Attention and Perception in the Deaf: A Case for Plasticity in Consciousness

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Introduction

Although philosophers of mind have not yet settled if mental states and functions are to be tied to neural activity per se, much of the current research into brain plasticity suggests that every experience that we go through modifies cortical connections and functionality. Cognitive functions related to attention, memory, perception, language and decision-making evolve as experiences sculpt brain networks (Mahncke et al. 2006; Merzenich et al. 1996). At times philosophers of mind look into and discuss data from experimental literature in order to understand conceptual issues better. One good example is the recent works of Ned Block (Block 2014, 2015a, b). Block takes experimental data very seriously and uses them to argue on the nature of consciousness or attention or other related things. Data from cognitive neurosciences have been used abundantly on such matters (Bor and Seth 2012). Whether consciousness arises from neural computations carried out by designated neuronal ensembles has been an open issue. There also have been many debates on the nature of attention, awareness and their relationship to consciousness (Montemayor and Haladjian 2015; Srinivasan 2007). Different cognitive psychologists and philosophers of minds have taken radically opposite positions (Koch and Tsuchiya 2007; Cohen et al. 2012; Lamme 2003; Kentridge 2011). In this chapter, we look at cognitive enhancement as a consequence of sensory deprivation as in the case of the deaf and try to see what we can infer about critical mechanisms such as attention and visual awareness.

Reorganisation of brain structures can have a far-reaching impact on both neural functioning and behaviour. For instance, continual practice of a skill such as meditation could influence awareness and attention (Manna et al. 2010; Raffone and

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Srinivasan 2009, 2010). These data suggest that one's neural apparatus can be altered through long-term practice. Other instances of brain reorganisation are seen in the case of sensory deprivation. Sensory deprivation since birth often leads to a complete and dramatic reorganisation of brain networks that assume spectacular power. This reorganisation helps the individual survive and dwell in the face of severe limitations that arise because of such deprivation. It is a similar case with deaf individuals where hearing impairment has been shown to promote superior visual awareness and visuospatial attentional abilities. Considering that the deaf participants have higher selective attention and accepting the theory that attention and awareness are in some form of causal relationship, then one must expect a fundamentally different kind of awareness in the deaf. Therefore, data from such participants are not only informative about their conditions; they can be used to answer deep questions about the mind. In this context, we present in this chapter data from hearing impaired people where they show enhancement in both perceptual and attentional mechanisms. Current research suggests that the dorsal visual processing stream undergoes considerable modification in the deaf (Bavelier et al. 2006). What does this imply for visual perception and visual awareness in deaf? Although our current understanding of visual awareness and attentional mechanisms comes from studies of normal participants, there is much to learn from the data on deaf. It is time we consider individual difference related factors while talking about awareness, perception and consciousness, at least while referring to experimental data.

Neuroplasticity of Cognitive Systems

Deaf signers need to pay constant attention to another signer's dynamically changing hand and lip movements for communication. Cognitive psychological studies with both children and adult deaf individuals have produced a range of data that testify to such excellent example of plasticity (Bavelier and Neville 2002; Dye et al. 2008). Deprivation in hearing strengthens vision. However, the mechanism of vision and its relations to such complex processes as attention and awareness has been a matter of debate for several decades. While we still do not know if our consciousness and awareness are dependent on our ability to attend, findings from the deaf have the power to throw new light on these questions. In this chapter, we will survey data that show the subtle nature of plasticity-induced cognitive abilities in the deaf in the area of visual attention and awareness. Research shows that deaf just do not see better but have developed a better sense of awareness of the visual world, at times extending into unconscious processing. Their heightened ability to respond to visual stimuli in the periphery is also seen with their superior ability to process unconscious stimuli presented below the thresholds of awareness. One of the hotly debated questions in cognitive science is whether attention and consciousness are one and the same thing? Or are they fully dissociated? Although reviewing all the differing viewpoints on this issue is beyond the scope of this

chapter, we will discuss some of the major theoretical frameworks and later examine how changes induced by deafness can be connected to them.

Is attention necessary for conscious perception? Attention, in this case, is mostly referred to the mechanism which selects an object out of many for further selective processing. Visual-spatial attention to a location leads to higher processing of objects that appear in that location. Attention to one object or location leads to lesser acuity in another location. Evidence from paradigms such as change blindness and attentional blink suggests that, if attention is not sufficiently engaged, then the perceiver does not extract objective knowledge of things (Dux and Marois 2009). Therefore, based on available evidence one can say that attention, being a limited resource, only illuminates certain aspects of the world for our consciousness. Subjective knowledge about a broader visual field is at best gross and people do not remember any useful detailed information. Selective attention is required for detailed task specific knowledge. Therefore, this line of argument makes attention mandatory for conscious perception and suggests that attention and consciousness cannot be fully dissociated (Cohen et al. 2012). Opposite to this view is that attention and consciousness are fully distinct processes (Koch and Tsuchiya 2007). A commonly cited example of consciousness in the near absence of attention is gist perception. When participants are shown a photograph or a scene for a brief duration, they are still able to correctly perceive the gist of the stimulus. As the duration of presentation is too low for the attentional system to be engaged, it has been claimed that conscious awareness can exist without top-down attention. Another example is that of pop-out in visual search. When participants are asked to identify a red circle among a set of green circles, the red circle 'pops out' instantly. The time required to identify such a salient stimulus is independent of the number of other distracting stimuli. It is said that attention is not engaged in such situations, but individuals are nevertheless conscious of the stimulus. In sum, the necessity of attention for conscious perception is a heavily debated issue in the scientific study of consciousness and there is no final consensus on the topic.

