Cognition 175 (2018) 169–185

Contents lists available at ScienceDirect

Cognition

journal homepage: www.elsevier.com/locate/cognit

Original Articles

Prevailing theories of consciousness are challenged by novel cross-modal associations acquired between subliminal stimuli

Ryan B. Scott[a,c,*], Jason Samaha[d], Ron Chrisley[b,c], Zoltan Dienes[a,c]

[a] School of Psychology, University of Sussex, Brighton BN1 9RH, UK
[b] School of Informatics, University of Sussex, Brighton BN1 9RH, UK
[c] Sackler Centre for Consciousness Science, University of Sussex, Brighton BN1 9RH, UK
[d] Department of Psychology, University of Wisconsin, 1202 West Johnson St, Madison, WI 53706-1611, USA

ARTICLE INFO

Keywords:
Multi-sensory
Cross-modal
Integration
Binding
Consciousness
Unconscious

ABSTRACT

While theories of consciousness differ substantially, the 'conscious access hypothesis', which aligns consciousness with the global accessibility of information across cortical regions, is present in many of the prevailing frameworks. This account holds that consciousness is necessary to integrate information arising from independent functions such as the specialist processing required by different senses. We directly tested this account by evaluating the potential for associative learning between novel pairs of subliminal stimuli presented in different sensory modalities. First, pairs of subliminal stimuli were presented and then their association assessed by examining the ability of the first stimulus to prime classification of the second. In Experiments 1–4 the stimuli were word-pairs consisting of a male name preceding either a creative or uncreative profession. Participants were subliminally exposed to two name-profession pairs where one name was paired with a creative profession and the other an uncreative profession. A supraliminal task followed requiring the timed classification of one of those two professions. The target profession was preceded by either the name with which it had been subliminally paired (concordant) or the alternate name (discordant). Experiment 1 presented stimuli auditorily, Experiment 2 visually, and Experiment 3 presented names auditorily and professions visually. All three experiments revealed the same inverse priming effect with concordant test pairs associated with significantly slower classification judgements. Experiment 4 sought to establish if learning would be more efficient with supraliminal stimuli and found evidence that a different strategy is adopted when stimuli are consciously perceived. Finally, Experiment 5 replicated the unconscious cross-modal association achieved in Experiment 3 utilising non-linguistic stimuli. The results demonstrate the acquisition of novel cross-modal associations between stimuli which are not consciously perceived and thus challenge the global access hypothesis and those theories embracing it.

1. Introduction

The Global Workspace Theory (GWT) introduced by Baars (1988) has arguably been one of the most influential theories of consciousness. Its principle notion of consciousness as the mechanism for providing global access – permitting the integration and sharing of information between functions otherwise operating independently, such as specialist sensory processors – has been especially influential. Indeed, there has been a convergence on this central idea among many of the most active researchers and theorists in the field (e.g. Dehaene et al., 2001; Dehaene, Sergent, & Changeux, 2003; Dennett, 2001; Edelman & Tononi, 2000; Freeman, 2003). Here we present evidence that directly challenges any account that holds consciousness to be necessary for the integration of information arising from different sensory modalities. We reliably demonstrate that new associations can be formed between subliminal stimuli perceived through separate senses.

Progress towards an understanding of the nature of consciousness will undoubtedly bring profound practical, ethical and clinical implications; it is argued by some to be one of the most pressing and important issues in biology (Crick, 1994; Seth, 2010). In keeping with this, the last two decades has seen the study of human consciousness move from an unpopular fringe topic to that of a highly sophisticated mainstream research endeavour. There now exist a number of different theories attempting to reconcile the burgeoning experimental data with models of cognitive and neurophysiological architectures (for reviews see, Dienes & Seth, 2010a, 2010b; Kouider, 2009; Seth, 2007). While

* Corresponding author at: School of Psychology, Pevensey Building, University of Sussex, Falmer BN1 9QH, UK.
E-mail addresses: r.b.scott@sussex.ac.uk (R.B. Scott), jsamaha@wisc.edu (J. Samaha), r.l.chrisley@sussex.ac.uk (R. Chrisley), z.dienes@sussex.ac.uk (Z. Dienes).

https://doi.org/10.1016/j.cognition.2018.02.008
Received 16 March 2017; Received in revised form 7 January 2018; Accepted 8 February 2018

theories differ considerably there is some common ground. The conscious access hypothesis (Baars, 2002), whereby consciousness is aligned with the global accessibility of information across cortical regions, is present in many frameworks though most explicitly articulated in GWT.

