The attentional requirements of consciousness

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It has been widely claimed that attention and awareness are doubly dissociable and that there is no causal relation between them. In support of this view are numerous claims of attention without awareness, and awareness without attention. Although there is evidence that attention can operate on or be drawn to unconscious stimuli, various recent findings demonstrate that there is no empirical support for awareness without attention. To properly test for awareness without attention, we propose that a stimulus be studied using a battery of tests based on diverse, mainstream paradigms from the current attention literature. When this type of analysis is performed, the evidence is fully consistent with a model in which attention is necessary, but not sufficient, for awareness.

Introduction

Although cognitive scientists have been unable to agree on an exact definition for the terms 'consciousness' and 'attention', there is enough agreement to discuss the relationship between the two. The term 'consciousness' is a notoriously ambiguous term that has resisted clear definition for many years, eliciting active debate about the nature and contents of conscious experience [1–5]. Here, we follow Koch and colleagues in focusing on the contents of conscious awareness rather than on states of consciousness (i.e., vegetative state, deep sleep, etc.) [6]. 'Attention' refers to the cognitive mechanism that allows certain information to be more thoroughly processed in the cortex than non-selected information. In addition, it is likely that attention allows information to be more fully transmitted across cortical regions than unattended information. This processing can operate on external sensory stimuli, such as selectively listening to one person in a crowded room, or internally generated information, such as representations in memory [7]. Because more information is more thoroughly processed and transmitted across multiple regions, increased attention often leads to an improvement in behavioral performance (e.g., faster reaction times, increased accuracy), and for several decades this was its primary diagnostic marker (but see [8,9]). More recently electrophysiology and neuroimaging has allowed researchers to understand the instantiation of attention in the brain by identifying the associated brain regions and neural circuits [10]. Microstimulation studies, in which a brief electrical pulse is delivered to a targeted brain region, have established a causal link between neural activation and behavioral improvement (for a review, see [11]). For example, stimulating saccade control areas leads to the behavioral performance benefits associated with visual spatial attention.

When attending to an item, we often become conscious of its attributes at the expense of unattended items. There are several examples of absence of attention leading to absence of awareness. Inattentional blindness [12], change blindness [13], and the attentional blink [14] all demonstrate that salient information can go unnoticed in the absence of attention (Box 1). These results led many to suggest that attention and awareness are inextricably linked [12,15–17]. Broadly speaking, this was a standard assumption for many years.

Against this, a significant number of researchers have recently made a bold and opposite claim: that attention and awareness can be fully dissociated [2,3,6,18–24]. In discussing this idea, two classes of evidence are brought forth. First is the possibility of attention without awareness. Here, researchers using a variety of paradigms report that attention can operate on or be drawn to stimuli that never reach conscious awareness [25–32]. Second is the claimed existence of awareness without attention: that observers can be conscious of certain stimuli in the absence of attention [12,33,34]. Taken together, these results are used to support the view that attention and awareness can be doubly dissociated.

This new perspective has important implications in the search for the neural underpinnings of consciousness. A double dissociation implies that each process can operate functionally without the other; that they are independent. Such independence would seem to diminish the role of brain architectures and computational theories where such processes are functionally coupled. At the very least, it means that the search for the processes associated with consciousness must be separated from the neural mechanisms of attention. Such strong and widely cited claims deserve critical assessment, especially because of very recent and relevant studies, which we review below.

Here, we endorse a model in which attention is the process that enables selected information to reach conscious awareness. Under this view, consciousness requires a requisite amount of attention and, if it is not met, stimuli will remain unconscious. Thus, attention is necessary, though not sufficient, for conscious awareness (Figure 1).

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Box 1. Attentional paradigms used for manipulating awareness

Inattentional blindness: participants perform a few trials of a primary task (e.g., visual search, multiple object tracking, etc.), and on a critical trial, a new and unexpected stimulus is presented, while participants are focused on the primary task. Participants routinely fail to notice the unexpected stimulus.
Change blindness: changes to natural images are difficult to detect when they occur during a blank gap, eye-movement, or camera cut. If properly masked, a single item can continually change (e.g., by repeatedly appearing and disappearing), without observers noticing.
Attentional blink: when a pair of targets is presented in rapid serial visual presentation, observers often fail to notice the second target when it comes 200 to 500 ms after the first.
Dual-tasks: two tasks (e.g., visual search and working memory) are performed separately and then concurrently. The attentional requirements of each task can be determined by measuring the difference between performance on the task in single- and dual-task settings. Typically, performance drops in dual-task conditions. However, in certain cases the addition of a second task has no effect; this is cited as an example of awareness without attention.