Is consciousness necessary for attentional engagement? In contrast to the question discussed above, most researchers agree to the point that attention can be directed to stimuli that never reach conscious awareness (Dehaene et al. 2006; Kiefer and Martens 2010). For example, interocular grouping (combining different parts of an image into a holistic representation) can happen without awareness (Lin and Yeh 2016). In this study, continuous flash suppression was used as a method to make stimuli presented to each eye invisible. Similarly, binocular rivalry can arise without awareness (Klink and Roelfsema 2016). Thus, even if the participant is not aware of a certain stimulus, attention can be directed to it. Studies from masked priming have shown that directing attention to a masked prime can increase priming effects. (Naccache et al. 2002; Shin et al. 2009; van den Bussche et al. 2010) Thus, deployment of attention does not necessarily result in conscious perception. In the context of deafness, if attention and awareness are two different mechanisms, then plasticity-induced changes should be seen in them differently. If they are causally related, then plasticity should influence them similarly.

Given these interrelationships between attention and awareness, it is then important to examine how to ground this in an experimental paradigm. Unfortunately, much theorisation in cognitive psychology on these constructs has been an outcome of the paradigms used to study them and the constraints that they come with. For example, the attentional blink or the inattentional blindness tasks exploit only specific aspects of attention. As is now widely known, attention is not a unitary mechanism but a collection of different processes. It has various attributes, such as local versus global; focused versus dispersed; selective versus non-selective. A single paradigm may not capture all these attributes. Therefore, a causal explanation regarding awareness and attention is also limited by the particular task or paradigm used to infer about such processes. As different tasks have been used to understand visual perception and attention in the deaf, they have given rise to multiple explanations in the field. It is not clear what exactly the deaf individuals have which in turn enhances the brain mechanisms related to awareness and attention. Further, plasticity-related changes in core brain functions leading to noticeable outcomes in behaviour is also a matter of skill and habit. Therefore, many researchers have also tried to link sign language use and its proficiency while understanding behavioural task outcomes in the deaf.

In the next two sections, we will discuss the issue of sensory deprivation leading to brain plasticity which in turn modifies attentional and perceptual skills. We will then discuss if brain plasticity changes both? People can be aware of many things in their visual field while they can attend only to some. The limited capacity system does not explain the extensive awareness which most observers seem to experience and believe strongly (Cohen et al. 2016). Although objective knowledge is acquired from very few objects, participants show subjective awareness of many. Constraints on visual perception and eye movements also suggest that much of our visual awareness comes from parafoveal and peripheral awareness. Cohen et al. (2016) question this and ask how come our visual awareness and our intuitive knowledge about things are so rich when our attentional and working memory capacities are justifiably so less? This question is of central importance to the deaf issue since we need to know what exactly brain plasticity does to the deaf brain. Does it increase their attentional capability or it enhances their scope of awareness without changing their attentional or working memory capacity? The evidence is sparse since only a few studies have examined these issues.

Enhanced Visual Perception and Attention in the Deaf

What exactly does plasticity mean? It refers to the neural changes because of acquisition and practice of some skills. This is seen, for example, in bilingual speakers whose brains show plasticity because of the practice of bilingualism (Abutalebi et al. 2011; Costa and Sebastián-Gallés 2014). Higher levels of language use lead to changes in the frontoparietal attention network in bilinguals. Another understanding of plasticity is related to transfer of neural selectivity because of

sensory deprivation. No cortical area is hard wired to process and be engaged in only one function. In the deaf, absence of audition leads to better vision. Therefore, these two types of plasticity are fundamentally different. Plasticity then refers to the possible changes in the brain as a function of adaptation to new skills. Even very short-term practice of a difficult task can improve plasticity in the neural system, in the form of new functional connectivity among areas or even structural changes. For example, a recent study (Rodrigue et al. 2016) shows that the practice of anti-saccade task in Schizophrenia leads to better connectivity between the pre-frontal region with the insular and temporal region. Playing video games like Super Mario changes structural plasticity in the grey matter (Kühn et al. 2014). Grey matter increase has long been thought to enhance cognitive skills. Children, if trained with music and second-language skills, show improvements in executive control (Janus et al. 2016). Training-induced plasticity in older adults has been shown to improve inhibitory control (Spierer et al. 2013). Often these studies measure changes in brain area volumes pre- and post-training to see the induced changes. Many more examples can be found in current research where some form of training in challenging skills leads to structural and functional changes in neural networks as well as behavioural improvements.

