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Review

Experience-Driven Auditory Attention

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In addition to conscious goals and stimulus salience, an observer's prior experience also influences selective attention. Early studies demonstrated experience-driven effects on attention mainly in the visual modality, but increasing evidence shows that experience drives auditory selection as well. We review evidence for a multiple-levels framework of auditory attention, in which experience-driven attention relies on mechanisms that acquire control settings and mechanisms that guide attention towards selected stimuli. Mechanisms of acquisition include cue–target associative learning, reward learning, and sensitivity to prior selection history. Once acquired, implementation of these biases can occur either consciously or unconsciously. Future research should more fully characterize the sources of experience-driven auditory attention and investigate the neural mechanisms used to acquire and implement experience-driven auditory attention.

Highlights

In addition to conscious goals and physical salience, experience also influences auditory attention.

Experience-driven attention operates at multiple levels, including an acquisition level involving the sources of attentional control and an implementation level involving attentional guidance.

There are many forms of experience-driven attention, including cue–target associative learning, reward learning, and selection history. These categories represent dissociable effects that rely on a complex of different learning mechanisms.

Experience can both consciously and unconsciously influence attentional guidance. In some cases, observers guide attention consciously based on explicit recognition of their experiences. Conscious recognition is not necessary for experience to affect auditory attention, however, as many forms of experience implicitly affect attentional guidance.

Experience Affects Auditory Attention

Statistical structure within the environment influences cognition in many domains. Speech comprehension involves complex processes predicting the probability of one word following another [1], object recognition involves grouping retinal images based on learned regularities in object curvature and other features [2], and various other everyday tasks involve predicting appropriate behaviors based on environmental features [3–5]. Although the influence of statistical learning on selective attention has been of considerable interest for years, most of this research has focused on the visual modality [6–9]. Does the auditory system similarly exploit statistical structure while guiding attention to features, locations, objects, or points in time? For example, listening to a piece of music written by Beethoven may engage different attentional behaviors than listening to one written by Justin Bieber, because each has unique statistical properties (e.g., the likelihood of transitions in tempo or from note to note). These properties, if learned, would allow attention to be allocated to specific points in time or to specific frequencies appropriate to the type of music being played.

Indeed, experience modifies auditory attentional allocation in a wide range of tasks, including frequency discrimination [10], speech perception [11], and auditory localization [12]. Although often considered a single node of attention and described using a single term, 'selection history', **experience-driven attention** (see Glossary) encompasses a complex of processes supported by dissociable cognitive mechanisms. Here, we provide a taxonomy of currently identifiable mechanisms by which experience affects auditory attention within a **multiple-levels framework**. First, we consider mechanisms supporting the acquisition of **attentional control settings** through experience, which include cue–target associative learning, reward learning, and short- and long-term selection history. Second, we consider mechanisms responsible for implementing auditory **attentional guidance** based on those experience-driven control settings, which include both conscious and unconscious influences on **attentional priority maps**. Figure 1 illustrates the multiple-levels framework of auditory attention that distinguishes between the acquisition and implementation of experience-driven attention.

The Multiple-Levels Framework of Attention

Selective attention involves two key processes, which constitute the two levels of the multiple-levels framework of attention. At the first level, the multiple-levels framework considers how attentional biases arise (the sources of attentional control) as well as the various mechanisms supporting the acquisition of those control settings. The second level considers the mechanisms supporting the selection of specific stimuli via attentional guidance. The multiple-levels framework emphasizes how attentional biases arising from different sources may guide attention in unique ways. This framework was recently developed to explain differences between attentional guidance arising from goal-

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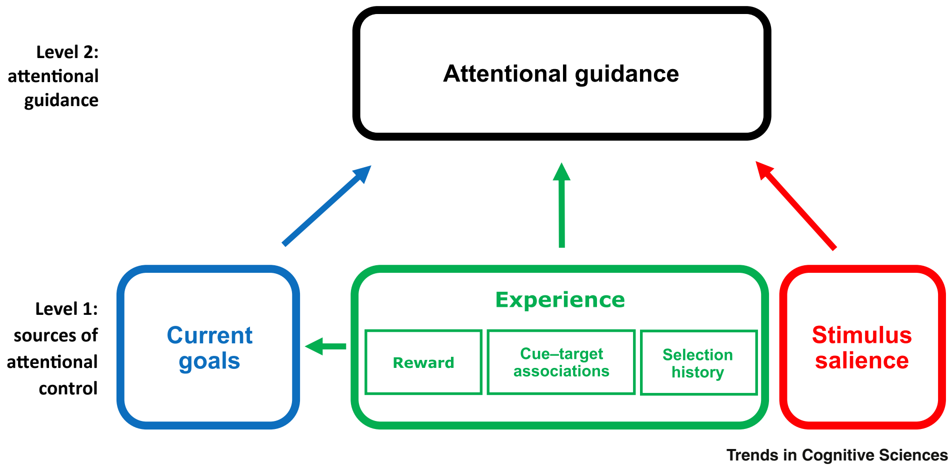

