, as well as differences in the perceptual impact of the environment across development, point to the importance of considering how acoustically and visually optimized learning environments will likely differ with age.

There are also similarities between the auditory and visual domains. For example, background noise can impair processing of a target through energetic or informational masking (Brungart & Simpson, 2002). In energetic masking, energy from one signal interferes with another; this can occur when a distractor at the same frequency as the target makes the target inaudible or when the auditory representations of two signals interfere as a result of spread of excitation on the basilar membrane. In vision, spatial occlusion of one object by another can be thought of as analogous to energetic masking. Informational masking refers to cases in which a potential distractor causes confusion, making the listener uncertain of which sounds belong to which signal; here, the target signal typically remains partially or even fully audible but can still be difficult to distinguish from background noise. In the visual domain, an analogous scenario occurs when a target object is fully visible but presented with other objects. The proximity of dis- tractor objects may increase the difficulty of distinguishing the target from distractors or generally reduce attention to the target.

In both the visual and auditory domains, distractors can be simple and static, such as the relatively constant sounds of the air conditioning humming, or plain and unadorned stationary objects. Distractors can also be complex and variable—for example, speech sounds changing in frequency, pitch, or volume or objects or displays that are bright, moving, or patterned. Regardless of domain, individuals may find it more difficult to habituate or ignore variable and complex stimuli (see Kavšek, 2013, for a review). Moreover, the level of concentration required for a given learning task may influence susceptibility to distraction as well as the level of impairment the distractor (or distractors) may cause.

Finally, the intensity of auditory and visual information can cause frustration and stress, and in some cases physical damage; for example, very loud sounds and bright lights can damage sensory receptors (Andley, 1987; Ising & Kruppa, 2004; Shield & Dockrell, 2003). Tolerance for extraneous noise and clutter may also vary. Children with autism or hearing loss may be disproportionately affected by extraneous information in the environment because of heightened sensitivity to noise and susceptibility to visual distractions (Dunn, Myles, & Orr, 2002; Guardino & Anita, 2012; Hanley et al., 2017). Similarly, bilingual children seem to be more susceptible to auditory noise (Mayo, Florentine, & Buus, 1997).

Implications for Learning

Background noise can be detrimental to children's speech comprehension and learning (Barr et al., 2010), which is important given that noise levels in day-care centers and schools are frequently higher than recommended levels (American Speech-Language-Hearing Association, or ASHA, 1995; Erickson & Newman, 2017). Hygge, Evans, and Bullinger (2002) reported a variety of negative effects on cognitive performance measures in elementary school students exposed to aircraft noise. Learning costs related to more pleasant background noise have also been shown, as instrumental music can impair learning from television among infants (Barr et al., 2010). Similarly, background speech can disrupt the acquisition of new labels: McMillan and Saffran (2016) found that toddlers struggled to learn new labels unless they were substantially louder than background speech. Although the cause of such difficulties in listening and learning when noise is present is uncertain, early maturation of the auditory system may implicate attentional difficulties (Erickson & Newman, 2017). Background noise that varies in content or volume over time may automatically capture attention, resulting in divided attention. Thus, background noise may increase the burden on children's attentional systems as they strive to attend to a learning activity.

Findings such as these have led to classroom design recommendations to help improve acoustics by adding drop ceilings, acoustical ceiling tiles, carpeting, and noise-absorbing surfaces (Crandell & Smaldino, 2001; Woolworth & Phinney, 2015). Specific recommendations regarding this latter acoustical modification include incorporating noise-absorbing materials, such as cork bulletin boards, and hanging quilts, flags, and student work from classroom walls (ASHA, n.d.; Crandell & Smaldino, 2001; Manlove, Frank, & Vernon- Feagans, 2001). However, such recommendations should be tempered considering how these design elements interact with children's visual attention: A growing literature has found greater inattention and reduced learning outcomes in environments containing visual distractions such as educational posters and artwork, compared with visually streamlined environments (Fisher et al., 2014; Hanley et al., 2017). Similarly, classroom complexity and color are negatively related to student achievement (Barrett, Zhang, Moffat, & Kobbacy, 2013); however, Barrett, Davies, Zhang, and Barrett (2015) recently found evidence of a curvilinear relationship suggesting that moderate amounts of visual stimulation may be optimal for learning. Given this evidence, hanging bulletin boards or soft materials may reduce noise but may inadvertently decrease attention and learning by directing attention to features of the visual environment.

As discussed above, visual clutter can be detrimental for school-age children (Barrett et al., 2015; Barrett et al., 2013; Fisher et al., 2014; Hanley et al., 2017), but it can also serve as a distraction and impair learning in early childhood. For example, visual clutter can impede vocabulary acquisition: Pereira et al. (2014) found that toddlers' acquisition of novel labels was enhanced when the target was centrally positioned in the toddlers' view, with few or no distractors, compared with cases in which the target was less central or among more distractors (see also Horst, Scott, & Pollard, 2010). However, here again, the relationship may be curvilinear, as label acquisition may be enhanced by the presence of a single distractor compared with conditions under which all visual clutter is omitted (Zosh, Brinster, & Halberda, 2013). Complexity of visual stimuli or overloading also affects preschoolers' ability to learn new words. Three-year-olds struggled to learn new words from books when they contained multiple illustrations per page compared with visually streamlined books containing a single illustration per page (Flack & Horst, 2017). Additionally, young children show diminished learning outcomes when learning novel words or content from books containing pop-ups or manipulative features compared with standard picture books (Tare, Chiong, Ganea, & DeLoache, 2010). Efforts to increase attention and engagement while reading have resulted in electronic books filled with animations and sound effects (for a discussion, see Moody, 2010). However, recent research suggests that extraneous auditory features can also reduce toddlers' story comprehension (Parish-Morris et al., 2013).

These examples highlight the importance of integrating across disciplines, and they underscore the significance of considering both auditory and visual properties and their potential for distraction when creating learning environments and instructional materials that support early learning. For example, if quilts are used to muffle distracting sounds, solid and neutral-color materials may be less visually distracting than colorful or patterned fabric. As discussed above, highly decorated learning environments, even those containing educational content, can increase inattention and decrease learning (Fisher et al., 2014). Educational practitioners can help mitigate these negative effects by reducing the amount of visual material displayed in the classroom. Instead of decorating the classroom itself, educators can create exhibits showcasing student work in hallways or the cafeteria. With advancements in technology, classrooms can become adaptive places where only materials relevant for the current lesson are projected, reducing attentional competition between the visual environment and learning activity—a possibility we are currently investigating. One could easily extend these ideas to other formats, including educational applications, games, books, and television programing. More generally, integrating knowledge across disciplines can lead to new insights and yield more visually and acoustically optimized educational materials and environments.

Conclusions

In this article, we provide an overview of selective, sustained attention as it relates to infants' and young children's formal and informal learning by considering how auditory and visual distractions are interconnected. Work on both auditory and visual attention can be brought to bear to guide interventions and inform design of optimal instructional materials and learning environments. More research is needed, as much remains unknown about how auditory and visual complexity interact in the context of attention and learning. Furthermore, assuming that perception is not amodal, it is unlikely that auditory and visual distractions work exactly the same way. Thus, considering these domains jointly could also have important theoretical implications. In conclusion, joint consideration of visual and auditory attention can generate new insights and enhance the efficacy of recommendations for research-based practices for caregivers, educators, developers, and policymakers.

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Acknowledgments

Thanks to Anna Fisher, Paulo Carvalho, and three anonymous reviewers for their insightful comments and suggestions for revision.

Funding

This work was supported by National Institutes of Health Grant 5R01HD081127-02.

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