The deaf person's plasticity-induced changes in cognitive functions is a different issue. Here, sensory deprivation leads to one modality becoming stronger than what is normally seen. The deaf individuals may learn a sign language while they are children and many who do not learn a sign language may use just gestures. Therefore, enhancement of cognitive processes in the deaf are not induced by training. Congenital deafness leads to very profound modification of the brain, most importantly the primary visual cortex. Much has been learned about compensatory plasticity-related changes in animal models (Rauschecker 1995) and also in blind people (Cohen et al. 1997). Neural data from the congenitally deaf show that their primary visual cortex has a greater and more expansive receptive field (Neville et al. 1982). The deaf occipital cortex also shows higher cortical thickness. In the deaf, it is not just the visual cortex which shows enhanced efficiency of processing but the auditory cortex which has taken over visual processing (Finney et al. 2001). Therefore, the deaf can attend to peripheral stimuli better and discriminate using superior spatial attention. More recently it has been suggested that such cross-modal reorganisation of the auditory and visual cortex in the deaf is linked to the age of onset of sign language use. Therefore, not all deaf develop a higher visual ability since it is linked to their practice of sign language. Some minimal structural modifications may happen during development, but more prominent changes are probably linked to the acquisition of sign language skills.

Why should neuroplasticity alter fundamental mechanisms related to attention, awareness or even consciousness? Several neurological conditions have been used to understand issues related to consciousness. Blindsight is perhaps the most common condition used specifically as evidence for unconscious processing (Ajina and Bridge 2016; Block 2015a, b; Danckert and Goodale 2000). Blindsight is a condition where there is damage to certain parts of the visual cortex (Weiskrantz 1986). Individuals with this condition are 'blind' in certain regions of their visual

field. Thus, they are not consciously aware of the objects presented in their blind regions. But they can nonetheless perform above chance level on tasks that require responding to such stimuli. The common explanation for blindsight is that, although the patients are unaware of the objects in their blind regions, they are nonetheless processing the features of the visual stimulus. This has provided convincing evidence that people can be influenced by unconscious stimuli. But not all researchers agree that blindsight is a convincing case of unconscious vision. This is because—as in most studies on unconscious processing—it is difficult to establish whether the patients were entirely unaware of the stimulus. Some researchers have argued that blindsight is a case of severely degraded conscious vision, but not unconscious vision (Overgaard 2012). It has been argued that participants fail to detect the stimulus during identification tests because they adopt a conservative criterion—responding that they have not seen the stimulus only because they are not sure. Studies with more sophisticated awareness tests, such as the perceptual awareness scale, have found a correlation between the reported visibility of the stimulus and the accuracy in responding to it (Overgaard et al. 2008). Thus, these researchers claim that traditional methods of testing awareness used in many studies underestimate visibility and so blindsight is a result of degraded form of conscious processing. This issue is still being heavily debated (Brogaard 2011) Interested readers can refer to the debates between Ned Block and Ian Phillips to know about the controversies regarding unconscious perception and the role of blindsight studies in examining this issue ('Block/Phillips debate on unconscious perception', NYU website). Controversies apart, the studies with blindsight and other conditions like hemineglect highlight the fact that naturally occurring conditions in human participants can shed new light on critical issues. The changes observed in the deaf due to plasticity is one such unexplored domain which has the potential to inform us more on conscious and unconscious visual processing in humans.

Visual Processing Advantages in the Deaf

Over the last few decades, several studies have provided evidence that other senses in the deaf—mostly sight—is modified due to the lack of auditory input. Most of these studies point towards a theory of compensation—that is, the deficit in a particular modality leads to advantages in the other. In contrast, there have also been deficit theories (Mitchell 1996) which are based on the division of labour hypothesis. They suggest that since the visual system has to perform the functions of both visual and auditory systems, certain deficits in visual processing are observed in the deaf population. This chapter will focus on the compensation aspect of the cross-modal plasticity in the deaf. Several factors contribute to the cross-modal changes observed in the deaf. Some of them are shown in Fig. 1. The deaf population can be extremely heterogeneous (A). Individuals can differ on the causes of deafness (congenital, neurological diseases, accidents), degree of deafness (moderate to profound) and the hearing status of their parents (deaf/non-deaf).
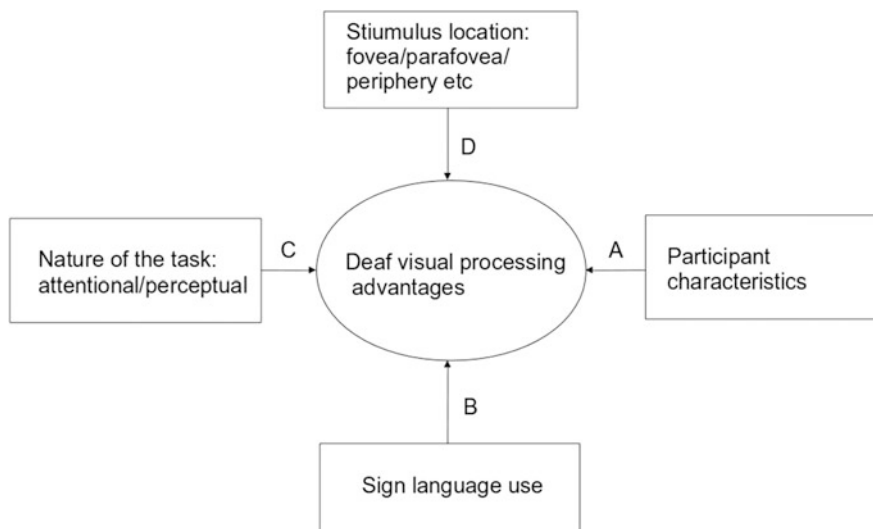
Fig. 1 Factors contributing to visual processing advantages in the deaf. The heterogeneity in the deaf population (*A*), proficiency in sign language use (*B*), whether the demands of the task are perceptual or attentional in nature (*C*) and whether the task requires responding to central or peripheral locations (*D*) are among the most important factors which decide whether processing advantages are seen for the deaf