Figure 1. The Multiple-Levels Framework of Auditory Attention.
A schematic depiction of the multiple-levels framework of auditory attention. At the first level are the three categories of mechanisms used to acquire attentional control settings: goals, experience, and salience. Sources of experience-driven attentional control settings include reward, cue–target associations, and selection history. The second level of the framework involves attentional guidance, which integrates the many sources of attentional control in allocating auditory attention. Critically, there is not only one route from experience to attentional guidance: experience can lead to awareness and therefore a modification of current goals and it can implicitly influence attentional goals without modifying goals or physical salience.

versus experience-driven attention in the visual modality [13]; this review applies the multiple-levels framework in explaining the effects of experience on auditory attention.

Acquiring Auditory Attentional Biases through Experience

The first level of selective attention involves acquiring attentional control settings. Traditional research has identified two main sources of attentional control: task goals and physical stimulus salience [14–17]. Goal-driven attention primarily consists of guidance of attention to things we want to find, as when someone listens for the voice of a friend in a crowd. Salience-driven attention often alerts us to physically salient stimuli like loud noises. Recent research provides compelling evidence that an observer's experience is a third source of auditory attentional control [10–12,18–29]. Research has frequently used a single term, 'selection history', to describe experience-driven attention [6,30]. We argue, however, that experience-driven attention is not acquired via a single mechanism; instead, it involves multiple learning mechanisms and can result in different types of attentional biases depending on the nature of what is learned. Some types of experience lead to global modification of attentional weights to feature values; others result in attentional control settings specific to task or stimulus contexts. We consider three mechanisms by which auditory attentional control settings are acquired through experience: cue–target associative learning, reward learning, and selection history effects.

Cue–Target Associative Learning

One form of auditory experience-driven attention involves associations between contextual stimuli irrelevant to a person's current task and some feature of task-relevant targets [10,21,23]. In one study [23], semantic information about background audio clips (e.g., dogs barking) predicted the spatial location of pure tone targets during a localization task. In a later phase in which audio clips no longer predicted target location, participants localized targets more quickly when the same clips were paired with targets at the learned (versus unlearned) locations. In another example [10], a tone sequence predicted whether a subsequent tone glide would increase or decrease in pitch. Participants detected whether a gap was present in the tone glide, meaning that both the initial tone

Glossary

Attentional control settings: the set of an observer's attentional biases. Control settings arise from many sources and characterize the types of stimuli with high attentional priority. For example, an observer's intention to listen for high-pitched sounds might result in attentional control settings prioritizing high frequencies.
Attentional guidance: the process of selecting specific stimuli in the environment, often involving guiding attention from one stimulus to another.
Attentional priority map: a model representing the attentional priority of stimuli at different points on an abstract map in stimulus feature space. In the visual modality, this feature space represents 2D spatial location, with the intensity of activation at any given location representing that location's priority. Auditory priority maps operate similarly, but instead represent stimuli along spectrotemporal dimensions (and often include many other features as well).
Experience-driven attention: attention influenced by prior experience. Experience-driven biases can be acquired through associative learning of cue–target relationships, reward learning, and attentional selection history.
Feature dimensions: axes along which stimuli can vary (e.g., frequency or color). Location as well as high-level characteristics like semantic category (e.g., 'vowel') are also feature dimensions. Specific points along feature dimensions (e.g., '600 Hz' or 'red') are often termed feature values.
Horse-race models: a class of models accounting for performance asymmetries in tasks involving stimulus features that are processed at different speeds. In these models, tasks requiring the processing of one feature but not another feature (the second of which is processed more slowly than the first) should result in little influence of the second feature, as task-related processing would finish before processing of the second feature.
Multiple-levels framework: an approach to auditory attention theory emphasizing two main components of attention: the

sequence and the direction of the tone glide were irrelevant to the response. Nonetheless, following a learning phase, disrupting the predictive relationship between the contextual stimuli (here, the initial tone sequence) and the target (the tone glide) slowed responses.