First, we will briefly review evidence showing that attention can operate on or be cued by unconscious stimuli. This is consistent with our model because attention must, by its serial, causal definition, be able to operate on unconscious representations. However, we take issue with the claim that information can reach awareness without attention. Before discussing this, we propose a set of criteria that must be satisfied before such a claim can be confirmed. This set of criteria not only establishes a framework for analyzing existing data, but also provides a potential reference point for discussing and considering future data.

Conscious vs unconscious stimuli

In order to fully understand the proposed relationship between attention and consciousness, it is important to understand the differences between conscious and unconscious neuronal processing. One well-known distinction between these processes is the depth and duration of the corresponding neural activations. Although unconscious stimuli can elicit widespread activation [35], such activation is restricted to afferent and anterior higher-order systems primarily in a feedforward manner [36], which rapidly decays [1,37]. In contrast, stimuli that reach consciousness are associated with more distributed activations in higher-level regions, such as the parietal and prefrontal cortices, which remain on-line for longer durations. This distinction between conscious and unconscious stimuli has been observed using paradigms such as the attentional blink [38], change blindness [39], and inattentional blindness [40]. Furthermore, recent studies with transcranial magnetic stimulation [41,42] and in patients with prefrontal lesions [43] show that these parietal/prefrontal regions likely play a causal role in conscious awareness.

The notion of widespread, sustained activation is a central pillar of several prominent theories of consciousness: the global neuronal workspace model [1,37], information integration theory [44], the multiple-drafts model [45], and higher-order theories [46]. Under such models, consciousness is the process that allows relevant information to remain on-line long enough so that it may be synchronously processed by multiple cortical networks.

The varieties of attention

In contemplating a dependent relation between attention and awareness, we have been referring to attention in its most general form. Attention acts upon and modulates information in each sensory modality: visual, auditory, olfactory, etc. [47,48]. Attention can also be divided within a modality: top-down (endogenous) and bottom-up (exogenous). In addition, visual attention can separately operate on basic features, locations in space, whole objects, or points in time (for reviews, see [7,49]). Although all of these processes undoubtedly interact with one another under a central executive, attention is comprised of multiple subsystems.

One common aspect uniting these various forms of attention is that each involves selection over some space or map. Consider visual spatial attention: this map, often referred to as a 'salience map' [50], has become the focus of intense physiological and behavioral study. The allocation of visual spatial attention is controlled by an occulomotor map for eye movement planning [11]. Above a certain