Further differences can arise due to the age of acquisition of sign language and the proficiency in sign language use (B). Deaf individuals have to effectively monitor the sign language of interlocutors to communicate. Dynamically shifting attention between hands and features of the face (such as eyes or lips) contributes to changes in the visual processing system. Normal-hearing individuals do not have to indulge in such wide spanning of their visual field. Thus, sign language is an important contributing factor in the plasticity observed in the deaf. The nature of the task and its demands play an important role in determining if deaf show an advantage in performance (C). Most studies have found evidence of superior performance in the deaf only when the task had an attentional component in it (Bosworth and Dobkins 2002; Bottari et al. 2010). One of the most important factors that determine visual advantage in the deaf is the stimulus location (D). Several studies have shown enhanced peripheral processing in the deaf. But whether this enhancement is at the cost of processing at the fovea or whether enhancement is observed at all locations in the visual field is still an open question (Dye 2016). As is evident, the locus of the changes as a result of cross-modal plasticity is still debatable and several factors contribute to it. We will, however, limit our discussion in this chapter to factors C and D and more importantly examine how they throw light on the issues of attention and consciousness.

Several theoretical frameworks exist to account for the various findings observed in deaf literature (Dye and Bavelier 2013). Codina et al. (2011) examined retinal

structures in deaf using optical coherence tomography (OCT) and observed significantly larger neural rim areas—suggesting a larger number of ganglion cells, compared to normal-hearing individuals. These results suggest that plasticity leads to changes in visual processing as early as the retinal level (perceptual enhancement hypothesis). In Bottari et al. (2010) deaf participants were found to be faster at detecting targets (at both centre and periphery) in a simple detection task compared to normal-hearing participants. In contrast, the two groups did not differ on a shape discrimination task. Since a discrimination task involves orienting of spatial attention to the targets, the authors conclude that enhanced attentional orienting is not a necessary component of deaf visual processing. Rather, deaf individuals are faster at reacting to visual stimuli. Further evidence for this theory comes from an ERP study by Bottari et al. (2010). In this study, deaf and normal-hearing were tested on a simple detection task while EEG recording was done. There were differences between the two groups in early visual components of ERP (C1/P1) suggesting that the changes in deaf are more sensory in nature rather than attentional. Similar results were found for central and peripheral targets. Thus, these studies suggest that the 'enhanced reactivity' is present across the visual field and not necessarily just at the periphery. Further, they suggest enhancement of perceptual representations of stimuli in the deaf.

In contrast, the dorsal route hypothesis predicts changes that are attentional in nature. These changes are said to arise due to modifications to dorsal processing stream in the deaf as a result of plasticity. Few studies have examined attentional orienting (Parasnis and Samar 1985; Colmenero et al. 2004; Prasad et al. 2015) and selective attention (Dye et al. 2007; Proksch and Bavelier 2002) in the deaf. The earliest study to examine orienting in deaf people was Parasnis and Samar (1985). They compared deaf and normal-hearing participants using a Posner cueing paradigm (Posner 1980). This paradigm is typically used to measure the orienting responses to targets. Cues are presented before target onset either at the same location as the target (valid trials) or at the opposite location (invalid trials). The valid cues are supposed to attract attention to the target location thereby speeding up responses to such targets. Invalid cues on the other hand orient attention away from the targets, thus, slowing down the responses on such trials. Parasnis and Samar (1985) found that deaf could disengage faster from an invalidly cued location leading to lesser costs for the deaf on invalid trials. There was no group difference in the ability to orient towards validly cued locations. Similarly, in two experiments, Colmenero et al. (2004) found that deaf subjects can disengage attention faster than normal-hearing participants. However, all of these studies examined attentional orienting through manual responses. Whereas, attention and eye movements are closely linked (Hoffman and Subramaniam 1995). So then, does the visual processing advantages in the deaf modulate spatial orienting with respect to eye movements? And does target eccentricity play a role?