These paradigms reflect associative learning of cue–target relationships, in which an external cue predicts what type of auditory target an observer might encounter (i.e., it predicts the appropriate attentional control settings). One cue might predict one type of stimulus, while another cue predicts a different stimulus. What is learned, then, is the rapid retrieval of context-dependent attentional control settings based on the presentation of a cue on a given trial. This contrasts with the two forms of experience-driven attention discussed next.

sources of attentional control and the implementation of attentional guidance.
P2 component: an event-related potential component consisting of a positive deflection of electrical voltage measured approximately 200 ms following the presentation of a stimulus. In electroencephalography studies of auditory perception, the P2 has been associated with midlevel stimulus encoding and may be sensitive to task demands.

Reward Learning

A second form of auditory experience-driven attention is reward learning, in which auditory targets associated with higher reward are selected more readily than those associated with lower reward [22,25,26]. In one study, participants received monetary rewards for identifying which of two simultaneously presented auditory stimuli contained a 75 ms gap during a reward training phase [26]. The stimuli differed in frequency and modulation rate (e.g., one 250 Hz stimulus modulated at 11 Hz and one 1000 Hz stimulus modulated at 17 Hz). On each trial, one stimulus was randomly chosen as the target, which contained the 75 ms gap. Unbeknownst to participants, the experimenters assigned one of the two stimuli to have higher reward probability than the other. Following reward training, participants completed the same gap detection task, except there was no reward and each trial contained either the previously high- or low-reward stimulus paired with a control stimulus (570 Hz, 6 Hz modulation rate). Following reward training, participants more often chose the previously high-reward stimuli as targets rather than the control stimuli, increasing both hits and false alarms for the high-reward stimuli. Conversely, the low-reward stimuli were less often chosen as targets than the control stimuli. This suggests that experience with monetary reward biased the allocation of attention towards more highly rewarded auditory streams.

Unlike cue–target associative learning, most reward learning experiments result in a general tendency to attend a rewarded feature rather than requiring settings that differ across trials. However, in both cases, observers associate some stimulus external to their current task (i.e., reward) with specific attentional control settings. This contrasts with a third form of experience-driven attention, in which selecting an auditory stimulus changes the likelihood of attending to that stimulus in the future.

Selection History

Attentional selection history influences guidance by modifying the likelihood of attending to stimuli that share features with previously attended stimuli. This can occur either when target selection enhances attentional biases towards features of a target [12,24,27,28], or when rejecting a distractor reduces the likelihood of attending to that stimulus in the future [11]. These selection history effects include short-term trial sequence effects (e.g., intertrial priming) and long-lasting effects of target or distractor probability learning. They also affect selection across a wide range of **feature dimensions**, from low-level features (e.g., frequency or location) to high-level ones (e.g., semantic or affective meaning).

One long-term effect of selection history is target location probability learning. This effect has been studied extensively in recent years using visual tasks (e.g., [7,54,90]), but a recent study provided the first evidence for a comparable auditory effect (Figure 2A) [24]. Participants identified whether a spoken number was odd or even while listening to a multitalker stimulus array of three letters and one number. The auditory target was more likely to occur in one location than any of the other three possible locations. Despite having little explicit awareness of the target's location probability, participants became faster at identifying targets at the high-probability location than at an azimuth-matched low-probability location (Figure 2B). The auditory spatial bias persisted for many trials during a phase in which targets appeared equally often in all locations.

On a shorter time-scale, intertrial repetition priming influences attention for as briefly as a few seconds. In one form of intertrial priming, a target repeats a nonspatial property (e.g., pitch) on consecutive trials. Repetition trials typically yield faster responses than feature-switch trials. However, the effects of repeating stimulus features may depend on whether they are relevant to an observer's task. For example, participants performing a harmonicity discrimination task on stimuli varying in both frequency and harmonicity respond faster when harmonicity repeats across trials; however, participants performing frequency discrimination are unaffected by the repetition of harmonicity [27,28]. These results have been attributed to **horse-race models** of auditory processing [33]: because fundamental frequency is processed sooner than harmonicity, participants responding only to the former may largely disregard harmonicity. This interpretation is consistent with event-related brain potential evidence in the same task [28]. When participants judged stimuli based on their pitch, the **P2**