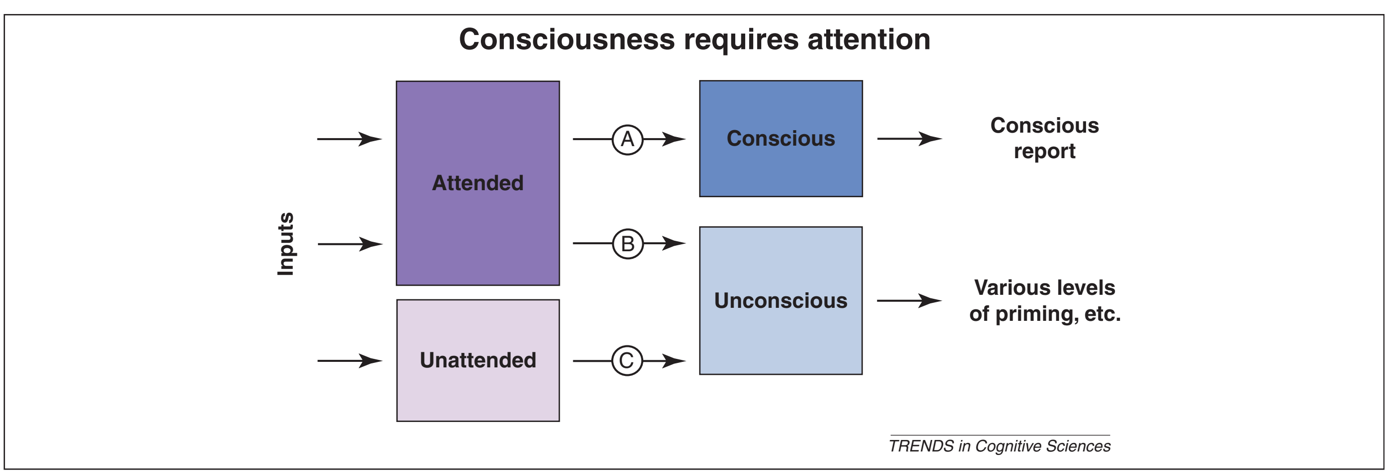

Figure 1. Representation of the relationship between attention and consciousness. Under the proposed model **(A)** information can only reach conscious awareness if attention operates on it. However, **(B)** not all attended items will reach awareness. It is possible for attention to operate on [25,28,29,54,55] or be drawn towards [26,27] a stimulus without that stimulus being consciously perceived. Even though such a stimulus does not enter awareness, the effects of attention can nonetheless be measured through behavioral (i.e. depth of priming or adaptation) and neural changes (i.e. amount of activation in a particular regions). Finally, **(C)** information that is not attended can also elicit substantive neural activation, though the priming effects that come from such activation will be less robust. (This figure was inspired by Figure 2 of [21]).

threshold, microstimulation at a location on the map triggers an eye movement to the corresponding location in space. However, stimulation below that threshold does not trigger an eye movement, but does enhance the neural responses for cells with receptive fields at that location [51].

Thus, any activity on these maps will result in attentional benefits to the corresponding locations, even though the stimulus at that location may not necessarily reach awareness. According to a recent proposal [52], activity at the location of an expected target (top-down, endogenous, voluntary attention) and the activity triggered by an unexpected target (bottom-up, exogenous, involuntary attention) both act through the same downward projections from the saccade/attention map to confer performance benefits.

Future work on the relationship between attention and awareness will need to consider all of the various forms of attention, both across and within modalities, and how they are implemented in the brain. The studies with visual salience maps demonstrate the concrete functional and anatomical level at which all forms of attention may one day be understood. In other words, the neural underpinnings of attention are already being revealed in surprising detail. If, as we claim, attention has a direct causal link to consciousness, these attention results will be critical in guiding the discovery of the neural processes associated with consciousness.

Attention without consciousness

Numerous studies have shown that attention can operate on or be directed towards an item that is not consciously perceived. For instance, temporal, featural, and spatial attention increases the amount of priming or adaptation caused by stimuli that fail to reach consciousness because of visual masking [25,29,53,54] or crowding [28,55]. In addition, attention can also be drawn towards a stimulus that is made invisible because of continuous flash suppression [26,27] or sub-threshold presentation [31]. This was even found in patient GY, whose attention could be drawn to an invisible stimulus in his contralesional (i.e., blind) visual field [32].

Together, these important studies demonstrate that (i) varying degrees of attention can determine the extent to which stimuli will be unconsciously processed and (ii) attention can be deployed and directed to stimuli that are not consciously perceived. These results, however, are consistent with a model in which attention is necessary for consciousness. To discredit this model, there must be evidence of awareness without attention. It is here that the empirical evidence is lacking, as evaluated below.

Consciousness without attention: establishing the empirical criteria

Before reviewing the recent literature, it is critical to broadly identify the class of empirical findings that could resolve whether awareness without attention can exist.

It should be stressed that a single instance of a stimulus being immune to attentional interference is not sufficient for demonstrating consciousness without attention. Critically, the absence of an effect of attention on awareness is necessarily a null finding and so needs to be treated with caution. If a stimulus truly does not need attention to enter conscious awareness, then this should hold across all paradigms. Given the differences in the relative strengths of psychophysical techniques used to prevent a stimulus from reaching awareness (for a review, see [56]) we propose that whenever a stimulus is considered for reaching consciousness without attention, it must be tested using a variety of attentional tasks. If attentional manipulations in any one task can block the stimulus from awareness, this demonstrates that there are indeed certain types of attention that are required for it to reach awareness.

