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Review

Progress in cognitive neuroscientific studies of visual awareness

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Abstract

The psychological and neural mechanisms of consciousness are among the most baffling problems in cognitive neuroscience. In this field, visual awareness is a topic that has been largely investigated, due to easy manipulation and measurable effects. The present article begins with the phenomena of dissociations between visual awareness and visual stimulus, visual awareness and visual attention, as well as visual awareness and vision-guided behavior, along with the corresponding experimental evidence. Furthermore, the neural mechanism of visual awareness is also discussed. It has been generally believed that visual awareness is the function of higher-order cerebral areas; however, recent discoveries have demonstrated that feedback from higher- to lower-order cortex areas is necessary for generating consciousness. The present article presents an in-depth analysis regarding this feedback process, and exploring its relationship with the generation and mechanisms of consciousness. Finally, theoretical controversies and discrepancies, as well as result conflicts from various studies, have been collected, compared and discussed. Because the field of consciousness continues to be an extremely mysterious and complicated psychological phenomenon, there is a great need for further studies to explore and clarify this topic.

Keywords: Visual awareness; Neural mechanism; Feedback process; Cortical areas

1. Introduction

What is consciousness? This question has been discussed by philosophers and psychologists since ancient times. Nevertheless, centuries of research have failed to provide a widely accepted definition of consciousness [1]. Most researchers do agree, however, that consciousness is a collection of an organism's subjective experiences of objects in the surrounding world, as well as of internal psychological and biological activities [2]; these experiences are the outcome of neural activities within the brain. Although many theories have proposed that phenomenal consciousness emerges from complicated neural activities, the mechanisms involved remain unclear. Visual awareness, which is generally defined as the subjective visual experience, is one of the most researched areas in the field of consciousness, parallel with auditory awareness, tactical awareness, etc. Before exploring and discussing consciousness in a general sense, visual awareness, which can be conveniently operationalized, serves as a good starting point. However, many years of dedicated research on conscious vision have failed to answer the question as to what consciousness really is. In contrast, the research has rather told us what consciousness is NOT. Through these studies, researchers have attempted to unveil the nature of consciousness. Many recent studies on visual awareness have endeavored to reveal dissociations between visual awareness and other factors, such as visual stimuli, visual attention, and vision-guided behavior, which will be reviewed in the next section.

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2. Dissociations in the field of visual awareness

2.1. Dissociation between visual awareness and visual stimuli

The dissociation between visual awareness and visual stimuli can be understood in two ways. On the one hand, a human being does not establish a detailed representation of the world he is looking at like a camera does. In contrast, not all information that reaches the retina can attain consciousness. The discovery of many visual blindness phenomena, such as change blindness [3,4], motion-induced blindness [5,6], and inattentional blindness [7–9], has lent support to this seemingly astonishing theory. Under certain conditions, a normal observer can fail to perceive a salient visual stimulus (or its change), although it is usually perceivable. Change blindness refers to the failure to detect changes between two successively presented scenes; motion-induced blindness is the sporadic disappearance and reappearance of a salient target stimulus presented against a moving background; inattentional blindness refers to when an observer dedicates his/her attention to a demanding main task and fails to detect the appearance of an outstanding, yet unexpected, stimulus presented in the visual field. Mack and Rock [10] determined that as many as 25% of their subjects failed to observe an unexpected, salient, peripheral stimulus. When this stimulus appeared in the fovea, the percentage surged to 80%. In a more dramatic experiment conducted by Simons and Chabris [7], subjects that were busy counting basketball passes even failed to see a gorilla walking right through the display. These studies together confirm the fact that visual stimuli do not necessarily lead to corresponding subjective experience, namely, visual awareness.

On the other hand, the generation of visual awareness does not always rely on external visual input. Commonplace phenomena, such as imagination and dreams, as well as phosphenes induced by TMS (as will be mentioned later in this review), are all cases where subjective visual experience exists, while external visual information input does not. Visual awareness is a broad concept encompassing various subjective visual experiences. It can refer to awareness of external visual stimuli, as well as visual representation internally generated (e.g., mental images).

2.2. Dissociation between visual awareness and visual attention

Visual awareness and visual attention have always been closely related – so close, in fact, that they are often considered synonymous. The various forms of visual blindness mentioned above also suggest that attention plays an important role in detection and visual awareness. Some researchers even went a step further to claim that there is no consciousness without attention [11]. However, the relationship between consciousness and attention might be more complex than that. As mentioned above, empirical evidence has indicated that the generation of visual awareness is dependent on visual attention [12]. However, emerging evidence leads to the conclusion that consciousness and attention might be two distinct processes after all [13,14]. Again, we take the example of inattentional blindness. As its name implies, the failure of unexpected stimulus to enter consciousness seems to be due to lack of attention; however, many studies do not support this notion. A very recent study [15] has shown in an inattentional blindness experiment that main task performance suffers impairment if, and only if, the subject is unaware of the unexpected stimulus. In the meantime, observers that claimed they did not see the unexpected stimulus gave a higher-than-chance performance when facing a forced-choice of stimulus properties, such as shape. This result indicates that even when not perceived, unexpected stimulus still occupies a portion of the subjects' attentional resources and receives processing to a certain degree. Experiments on motion-induced blindness also suggest a distinction between attention and consciousness. In a typical experiment, where a high-contrast stationary target was presented on a continuously moving background of relatively lower contrast, the target repeatedly disappears and reappears in the observer's percept. Studies have demonstrated that targets that are more salient (therefore require more attention), result in a greater possibility and longer duration of disappearance [5,6]. Furthermore, Jiang et al. [16] employed the Continuous Flash Suppression (CFS) [17] paradigm, and found that erotic pictures affect the allocation of spatial attention, even when they are not consciously perceived.

Lamme [14] explained the dissociation between consciousness and attention from a unique angle, by dividing consciousness into two subcategories, namely, transient consciousness and reportable consciousness, which are similar to Block's "phenomenal consciousness" and "access consciousness" [18]. Lamme used change blindness as an example and postulated that even in the complicated scenario of a change blindness experiment, subjects were still able to perceive most information; however, information was overwritten by the successor before it was transformed to reportable consciousness. If the subjects were cued as to where the change should occur prior to appearance of the post-change picture, they performed almost 100% accurately. Similar explanations have been proposed for inattentional blindness, which is why some researchers prefer to call it inattentional amnesia [19].

2.3. Dissociation between visual awareness and vision-guided behavior

Another typical dissociation is the one between visual awareness and vision-guided behavior, which, compared with the distinction between attention and consciousness, is easier to understand, because many of our daily activities rely heavily on visual processing and can be performed without conscious effort. A common example is that a driver can arrive safely at his destination while thinking about other things, not aware of how he has been driving. Stricter