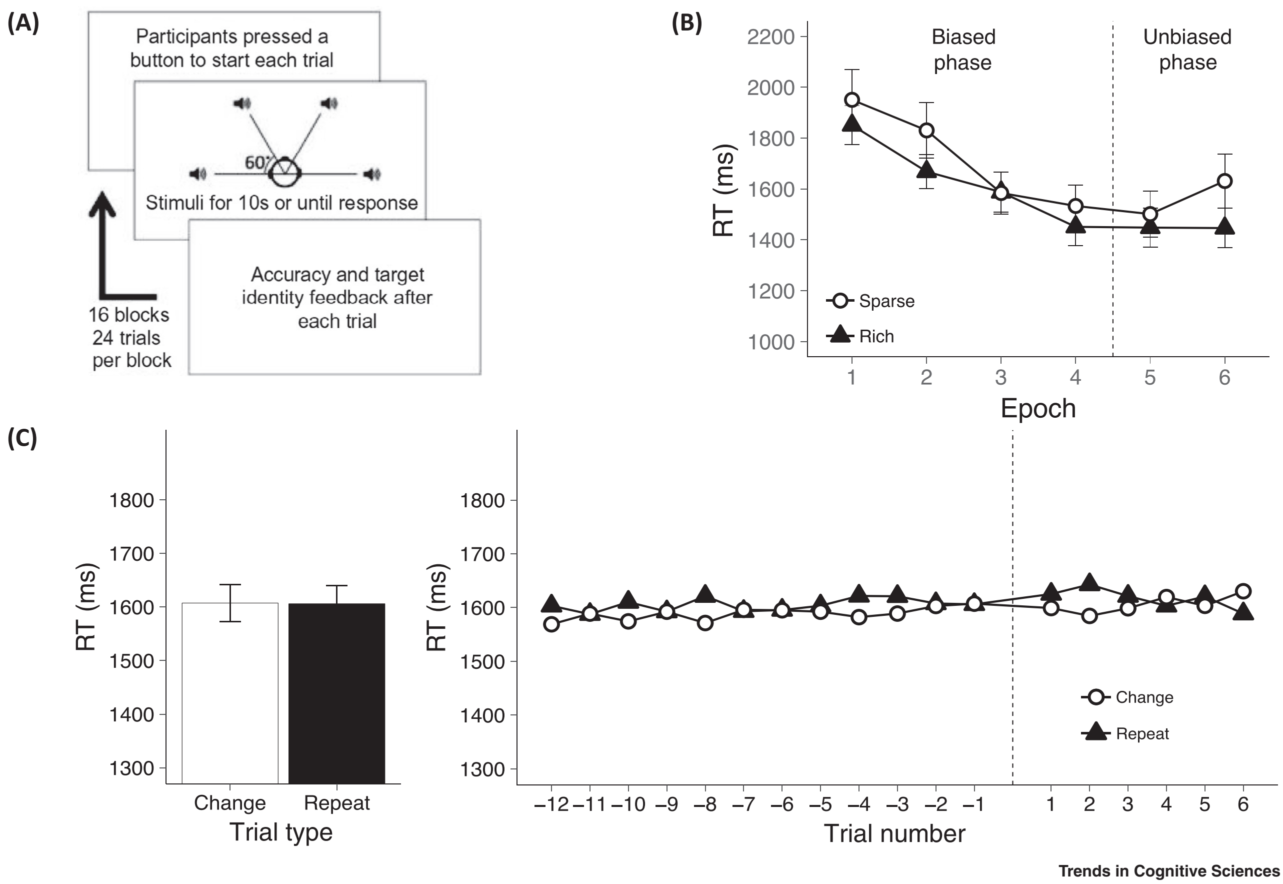

Figure 2. Auditory Spatial Selection History.
(A) The auditory search paradigm from [24]. Participants did an odd–even discrimination task while listening to spoken numbers repeating simultaneously amidst three letters. Each speech stream played from a different location on the horizontal plane. Unbeknownst to participants, target numbers appeared in one of two more central locations on half of trials during the first four epochs, whereas during the final two epochs, targets occurred in each of the four locations with equal probability. (B) Data demonstrating auditory location probability learning. Average reaction time (RT) on accurate trials is plotted based on whether the target appeared in the rich, high-probability location (filled triangles) or its eccentricity-matched sparse, low-probability location (open circles) during a biased location probability phase and an unbiased location probability phase. Participants responded faster to rich-location targets during both phases. These effects, though present, are smaller than those in the visual modality (e.g., [54]). (C) Data from the same experiment demonstrating a lack of auditory intertrial location priming. Left, average RT on accurate trials in which targets occurred in the high-probability location is plotted, separated by whether target location repeated versus changed from the previous trial. Right, the influence of many trials on RT, based on whether target location repeated or changed across trials. The x-axis indicates the trial number relative to the current trial: negative numbers indicate preceding trials; positive numbers indicate future trials and are present only to provide a rough estimate of measurement error. Reproduced from [24].

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component, a component modulated by both auditory stimulus encoding and task demands [28,31,34], differed based on whether stimuli repeated or changed pitch across adjacent trials, whereas harmonicity repetition did not affect the P2. In the harmonicity judgment task, repetition of pitch and harmonicity both affected the P2.

