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Subjective discriminability of invisibility: A framework for distinguishing perceptual and attentional failures of awareness

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A B S T R A C T

Conscious visual perception can fail in many circumstances. However, little is known about the causes and processes leading to failures of visual awareness. In this study, we introduce a new signal detection measure termed subjective discriminability of invisibility (SDI) that allows one to distinguish between subjective blindness due to reduction of sensory signals or to lack of attentional access to sensory signals. The SDI is computed based upon subjective confidence in reporting the absence of a target (i.e., miss and correct rejection trials). Using this new measure, we found that target misses were subjectively indistinguishable from physical absence when contrast reduction, backward masking and flash suppression were used, whereas confidence was appropriately modulated when dual task, attentional blink and spatial uncertainty methods were employed. These results show that failure of visual perception can be identified as either a result of perceptual or attentional blindness depending on the circumstances under which visual awareness was impaired.

1. Introduction

Conscious visual perception can be impaired in many circumstances such as when a visual stimulus is degraded or when we are distracted by other stimuli (Kim & Blake, 2005). Such instances of stimulus blindness have revealed that visual stimuli are processed in many brain regions even when they do not reach visual awareness (Lin & He, 2009). However, the causes and processes leading to failure of visual awareness are likely to be different depending on the circumstances under which visual awareness is impaired. Disruption of visual awareness could occur when stimulus signals are degraded to the degree that they are hardly indistinguishable from any signal at all (Dehaene, Changeux, Nacache, Sackur, & Sergant, 2006; Lamme, 2003, 2004). Even if sensory signals remain strong, they could go unnoticed when attention was distracted by other stimuli (Chun & Potter, 1995; Dehaene et al., 2006; Norman & Bobrow, 1975; Pashler, 1994; Sigman & Dehaene, 2006) (Fig. 1). In other words, psychophysically induced unawareness seems to be divided into *perceptual blindness*, in which subjective invisibility is caused by suppression of low-level sensory signals, and *attentional blindness*, in which observers fail to notice the presence of a target due to failure to access low-level signals despite their presence. However, it has been difficult to operationally distinguish these causes of blindness. Yet, the distinction of the two is critical for understanding the neuronal mechanisms underlying conscious visual perception (Block, 2007; Lamme, 2006).

The two levels of awareness failure have also been proposed on the basis of neuroimaging studies of conscious face perception (Block, 2007). In a study with binocular rivalry with faces and houses as stimuli, the activity in the fusiform face area (FFA) was suppressed when conscious perception of a face was impaired by a competing stimulus presented to the other eye

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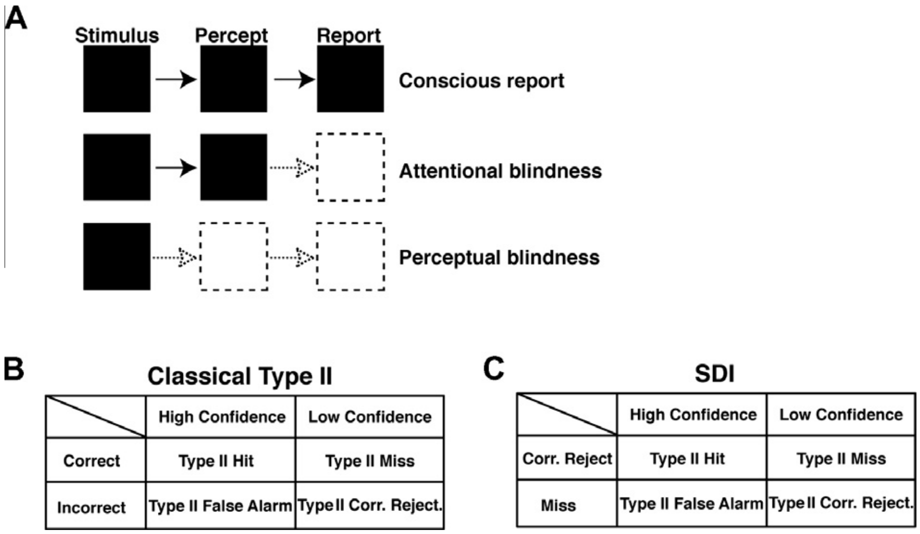