To examine this, Prasad et al. (2015) compared deaf and normal-hearing participants on an oculomotor version of the Posner cueing task (Fig. 2a). Targets (white discs) appeared either at parafovea (7°) or at the periphery (21°). Spatial cues in the form of brief (100 m) flickers were presented just before the targets. Targets
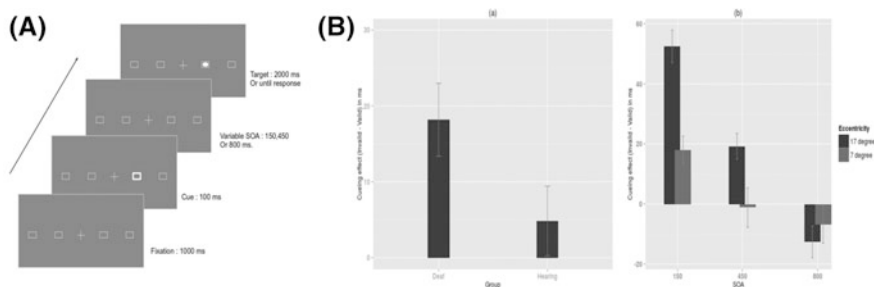
Fig. 2 A Sequence of events in a sample trial. A brief cue was presented for 100 m after the fixation cross. Target was presented either at the cued location or at an uncued location. The figure shows a sample sequence on a valid trial where there is match in the cue and target location. **B** Oculomotor responses (*a*) Cueing effect for deaf and hearing groups (*p* < 0.05) (*b*) cueing effect at 150, 450 and 800 m SOA at both perifovea and periphery (*right panel*), Prasad et al. (2015)

and the cues were either presented at the same location (valid trials) or at the opposite location (invalid trials). The stimulus onset asynchrony (SOA) between the cue and the target was varied: 150, 450 or 800 m. Participants were asked to make a saccade to the target as soon as it appeared on the screen. Facilitation (faster responses on valid trials) was observed at shorter SOA (150 m) and inhibition of return (faster responses on invalid trials) at long SOA (800 m). Inhibition of return (IOR) refers to delayed responding to already attended locations. This arises due to the reluctance of the attentional system to orient towards a previously attended location. In this study, the two groups did not differ with respect to facilitation or IOR. However, the overall cueing effect (RT difference between invalid and valid trials) was higher for the deaf compared to normal-hearing participants (Fig. 2B). This difference was not modulated by target eccentricity. In sum, the findings of this study suggest that deaf have a higher ability to utilise spatial cues to orient towards target locations.

In another study, Jayaraman et al. (2016) examined attentional disengagement without relying on ignored cues to generate IOR. Jayaraman et al. (2016) replicated the experiment by Vaughan (1984) in which participants were asked to track with their gaze a fixation stimulus that moved to different locations on the screen resulting in a sequence of saccades (Fig. 3a). The last saccade was designed to be at a previously fixated location or at the opposite location. The time delay between the third and the fourth fixation was also manipulated to examine the time course of IOR. IOR was observed as a slower saccade latency to the last fixation when it appeared at a previously viewed location. This effect was also modulated by the distance from the location that was previously visited. As the distance increased, the magnitude of IOR decreased. Importantly, the authors found that the deaf and normal-hearing participants did not differ with respect to the magnitude or time course of IOR (Fig. 3b). The findings of the two above studies suggest that deaf individuals are not necessarily better at disengaging attention. This is in line with
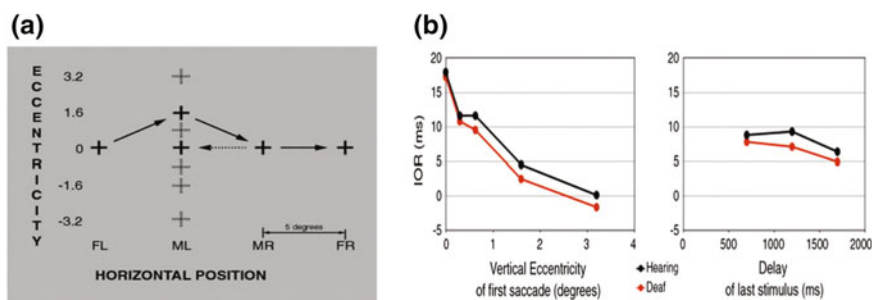
Fig. 3 **a** Illustration of the possible events on a trial. **b** IOR scores for the two groups as a function of vertical eccentricity of the first saccade and the time delay between the third and the fourth fixation (Jayaraman et al. 2016)

previous studies which have found comparable results in deaf and normal-hearing in terms of inhibition (Chen et al. 2006).