Intertrial feature priming can also lead to reduced distractor interference. In one auditory demonstration [11], participants listened to a sequence of vowel sounds that included a singleton target (e.g., 'UH') among identical distractors (e.g., 'EE'). They reported whether targets were presented to the left or right ear. Compared with trials using stimuli not heard on a previous trial, participants were slower when a previous trial's distractor became a target and faster when distractor identity repeated across trials, suggesting that presenting a stimulus as a distractor on one trial interferes with selection of that stimulus on a subsequent trial. These results show that attentional shifts to stimulus features can be suppressed due to rejection as a target on a previous trial (analogous to negative priming in the visual modality [32]).

A second form of intertrial priming occurs when a target repeats its location, rather than a nonspatial feature, on consecutive trials. In the auditory modality, intertrial location priming is less robust than feature priming. In one study [12], participants completed either a frequency discrimination task or a localization task on 200 ms pure tones mixed with noise. Each trial contained a single target stimulus, which varied randomly in both location (above or below participants) and frequency (250 or 612 Hz), one of which was designated the relevant (i.e., target defining) dimension on a trial-by-trial basis. Regardless of task, participants responded faster when both frequency and location repeated on consecutive trials compared with when both features changed across trials. Repeating just the location but not the frequency of the tone, however, did not induce intertrial priming. Other work has shown a complete lack of auditory intertrial location priming using a multitalker setup in which nonspatial features regularly changed from trial to trial (Figure 2C) [24].

The lack of consistent auditory intertrial location priming stands in stark contrast to results from studies of visual intertrial location priming, a pattern suggesting that experience-driven auditory attention operates more effectively on nonspatial than spatial features. Whereas location priming in the visual modality occurs whether or not stimuli repeat other features (e.g., color [35]), auditory location priming may depend on repetition of holistic auditory objects (e.g., location–frequency conjunctions [12]). In fact, these auditory location priming results parallel findings for nonspatial visual priming, which often occurs only when holistic visual objects repeat ([36]; though see [37,38]). Dissociations between temporal and spatial orienting across modalities have been found using other paradigms as well, leading some researchers to argue that, whereas visual attention typically involves attending to spatial locations, auditory attention typically involves attending to frequencies [39,40]. These differences may arise from the different neural coding schemes used in vision and audition (Box 1).

How Do Sources of Experience-Driven Attention Differ?

Existing attention research often groups all experience-driven sources of attentional control into a single category, with any effects outside the dichotomy of top-down and bottom-up attention referred to as selection history effects. However, most of these effects do not arise from an observer's history selecting certain stimuli more recently or more frequently than others [6,30]; in reality, so-called 'selection history effects' arise from many different kinds of experience.

This diversity of experience-driven auditory attention effects rely on a complex of learning mechanisms, including cue–target associative learning, reward learning, and learning of selection history. Cue–target associative learning involves guiding attention to targets based on stimuli that are not part of the search set (i.e., neither targets nor distractors). Furthermore, it does not guide attention to a consistent feature value (e.g., attend to high pitch or to the right), because it requires attentional control settings that differ depending on the presented cue (e.g., attending to the right when a dog

Box 1. Mechanisms of Experience-Driven Attention in Vision and Audition

Shifts of goal- and salience-driven attention are linked across the visual and auditory modalities, such that shifts in one modality affect processing in the other [72–82,91]. Even so, attention affects visual and auditory perception differently. Visual attention can be directed more precisely to locations, whereas auditory attention can be directed more precisely to points in time [18,40,83]. This pattern may result from differences in neural coding of perceptual features rather than from differences in mechanisms of visual and auditory attention themselves.

Differences between visual and auditory experience-driven attention parallel those of goal- and salience-driven attention. For example, location probability learning yields smaller effects in auditory tasks than in visual ones [24]. Similarly, visual intertrial location priming typically occurs even when nonspatial features (e.g., shape) change [35], whereas visual nonspatial feature repetition often facilitates performance only when whole objects repeat [36–38]. Auditory location priming is less robust, often failing to occur when nonspatial features change across trials [12,24].

Electroencephalography research further demonstrates modality differences in experience-driven spatial and temporal orienting. In two studies, one using visual stimuli [84], the other auditory [18], participants completed a go/no-go task based on a feature of the final stimulus in a sequence of rapidly presented stimuli. Sequences preceding targets could appear in predictable or unpredictable locations and at predictable or unpredictable times. In the visual task, the P1 component was enhanced by spatial but not temporal predictability, whereas in the auditory task, early P1 and N1 components and the later N2 component were enhanced by temporal but not spatial predictability. These differences suggest that spatial orienting plays a restricted role in auditory attention, whereas temporal orienting may be more central to auditory attention than visual attention.