Given the practical and logical difficulty of testing all possible attentional paradigms, can researchers agree on a pragmatic and theoretically justified standard for which tests to use? Paradigms appropriate for testing the attention/consciousness relationship must render stimuli invisible specifically because of attentional limitations. Other tasks that render a stimulus invisible, such as forward/backward masking or binocular rivalry, are not appropriate because attention is not the critical factor. With this focus on attentional engagement in mind, we suggest that any candidate stimulus should be tested across at least the following paradigms:

(i) Inattentional blindness
(ii) The attentional blink
(iii) Change blindness
(iv) Dual task interference (load manipulations)

It should be stressed that these four paradigms do not represent the 'ultimate test.' In the future, it is possible that new attentional paradigms that render stimuli invisible will be developed that should be included. However, this set represents the best tests available from the current attention literature. The primary point is simply that a stimulus cannot be claimed to reach awareness without attention until it has been shown that it cannot be blocked by any of the established attentional paradigms that vary in their relative strength and types of attention tested (Box 2).

Is there evidence for consciousness without attention?

Numerous authors [2,3,6,18–24] claim there is proof of awareness without attention. The three stimulus categories most frequently cited in support of this notion are the gist of a scene, the presence of an animal, vehicle, or face in dual-tasks, and features that pop-out in visual search (Box 3) [2,3,6,18,22,24]. If these stimuli can truly be consciously perceived without attention, they should be systematically unaffected by multiple attentional paradigms. However, a thorough analysis reveals that none of these categories meets the standard of converging tests. That is, although they may escape attentional load in one test, they fail to reach awareness when tested by another attentional paradigm. Thus, these stimuli require attention to reach awareness.

The gist of a scene

In spite of the fact that rather salient items can be missed because of inattentional blindness, it was initially found that the same did not hold true for the gist of a scene. When a scene was unexpectedly presented for only 30 ms while participants performed a demanding primary task, the gist was always perceived without error [12]. From this, it has been claimed that gist perception does not require attention.

Box 2. Opposite behavioral and neural effects of attention and awareness

The claimed double dissociation of attention and awareness is often based on demonstrating awareness without attention, and attention without awareness. Recently this dissociation has been claimed by citing instances of attention and awareness having distinct effects on behavioral performance [84] and neural activity [82,83,85]. These studies represent a new and exciting approach to studying the relationship between attention and awareness. However, the results of these studies do not falsify our claim that attention is necessary for consciousness for certain methodological and theoretical reasons.

First, there are certain outstanding issues with these paradigms that future research will need to resolve. For example, van Boxtel and colleagues [84] show opposite effects of awareness and attention on the length of visual afterimages (i.e., attention shortens afterimage duration, whereas awareness increases it). However, it remains possible that the effects observed in this experiment were due to differences in contrast adaptation as a function of the presence or absence of attention or a suppressing grating. Wyart and colleagues [83,85], on the other hand, show dissociable neural signatures associated with attention and awareness. However, the fact that they report no behavioral benefit from the cue in their attentional paradigm casts doubt on their interpretation. How can it be known that they are measuring the neural correlates of attention and not the neural correlates of the cue which itself had no attentional consequences?

In addition, and perhaps more importantly, demonstrating that attention and awareness have independent effects on a stimulus does not demonstrate conscious awareness without attention. We claim that attention is necessary, but not sufficient, for conscious awareness. It does not follow from this view that attention and awareness must always have the same effect on a stimulus (positive or negative). It simply states that there are no instances in which a stimulus reaches awareness without attention (Figure 1).

However, multiple groups have recently shown that the gist of a scene is indeed subject to inattentional blindness if attention is properly engaged [57,58] (Figure 2). The gist can also be missed because of the attentional blink [38,59,60]. Furthermore, detecting and classifying the gist of a scene is impaired if attention is divided between tasks if the primary task is sufficiently difficult [59,60]. If the primary task is not sufficiently engaging, excess attentional resources seem to 'spill over' to the scene [61], resulting in no decrease in performance. Thus, rather than being perceived without attention, gist perception is so efficient that the attentional system must be properly taxed to reveal its attentional requirements.

Animal/vehicle and face perception in dual-tasks

A dual-task paradigm often used to study attention/awareness has participants perform a difficult search task (e.g., T vs L), while simultaneously determining whether a briefly presented photograph contains an animal or a vehicle [33], a famous/non-famous face [62], or a male/female face [63]. Surprisingly, performance on the two tasks is equivalent in single and dual-task scenarios. Therefore, perception of animals/vehicles and faces is claimed to require no attention since tasks involving these stimuli do not affect the search task.