It is difficult to say which theoretical perspective explains the majority of findings observed in the deaf literature. However, as Dye and Bavelier (2013) note in their comprehensive review, 'a majority of the literature on visual adaptation to deafness in deaf native signers reveals compensatory changes that favor the dorsal route hypothesis and variants thereof (p. 244)'. It is important to first understand the role of dorsal stream in visual processing in general. The dual stream hypothesis has been an influential model of visual processing (Goodale and Milner 1992). According to this model, visual processing is mediated by two distinct streams or pathways in the brain. One is the ventral pathways concerned with 'vision for perception'. The other is the dorsal pathways which mediate 'vision for action'. Ventral pathways are said to be responsible for processing features of the stimuli that result in awareness, such as shape, colour or size of an object. On the other hand, dorsal pathways are responsible for guiding actions, such as grasping. Thus, aspects of the visual object processed in the dorsal stream do not reach conscious awareness. As Goodale and Milner put it, 'The dorsal stream is not in the business of providing any kind of a visual representation of the world: it just converts visual information directly into action (2004: 114)'. Several studies using continuous flash suppression have given evidence for the role of dorsal stream in unconscious processing. Fang et al. (2005) showed in a fMRI study that activation in the ventral stream, but not the dorsal stream depended on the visibility of the stimulus. Neuroimaging data showed substantial activity in the dorsal stream for invisible objects suggesting that dorsal stream is largely responsible for processing unconscious information. The dual stream hypothesis is important for a discussion on consciousness as it suggests that any processing carried out by the dorsal stream is essentially unconscious. Brogaard (2011) argues for this point and suggests that functioning of the dorsal stream has also been evolutionary beneficial to us. She takes the example of reaching for a coffee mug where the person performing the action is aware of the colour, size and location of the coffee mug. But reaching for

the mug requires complex mathematical calculations, such as estimating the speed at which the arm must be moved and the trajectory to be followed in order to reach the mug precisely. We are never aware of these computations and we perform them on-the-fly. Brogaard argues that such computations which are truly unconscious are taken care of by the dorsal stream. Again, there have been oppositions to these ideas. Specifically, researchers have argued that the distinction between the two pathways is not so rigid and that there may be intersections (Hebart and Hesselmann 2012). But given what we know about the function of dorsal pathways and the changes to them due to deafness, what are the implications for unconscious processing in the deaf?

Unconscious Processing in the Deaf

The question is how does the deaf visual system process a stimulus that is below the threshold of awareness? It seems logical that there would be differences between deaf and normal-hearing in the processing of unconscious stimuli because of plasticity-induced changes in the dorsal stream in the deaf. But what is the exact nature of this influence? Specifically, if the changes in the deaf are largely attentional in nature as suggested by many researchers, then what does higher attention in the deaf particularly do to unconscious stimuli?

Dehaene et al. (2006) proposed the following taxonomy to explain the relationship between attention and (un)conscious processing based on the global workspace model (Dehaene and Naccache 2001). They refer to a 2 by 2 matrix resulting from an interaction between top-down attention and stimulus strength (Fig. 4). A sufficiently strong stimulus coupled with top-down attention is required

Bottom-up stimulus strength	Top down attention	
	Absent	Present
Weak or interrupted	Subliminal(unattended)	Subliminal (attended)
Sufficiently strong	Preconscious	Conscious

Fig. 4 Taxonomy proposed by Dehaene et al. (2006) for the possible relationships between bottom-up strength of a stimulus and the top-down attention directed on it (adapted from Dehaene et al. 2006)

for conscious access to a stimulus. Consequently, lack of conscious access can occur due to failure at one of these levels resulting in two types of non-conscious processing: subliminal (as a result of weak bottom-up the strength of the stimulus) and preconscious (as a result of lack of top-down attention to an otherwise strong potentially accessible stimulus). Paradigms such as attentional blink are given as examples of preconscious processing. More important to our discussion, they discuss two types of subliminal processing as a result of weak stimulus strength—subliminal-attended and subliminal-unattended. The subliminal-unattended stimuli produce no or weak priming effects. A majority of studies in subliminal priming thus fall under the category of examining subliminal-attended stimulus. These are the stimuli that have weak bottom-up stimulus strength which is insufficient to enable conscious access in spite of top-down attention. Thus, the 'subliminal' nature or, in other words, the lack of conscious awareness of such stimuli is independent of the presence or absence of attention. The presence of attention can, however, amplify the depth of processing of such stimuli leading to greater priming effects. It is important to maintain the distinction between the perception of the subliminal stimulus and the processing of that stimulus. The former refers to the reportability of the stimulus which is related to the perceptual representation. The latter refers to the influence of a subliminal stimulus on a subsequently presented target. Thus, according to the taxonomy proposed by Dehaene et al. (2006), presence of attention amplifies subliminal processing leading to priming effects.

In the context of deafness, we refer to Fig. 5 to examine which aspect of subliminal processing is affected by the plasticity-induced changes in the deaf. There are two ways of processing a subliminal stimulus, referred to here as A and B. Process A refers to the perceptual processing of the stimulus which enables conscious reportability or the detection of the stimulus. Process B refers to the sensorimotor activations triggered by a subliminal prime, which is measured as the priming effect. Thus, A represents how well a participant can 'see' the prime stimulus whereas B represents what the primes do to a subsequent action. Which of these processes, if any, is modulated by the deaf visual system? According to the
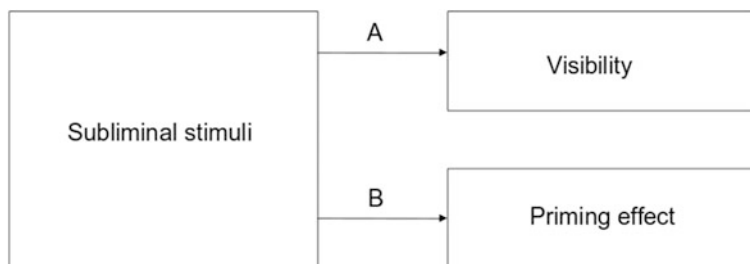