These differences may arise from perceptual coding constraints or from modality-specific attentional mechanisms. Crossmodal linkages in goal- and salience-driven attention point to the former. However, another form of statistical learning, artificial grammar learning [85], has modality-specific effects and does not transfer across modalities [86–88]. Recent models attribute these findings to modality-general computational principles implemented separately in different networks operating in sensory areas of cortex [89]. Sensory-specific mechanisms with similarities across modalities may also support at least some forms of experience-driven attention. This view would predict that experience-driven attention, despite occurring in multiple modalities, should not result in the crossmodal effects of goal- and salience-driven attention; future research should explore this possibility.

barks but to the left when a cat meows). By contrast, reward learning and selection history effects like probability learning involve reinforcement of attentional shifts to specific feature values or specific locations. Even within any of these three categories, it is unlikely that a single mechanism explains all possible effects. For example, despite their somewhat comparable effects, intertrial priming that lasts a few seconds and probability learning that lasts hours are likely acquired via different mechanisms. Whereas the first may transiently speed selection and response to stimuli like those recently selected, the latter may involve more durable statistical learning mechanisms operating within networks that implement shifts of attention.

Implementing Experience-Driven Auditory Attention

The previous section identifies different types of experience that influence attentional control; in this section, we consider how experience-driven attentional control settings, once acquired, influence attentional guidance. The guidance of auditory attention is a topic of considerable recent interest [41], but it is less well-understood than the sources of control themselves. Some models draw on highly successful theories of visuospatial attention that characterize attentional selection as operating via attentional priority maps [42,43]. In the visual modality, these models explain selection through a set of spatial maps, each of which represents the physical salience of a specific feature value within the current visual field. A single integrated priority map then computes an average of these maps, with each feature map weighted by the current goal-driven attentional priority of that feature. Adaptations of this view accommodate the demonstration of experience-driven visual attention to argue that priority maps integrate experience as well as salience and goals to determine a selected location in a winner-take-all fashion (Figure 3) [6,7,44].

Auditory Attentional Priority Maps

Recent models of auditory attention have developed analogs to the priority map view of visuospatial attention, though these models highlight the important role of spectrotemporal features in auditory perception by including frequency- and time-based priority maps instead of, or in addition to, spatial ones [45–49]. For example, early models used the same winner-takes all approach found in visual models, only on a spectrogram (representing intensity across frequency and time) rather than a 2D spatial image [48]. More recent models are comparable, but incorporate a wider range of auditory features (e.g., intensity, pitch, and timbre [46,47]). Some approaches have even begun to consider the role of one type of experience in auditory attention, in which Bayesian priors are computed over past auditory stimuli to determine whether some current feature is unexpected and therefore more salient [49,50]. Although this approach is promising, it only considers how exposure to auditory stimuli influences salience, not how other forms of experience, including external predictive cues,