Although compelling, these demonstrations of awareness without attention do not stand up to other subsequent tests. Multiple studies using a variety of demanding primary tasks have shown dual-task interference when paired with a secondary task involving the detection of animals in a scene [59,64]. Furthermore, animals/vehicles in a scene can be missed because of inattentional blindness [59,60], the attentional blink [65–67], and change blindness [68,69]. The attentional cost for faces (in terms of their presence, emotional state, or gender), meanwhile, has been repeatedly demonstrated using the attentional blink [70,71], inattentional blindness [12,72], and change blindness [73] paradigms. Again, these results suggest that animal/vehicles and faces can go unnoticed because of attentional limitations.

Box 3. Iconic memory and partial report

Iconic memory has been cited as evidence of awareness without attention [2,3,21,22]. In these experiments, participants are shown 8-12 items and asked to recall as many of them as possible. Without a cue, participants correctly report approximately 4 items. If cued to report only a subset of items, performance is nearly perfect for that subset. Since any subset might be cued on a given trial, it is concluded that subjects can successfully store every item on the display. It is claimed that participants are conscious of every presented item – they are able to correctly report every item if properly cued, but can only freely report attended items. In other words, participants have the capacity to consciously represent far more than what can be attended and reported.

This interpretation of the results is controversial. Others claim that the identities of many of the items are stored unconsciously until cued [4,37], at which time attention is directed to the cued items. It is the act of attending to these unconscious items that lifts them into awareness and allows them to be successfully reported. Others have claimed that participants feel that they are conscious of the identity of each item simply because of cognitive and perceptual illusions; for example, participants confidently report seeing expected items (letters), even when actual items were non-letters or pictograms [5].

Moreover, Matsukura and Hollingworth [86] demonstrated that these results depended on the effects of large scale figural grouping. Estimates of capacity fell to standard levels when these groupings were eliminated. Furthermore, it was shown that high capacity estimates only emerged with extensive practice, suggesting that such increases could be caused simply by 'changes in the efficiency of perceptual processing, memory encoding, maintenance, comparison processes, and involvement of long-term memory ([86], p. 1103)'.

Pop-out in visual search

Certain visual features are thought to be so elementary that no attention is required to consciously perceive them. These features 'pop-out' in visual search displays: the amount of time needed to detect a target feature amongst a set of distractors is independent of the number of distractors [34]. However, several paradigms have revealed that attention is needed for the item to pop-out. For example, features that ordinarily 'pop-out' go entirely unnoticed during the attentional blink [74–76] and during inattentional blindness [12,77] paradigms. These results demonstrate that, when attention is sufficiently engaged, even the most salient visual features will fail to reach awareness.

These studies, and many others, suggest that attention has to be tuned in a particular way for a stimulus to pop-out into consciousness. Whereas the stimulus may still pop-out at unconscious levels of processing, it will not pop-out in consciousness without sufficient attentional resources. The flat search slope associated with visual pop-out disappears when spatial attention is directed away from the target item [78]. In addition, attention will not be drawn to the location of a subconsciously presented feature singleton if attention is engaged by another task [27]. If the processing of such