Fig. 5 Two distinct effects arising from the processing of a subliminal stimulus. The direct processing of a subliminal stimulus is measured by its visibility (*B*)—for example, on a prime identification test. Priming effects are an indirect measure of subliminal processing where the prime influences a subsequent conscious behaviour (*A*)

model based on the global workspace hypothesis, depth of processing of a subliminal stimulus can be modulated by attention and thus, enhanced attention should lead to enhanced priming effects. For instance, in Sumner et al. (2006), Participants were asked to respond to left or right arrows through a manual response. Masked primes were presented prior to the targets. The prime duration was selected such that they produced distinct positive (with 'visible' primes) and negative priming (with 'invisible' primes) effects. Attention was modulated using exogenous cues that were either presented at the location of the prime ('cued') or in the opposite ('uncued') location. Negative effects of the prime were found to be higher when primes appeared on cued locations as a result of attentional cueing. Several studies have similarly provided evidence regarding the role of attention on subliminal priming (Marzouki et al. 2007; Kiefer 2012).

What happens to the visibility of a subliminal stimulus under attention is less clear. Kouider and Dehaene (2007) note that 'subliminal information is information that cannot be brought into consciousness, in spite of all efforts of focused attention'. Does this mean that attention has no effect on the visibility of a subliminal stimulus? However, there is previous evidence that attention can modulate perceptual threshold (Müller and Humphreys 1991). Additionally, it is widely agreed that attention enhances the perceptual saliency of a stimulus. As Carrasco et al. (2004) have noted, 'attention changes the strength of a stimulus by increasing its "effective contrast" or salience'. In that case, can top-down attention turn an invisible stimulus into a visible one? But this seems contradictory to the very definition of 'subliminal' under the classification proposed by Dehaene et al. (2006). A possible explanation is that attention can enhance visibility in a graded manner but only till the conscious threshold is reached. Thus, although a subliminal stimulus can never cross the threshold and become visible, attention can nonetheless enhance the perceptual strength.

Prasad et al. (2017) compared deaf and normal-hearing participants on a subliminal priming paradigm to examine these issues. This paradigm has been used to understand the influence of invisible stimuli on a conscious action. Initially used in lexical priming studies, the paradigm is now extensively used to understand unconscious influences on any conscious behaviour. Typically, a prime is presented for a brief duration followed or preceded by a mask. The mask is supposed to suppress the retinal afterimage of the prime thus ensuring its invisibility. Following this, a target is presented to which the participants are asked to respond. The relationship between the prime and the target is manipulated between different trials. A prime similar (visually/semantically) to the target results in faster responses whereas a dissimilar prime leads to slower responses. This effect is known as priming.

In this study, deaf and normal-hearing participants completed 'fixed' and 'free' trials. On fixed trials, numbers 1 or 2 were used as target cues to which the participants had to respond based on the instruction (Fig. 6). On free trials, 0 was used as the free choice target and participants were asked to freely choose between two response alternatives. The free and fixed choice targets were presented only at
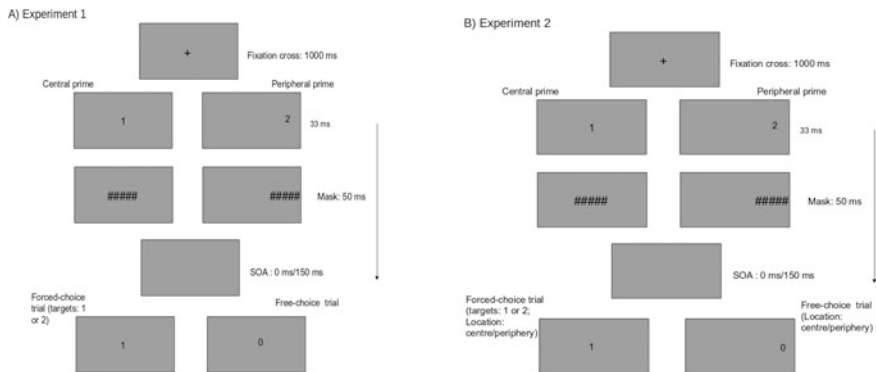
Fig. 6 Sequence of events on a sample trial—experiment 1 and experiment 2. In experiment 1, primes (1 or 2) were presented at centre or periphery followed by a mask (#####). Participants then responded to the target cue (fixed trials) or chose between two alternative responses (free trials). The target numbers (1, 2 or 0) were always presented at the centre. In experiment 2, the design was similar to experiment 1. The only difference was that the targets were also presented at periphery, always matching the prime location (Prasad et al. 2017)

centre in Experiment 1 and at both centre/periphery in Experiment 2. Both fixed and free trials were preceded by number primes (1 or 2) presented at centre or periphery.