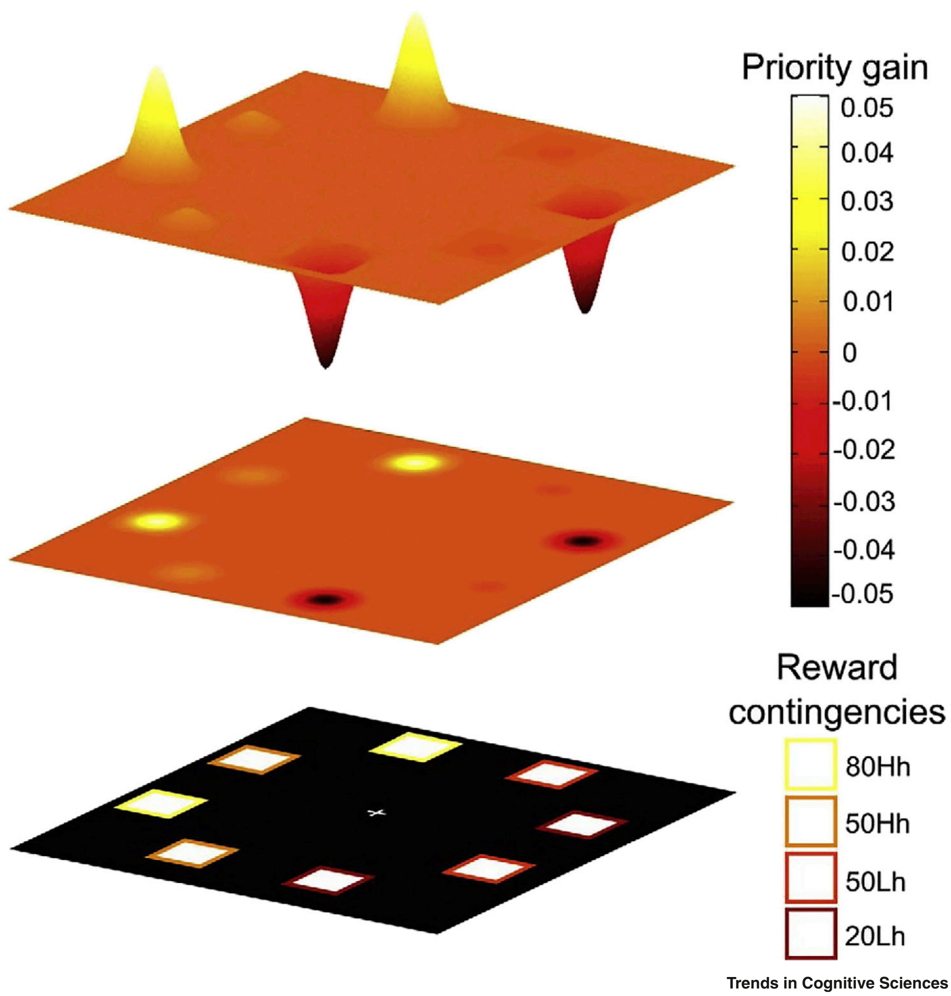

Figure 3. Modeling Experience-Driven Attention with Priority Maps.
A model representation of how reward influences attentional priority from [44]. The bottom row represents the reward associated with potential target locations in a visual search task; the middle and upper rows are 2D and 3D representations, respectively, of the attentional priority associated with those locations computed from experimental data. Although this figure depicts the influence of reward on visuospatial attentional priority maps, analogous models may also be useful in characterizing multiple sources of auditory experience-driven attention (e.g., selection history) along a variety of feature dimensions (e.g., frequency). Reproduced from [44].

reward, or past attentional behaviors, also influence attention. It is likely that, as has been argued for visual attention [6,7,44], these forms of experience are additional factors influencing auditory attentional priority.

Conscious and Unconscious Guidance of Experience-Driven Attention

Although experience-driven auditory attention can be well-characterized using priority maps, experience influences those maps in multiple ways. Specifically, experience can unconsciously bias attentional priority or it can lead to awareness of some aspect of a person's experience that results in goal-driven shifts of attention, as when participants become aware that targets in a task are more likely to occur in some locations. These two routes from experience to guidance are not mutually exclusive. For example, unconscious biases can emerge initially, with participants later becoming aware of some aspect of the task structure. Once this occurs, there may be unconscious influences of experience on attention operating alongside goal-driven shifts of attention.

Whether goals come from experience or from task instructions, it is likely that similar neural mechanisms are involved, engaging frontoparietal networks that include portions of superior prefrontal cortex and posterior parietal cortex, among other regions [51–53]. The neural mechanisms of unconscious shifts of experience-driven attention are less well understood and may or may not be supported by the same frontoparietal regions as goal-driven attention.

Although some forms of experience can unconsciously influence auditory selection, others may only affect attention via conscious, goal-driven attention. Furthermore, some types of experience are more likely to be consciously recognized than others. Evidence for unconscious guidance of attention due to experience has thus far been provided for cue–target associative learning and selection history effects. For instance, cue–target associative learning can occur even in participants who were tested (through memory tests and/or self-report) to ensure that they had no conscious awareness of the associations [26]. Similar tests show that selection history in the form of long-term location probability learning occurs unconsciously [24], and it is generally accepted that the transient effects of intertrial priming are unconscious as well (indeed, there is some evidence they cannot be overcome even through conscious attempts to do so [35]).

Visual demonstrations of probability learning and other selection history effects make it clear, however, that some participants can become aware of probability manipulations [54–56]. When experimenters make participants explicitly aware of the probabilistic structure of a task, participants actively engage goal-directed attention, increasing the magnitude of selection biases [57–59]. In the absence of task instructions, some participants may become aware of statistical regularities, as revealed by above-chance recognition tests in postexperiment awareness tests. In some paradigms, these 'aware' participants do not show greater selection biases than 'unaware' participants, suggesting that even in aware participants selection biases were largely implemented without deliberate control [55]. In other paradigms, awareness is critical for the acquisition of an attentional bias. For example, reward history for target locations often influences spatial attention only after observers become aware of the reward structure, causing participants to prioritize locations associated with higher reward [56]. In most auditory paradigms, studies have not clearly delineated the role of awareness in experience-driven attentional biases. Future research should attempt to untangle how conscious and unconscious guidance interact in experience-driven auditory attention.