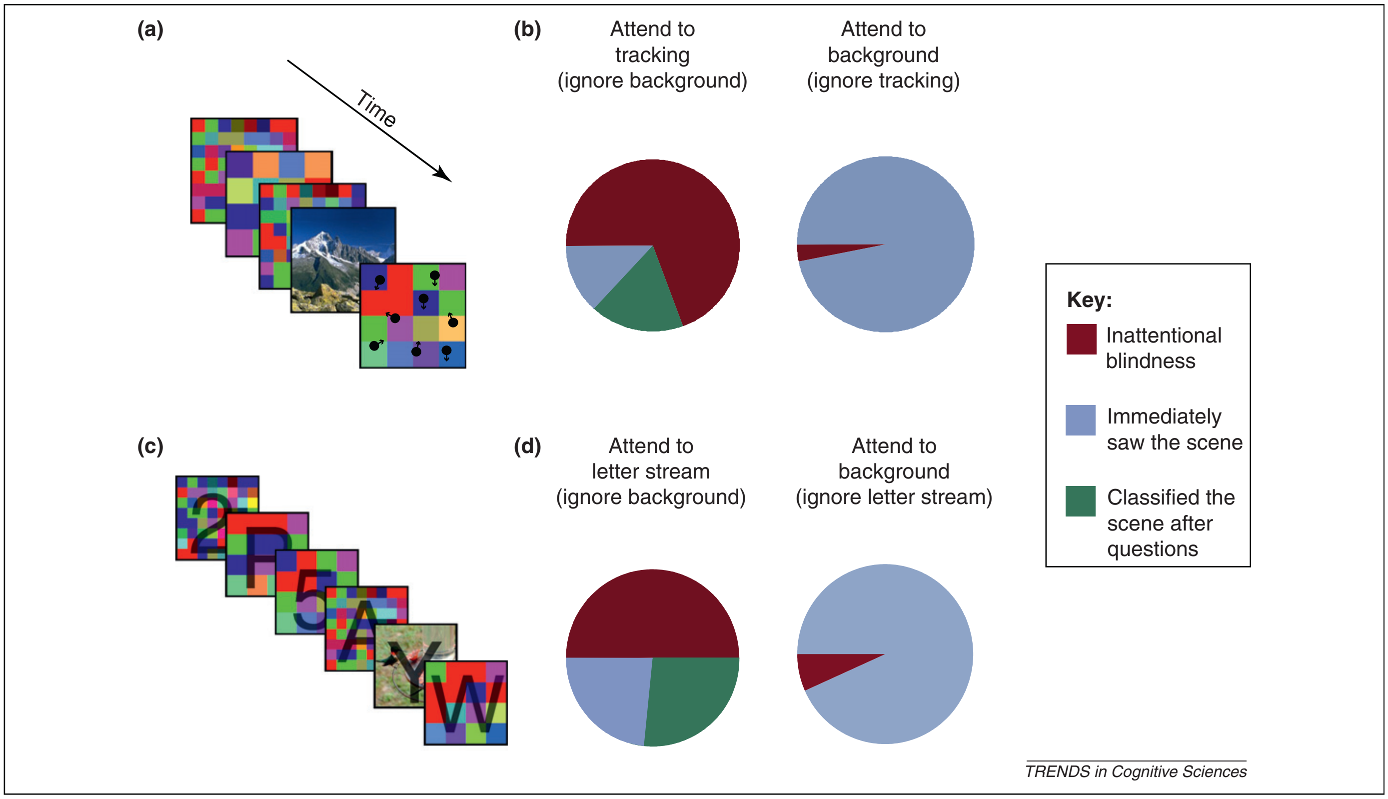

Figure 2. Illustration of the inattentional blindness stimuli and results [59]. **(a)** Participants tracked 4 of 8 identical moving discs in front of rapidly changing (15 Hz) colored checkerboards. On the fifth trial, the second to last checkerboard was replaced with a scene (e.g., displaying a mountain, highway, etc.). **(b)** 64% of participants experienced complete inattentional blindness. When asked to then monitor the same displays and report the presence of a scene, participants detected and classified the scene with 96% accuracy. **(c)** In another experiment, participants monitored a stream of rapidly changing letters (10 Hz) and were instructed to count how many digits were presented. On the fifth trial, a scene containing an animal or vehicle was unexpectedly presented on the second to last frame. **(d)** 50% of participants experienced complete inattentional blindness, even though scenes could be classified with 93% accuracy when then instructed to attend to the background.

salient items reached consciousness without attention, these attentional manipulations should have no effect. Thus, although detection of salient visual items is efficient, attention does appear to play a significant role (Box 4).

The source of performance limitations

Resource vs data limitations

Researchers who argue in favor of a double dissociation of attention and consciousness regularly cite results in which the perception of particular stimulus (e.g., an animal in a scene) is unaffected by the presence of a second, attentionally demanding task. The logic behind such a conclusion is as follows: if performance is below ceiling on an attentionally demanding primary task (e.g., visual search), attention is thought be fully engaged by that task. Therefore, if performance with a secondary stimulus is unaffected by the primary task, the secondary stimulus must be consciously perceived without attention.