Results of Experiment 1 showed that deaf participants chose the response congruent with the prime more often than hearing participants. Similarly, faster responses on free and fixed trials were observed on congruent trials—that is, trials on which the prime and the target matched. Importantly, this effect was enhanced in the deaf. Thus, higher priming effects were observed in the deaf compared to normal-hearing, in terms of both choices and response times. In Experiment 2, when the prime-target location matched on all trials, higher priming effects in the deaf were observed only at centre, but not at the periphery.

Could the deaf 'see' the primes better? No, and yes. The answer is ambiguous because although we largely did not find differences in prime visibility between the two groups, in Experiment 1 the prime visibility index was significantly higher for the deaf for peripheral primes. This means that deaf were more consciously aware of the primes at the periphery in Experiment 1 compared to normal-hearing. This suggests that there was also a perceptual enhancement of the stimulus representation when presented at the periphery. In sum, we found evidence of modulation of sensorimotor activations (process B) due to the plasticity-related changes in the deaf, in the form of enhanced priming effects in the deaf. The effect on prime visibility (process A) was observed only in a particular case—for peripheral primes in Experiment 1.

It is difficult to draw definitive conclusions based on Prasad et al. (2017) since the primes were not exactly at the perceptual threshold. The sensitivity index of the primes was above chance level. Nonetheless, the findings largely suggest that the visibility of the primes was not greater in the deaf. Thus, deaf were not better at 'seeing' the primes but we still observed that higher priming effects were observed.

Is it possible that the threshold for perception itself is lower for the deaf? Answering this question would require measuring the threshold at which a stimulus becomes invisible to deaf and normal participants and see if there is a difference. Few studies in the past have examined what happens when deaf are presented with stimuli just at the threshold of awareness (Bosworth and Dobkins 1999; Finny and Dobkins 2001). More studies are required to clearly examine which aspect of visual processing is modified in the deaf.

Conclusion

It is important to note that philosophers of mind interested in cognition allow only some type of data into their discussion. However, many long-held paradigms inside psychology are fast changing. Examples are the replication crises and also the inclusion of individual and cultural diversity in experimentation. In such times, it is then important to consider data from different areas to see whether they help us refine higher theories. The rich data from the deaf cast light on critical issues that include perception, awareness, attention and ultimately consciousness. Therefore, we have presented data from experiments that show a very different nature of cognitive organisation in the deaf. Although the deaf live among us and share our world, they may be altogether having a different consciousness?

What are the larger implications of these diverse experimental effects seen in the deaf on visual and attentional tasks? The experimental results that we have described for the deaf have far-reaching consequences for our conceptualisation of important cognitive mechanisms like visual perception, attention and visual awareness. One finds philosophers of mind debating on issues like attention and consciousness when they draw data from patients with visual neglect or from tasks administered with normal college going population. Of course, these data do have a lot to suggest on such controversial issues like the role of attention in consciousness. However, we also need data from neural plasticity on such issues. The deaf data indicates reorganisation of core neural networks that then function differently and aid in behaviour. We have shown that neuroplasticity in the deaf leads to substantial enhancement in several attentional and perceptual capabilities. This enhanced control over attention is central to contemporary theorising about executive control (Posner 2016). The data from subliminal priming experiment suggest that the deaf seem to strongly process stimuli that they cannot even perceive. It is not that neural reorganisation leads the deaf to see better. They do, however, seem to have a broader attentional and visual span. Invisible stimuli in the visual periphery seem to influence how they take decisions for visual actions. However, the different paradigms we have mentioned do not refer to similar mechanisms. One can find also a discrepancy in the experimental literature where the deaf have shown superior performance on some tasks and not on others. It is not of course clear what exactly is altered and modified in the deaf neutrally, the effects of which one can see behaviourally.

The connection to larger issues like awareness attention and consciousness are straight forward in the deaf studies. That is because all these mechanisms are altered differently due to neuroplasticity in the deaf. We know that there is no general agreement in the field if, for example, attention and awareness are related or unrelated processes (Lamme 2003). Some think that awareness and attention diverge as distinct mechanisms from the earliest stages of visual processing (Koivisto et al. 2005). It has also been suggested that one can be attentive without awareness as in the case of blindsight (Kentridge et al. 1999). Evidence from EEG studies has shown that participants can become subjectively aware of stimuli much before they have deployed attention to it. At the beginning of the chapter, we set out to examine whether one expects changes in the interrelationships between attention and consciousness because of neuroplasticity? From the evidence provided in this chapter, the answer to this question is yes. Neuroplasticity in the deaf leads to changes in the dorsal stream functioning. This influences the mechanisms of conscious and unconscious processing in the deaf. Because of extensive sign language practice, these mechanisms further develop in the deaf compared to normal-hearing. Therefore, it is important to consider data from such areas like the deaf when trying to propose theories about the causal nature attention and awareness.

The scientific study of consciousness has progressed to a large extent over the last few decades. Although still controversial, it has developed into a serious topic of empirical research. It has also captured public imagination because understanding what consciousness is and how and why we are conscious is a fundamental question for human beings. One of the foundational issues in consciousness science is the relationship between attention and consciousness. As current debates in the field are fought on hard experimental evidence, the data from hearing impaired individuals will offer a new perspective and contribute to this debate.

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