Visual studies using the location probability learning paradigm also show that conscious goal-driven attention and unconscious experience-driven attention have dissociable effects on perception. For example, although goal-driven attention tends to operate in both environment- (allocentric) and viewer-based (egocentric) reference frames, implicit effects of probability learning appear to be exclusively viewer-based [58,60–63]. When viewers learn to prioritize a region of a screen through location probability learning, the learning persists following a viewpoint change, but it does so in the same region of the visual field, not the same part of the screen. Furthermore, location probability

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learning is intact in a range of conditions that impair goal-driven attention, including Parkinson's [64], autism spectrum disorders [65], and healthy aging [66].

Based on these and other related results [66–70], we have argued that implicit location probability learning arises from search habits that influence how attention operates [13]. These habits may be reinforced within orienting systems themselves, rather than (or perhaps in addition to) operating via frontoparietal attention networks (i.e., the frontal eye fields and the lateral intraparietal area). In the visual modality, spatial orienting habits can be modeled as movement vectors guiding search in reinforced directions. By contrast, even though similar search habits occur in auditory tasks, audition does not have an analogous oculomotor system for implementing search habits. However, it remains possible that different forms of auditory attention, especially implicit experience-driven attention and goal-driven attention, may differ in how they change attentional priority. Future research should aim to identify mechanisms of these auditory habits.

Concluding Remarks and Future Perspectives

The visual attention field widely accepts experience as a third major influence on selective attention, in addition to conscious goals and physical salience. Recent studies suggest that the auditory attention field should do the same. Importantly, however, experience-driven auditory attention is not just one additional node of attention. Rather, it consists of a complex of mechanisms, each of which can interact with attention in different ways. Cue–target associations lead to rapid alterations of attentional control in response to predictive stimuli, whether through conscious or unconscious processes. Reward learning can lead to guidance of attention towards stimuli associated with higher reward. Intertrial priming and long-term probability learning often implicitly bias attention directly towards certain features or locations. These mechanisms may apply broadly, in multiple sensory modalities. In all these cases, shifts of auditory attention based on experience-driven attentional control settings may operate in a similar fashion as those derived from goal- and salience-driven attention, at least when experience-driven attention is implemented via conscious control. When consciously implemented, experience-driven auditory attention may involve the use of priority maps organized along temporal, spectral, or spatial dimensions. Implicitly learned auditory attention could also act via priority maps, although studies have yet to identify specific mechanisms of implementation for implicit auditory attention.

Recent work has provided compelling evidence for three main forms of experience-driven attention, but future experiments may identify classes of experience that shape attention beyond the three considered here (see Outstanding Questions). Researchers should continue to investigate new forms of experience-driven attention, both with respect to the types of learning mechanisms that shape attention (e.g., statistical learning, reward learning) and the types of control settings that experience can introduce (e.g., in addition to simple stimulus features, experience might be able to guide attention to auditory objects [71,72]). As work on experience-driven auditory attention continues, theories explaining the sources of auditory attentional control should expand to incorporate new classes of experience-driven effects. Studies should also aim not only to identify additional sources of attentional control but also to elucidate the specific cognitive and neural mechanisms by which experience actively guides auditory attention. Understanding the implementation of attentional guidance may prove particularly valuable in helping refine models of auditory attention such as priority map accounts.

Outstanding Questions

What other sources of experience-driven auditory attention might exist, besides cue–target association, reward learning, and selection history? Multiple mechanisms support the acquisition of experience-driven attention and there are likely important mechanisms that have not yet been identified. Future research should explore novel paradigms for eliciting experience-driven auditory attention.

Can experience-driven auditory attention bias selection towards auditory objects? While existing studies investigate the influence of experience on selecting specific auditory feature values, goal- and salience-driven auditory attention can select not only low-level features but also auditory objects. Future research should investigate whether similar attentional guidance can result from experience-driven auditory attention.

What are the specific neural mechanisms supporting experience-driven attention? Experience-driven attention involves both learning mechanisms and mechanisms for implementing attentional guidance, but the neural substrates of both classes of mechanisms are poorly understood. Future research should explore these mechanisms, particularly with respect to how experience, goals, and salience combine to guide attention.

In what contexts does experience-driven attention have crossmodal effects? While goal- and salience-driven attention have clear audiovisual links, recent evidence suggests that many forms of experience-driven attention are modality-specific. Future research should aim to dissociate models of experience-driven attention that are modality-specific from those that are modality-general but, due to differences in neural codes for sensory modalities, still lead to disparate effects on attentional selection.

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