This logic rests on the assumption that attention is fully allocated to a given primary task when performance is below ceiling. Although this is sometimes true, there are other critical factors that can limit performance. For example, the amount of attention any task can summon is limited [79]. In other words, it is unlikely, if not impossible, that a single task will engage all of attention in a sustained manner. In those cases, a certain amount of attention can be allocated to a secondary task. In addition, performance

Box 4. Top-down and bottom-up attention

Whereas attention may be necessary to perceive a red target amongst blue items, is it necessary to notice the sound of a gun firing outside? Or the feeling of a hammer being dropped on your foot? What role does attention play in these cases? Under the model endorsed in this article, attention is initially drawn to these salient stimuli in an exogenous, bottom-up manner that raises that information into consciousness (first attention, then consciousness). Researchers who argue for a double dissociation would claim that the individual is first conscious of those salient stimuli and then attention is directed towards that information (first consciousness, then attention). Unfortunately, as it currently stands, there are no testable predictions that can determine which of these theories is right. If an experiment had a stimulus so extreme (e.g., a hammer on your foot) that it could never go unnoticed, it is not clear how to tell if attention or awareness happens first.

For this reason, Koch and colleagues [6,18–20] specifically focus on how top-down, endogenous attention is not necessary for consciousness. It should be stressed, however, that the stimuli these researchers have proposed reach awareness without top-down attention (gist, animals, vehicles, faces, and pop-out) can all be rendered invisible using explicitly top-down tasks (e.g., the attentional blink task). Indeed, in many cases, participants are explicitly told to look for and make judgments about these targets that are nonetheless not perceived.

Our defense of the causal model does not rely solely on the idea that certain stimuli reach awareness via exogenous attention. There are currently no stimuli that can be studied in laboratory settings that seem immune to attentional tasks that are designed to engage top-down, endogenous attention.

may also be affected by limitations in the quality of the original stimulus itself [80]. If stimulus quality is degraded to achieve below-ceiling performance (e.g., by adding noise to a stimulus or decreasing its presentation time), increases of attention will have no effect on performance.

In studying the relationship between attention and consciousness, it is often necessary for performance on a particular task to be below ceiling. Going forward, the nature of these performance limitations must be understood before any firm conclusions regarding the role of attention can be reached.

Attention is not a monolithic resource

In order to infer awareness without attention from a lack of interference (i.e., attentional blink, inattentional blindness, dual-tasks, etc.), it must be assumed that all of attention is fully engaged by the primary task. However, as previously discussed, a body of research challenges this monolithic view by demonstrating that attention has a variety of resource pools and subsystems [7]. This is critical for understanding the relationship between attention and awareness, as two stimuli may not interfere with one another because they rely on separate resource pools rather than because one of the stimuli can be conscious perceived without attention.

For example, in a study by Alvarez and Cavanagh [81], participants performed two identical, attention-demanding tasks (multiple object tracking) simultaneously. Dual-task interference was only observed if stimuli from both tasks were presented within a visual hemifield. There was no performance loss when the tasks were separated across visual hemifields. Given that the two tasks were identical, the lack of interference could not be attributed to an asymmetry in their attentional demands; it had to be due to separate resource pools in each hemifield. In addition, Yi and colleagues [61] showed that even when task difficulty was equated, processing of an unattended stimulus was affected by a perceptual detection task, but not a working memory task. These results, and several others, speak against the basic assumption that attention is a monolithic resource.

Concluding remarks

With no empirical evidence yet meeting the criteria of awareness without attention, we argue that attention is necessary for awareness (Figure 1). Under this view, information that is not attended cannot reach consciousness. Attention is necessary for consciousness because attention allows information to remain on-line long enough to be thoroughly processed by a distributed network of cortical circuits. Future work will be needed to determine what specific type of sustained activation, and the representations associated with that activation, is sufficient for conscious awareness. Current ideas include the formation of a 'neuronal workspace' from neurons with long-range connections [1], a central 'core' system that represents many different, complex informational states [44], or representations depicting oneself as being in a specific mental state [46].

The relationship between attention and awareness is a foundational issue for the study of consciousness. Understanding the relationship between these processes will place necessary constraints on our understanding of the neural correlates of consciousness. It has been suggested that research on attention and awareness be conducted independently, but in parallel [2,3,6,18–24,82,83]. Such a strategy, however, assumes a double dissociation between attention and awareness. Without such dissociation, the search for the neural bases of awareness must incorporate a role for attention, because it is the cognitive process that elevates selected information to awareness. Identifying the neural correlates of consciousness will require an understanding of the overlapping neural networks of attention and awareness, with an emphasis on how information is passed from the former to the latter.

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