Fig. 1. A schematic conceptualization of perceptual and attentional blindness (A) and contingency matrices used in the analyses of classical Type II task and in subjective discriminability of invisibility (B and C). Usually conscious report consists of sufficient neuronal responses at a sensory processing stage and access of the information at a decision stage for a report. However, if the sensory information is not accessed successfully, conscious report is hindered despite the presence of strong responses of sensory neurons (*Attentional blindness*). If sensory signals are suppressed in an early stage, conscious report is hampered despite the attempt to cognitively access the information (*Perceptual blindness*). (B) A Type II performance is calculated by substituting correct trials with high confidence as "hits" and incorrect trials with high confidence as "false alarms" at a second-level, respectively. (C) In the calculation of SDI, instead of aggregating hit (or miss) and correct rejection (or false alarm) trials as correct (or incorrect) trials, the second-level contingency matrix is constructed only for trials on which observers reported the absence of a target, i.e., correct rejections and misses.

(Tong, Nakayama, Vaughan, & Kanwisher, 1998). On the other hand, a visual extinction patient exhibited FFA activity even when he failed to consciously register the face presented in his left visual field due to a competing stimulus on the right (Rees et al., 2000). The former case of binocular rivalry can be interpreted as suppression of visual signals in FFA or even at earlier stages, whereas the latter case appears to be due to lack of attentional (or cognitive) access to the information of the face present in the FFA.

Despite the mounting evidence, it has been difficult to operationally distinguish at a behavioural level the suppression of low-level sensory signals and failure to access sensory signals, because they both result in the same responses, i.e., reports of absence of stimuli. Moreover, the fact that attention often boosts sensory signals independent of awareness (Koch & Tsuchiya, 2007) makes it difficult to separate the effect of attentional access from modulation of sensory signals.

The goal of the present study was to introduce a framework to distinguish perceptual and attentional blindness and examine the framework in light of empirical data from a series of psychophysical experiments. To illustrate the idea behind the development of such a framework, we first provide an overview of signal detection theory (SDT) (Green & Swets, 1966; Macmillan & Creelman, 2005) as applied in awareness studies and discuss their limitations.

1.1. Objective sensitivity: Type I signal detection theory

The most common use of SDT in experimental psychology is a Type I task in which observers make decisions in a presence–absence judgment task or in a stimulus discrimination task. In Type I SDT, objective sensitivity independent of decision criterion is computed. In a presence–absence judgment task, for example, observers make judgments as to whether a stimulus is present or absent. Trials in a presence–absence judgment task are categorized into the following four types:

1. *Type I hits:* stimulus present & response present.
2. *Type I correct rejections:* stimulus absent & response absent.
3. *Type I misses:* stimulus present & response absent.
4. *Type I false alarms:* stimulus absent & response present.

From the *z*-scores of hit and false alarm rates (i.e., hits as a proportion of present trials and false alarms as a proportion of absent trials), sensitivity measures such as d' or the AUC (the Area Under the ROC curve) are computed and they are used as criterion free measures of sensitivity (see a standard textbook on SDT for the formulas of these measures; e.g., Green & Swets, 1966; Macmillan & Creelman, 2005).

Null sensitivity to a stimulus (i.e., $d' \sim 0$, misses and false alarms make up 50% of responses) has been used as evidence of no awareness under experimental situations (e.g., Dagenbach, Carr, & Wilhelmsen, 1989; Eriksen, 1960; Fowler, Wolford, Slade, & Tassinary, 1981; Kemp-Wheeler & Hill, 1988; Marcel, 1983; Nolan & Caramazza, 1982; Schurger, Pereira, Tresiman,