The global workspace account holds that the brain comprises a network of specialised processors which operate to support sensory functions, motor control, etc. These are thought to operate largely independently with processing taking place unconsciously. The global workspace, in contrast, is proposed to be widely distributed throughout the brain, primarily through cortical regions, and thus provides a mechanism by which information can be broadcast to disparate functional areas. The separate specialised processes are held to compete for access to the workspace and hence the potential to distribute information globally. By this account, *conscious content* at any given moment is that which resides within the global workspace and is hence globally available.

Support for GWT comes both from successful computational simulations and empirical data revealing global dynamics consistent with conscious experience. A neuronal global workspace theory proposed by Dehaene (Dehaene et al., 2003) incorporates oscillatory behaviour whereby stimulation results in a coherent global pattern of activity, momentarily inhibiting processing of new stimuli. This and other neural network instantiations have successfully simulated phenomena such as the attentional blink, where the second of two rapidly presented stimuli fails to reach conscious awareness (Dehaene et al., 2003; Raffone & Pantani, 2010). The notion that unconscious processing is restricted to local sensory regions while conscious processing activates a global network of cortical areas also enjoys a degree of empirical support. Unconsciously perceived words are found to primarily activate the visual cortex while their conscious equivalents extend to additional parietal and prefrontal regions (Dehaene et al., 2001). Gamma oscillations, hypothesised to be a neural correlate of consciousness (Crick & Koch, 1990; Ward, 2011), reveal a similar pattern with subliminal words eliciting local gamma-band oscillations while consciously perceived words induce long-distance synchronised oscillations across distant regions (Melloni et al., 2007). Functional brain imaging studies reveal significantly lower metabolic activity in cortical regions, particularly frontal and parietal cortex, during coma and general anaesthesia relative to conscious waking states (Baars, Ramsoy, & Laureys, 2003). Other studies demonstrate both increased communication between cortical regions and corresponding increases in metabolic activity while new tasks are consciously acquired, which are then observed to reduce when those tasks become automatic (Baars, 2002; Haier et al., 1992).

A key strength of GWT has been its ability to generate specific testable predictions such as: that '*unconscious input processing is limited to sensory regions*', and that '*consciousness is needed to integrate multiple sensory inputs*' (Baars, 2002 p. 47–48). A reliable demonstration of the integration of unconsciously perceived stimuli from different sensory domains would challenge both predictions and thus provide evidence against GWT, at least in its original formulation, and the global access hypothesis more generally. Importantly, any such demonstration needs to ensure that *neither* stimulus is within conscious contents; were one stimulus to reside within the workspace it could be broadcast to other sensory regions and integration arise from local processing without contradicting the theory. Similarly, it is not sufficient for the process of integration to be unconscious but rather the stimuli themselves must not be consciously perceived. Humans clearly integrate different sensory sources without being conscious of doing so. For example, the McGurk effect where mismatched lip movements and spoken sounds are integrated to create an auditory illusion occurs without our awareness of performing that integration (McGurk & MacDonald, 1976). This does not present a challenge to the global access hypothesis however, as the stimuli are themselves consciously perceived and hence globally available to be integrated. In the current paper where we refer to 'unconscious cross-modal binding' or 'unconscious associative learning', we mean associations which are formed without conscious perception of the stimuli, not simply without conscious awareness of the binding process. Interestingly, in the case of the McGurk effect there is evidence that integration does not occur if the lip movements are presented subliminally (Palmer & Ramsey, 2012).

In principle, integration could be demonstrated either by the re-activation of existing associations or, more impressively, by the acquisition of new associations. While unconscious associative learning has been controversial (Shanks, 2010), a growing number of studies now demonstrate that conditioning (Pessiglione et al., 2008; Raio, Carmel, Carrasco, & Phelps, 2012; Seitz, Kim, & Watanabe, 2009), the formation of simple associations (Duss, Oggier, Reber, & Henke, 2011; Henke, Reber, & Duss, 2013), scene analysis (Tachibana & Noguchi, 2015), and sequence learning can all be achieved where (single modality) stimuli are subliminal. Furthermore, in the case of sequence learning, the sequences can be relatively simple, involving only first-order relations (Atas, Faivre, Timmermans, Cleeremans, & Kouider, 2014), or more complex (Rosenthal, Andrews, Antoniades, Kennard, & Soto, 2016; Rosenthal, Kennard, & Soto, 2010). Cross-modal effects where one of the stimuli is subliminal have been observed in the case of visual motion disambiguation (Dufour, Touzalin, Moessinger, Brochard, & Després, 2008) and cross-modal priming (Lamy, Mudrik, & Deouell, 2008; though see Kouider & Dupoux, 2001). There have been some related cross-modal findings involving olfaction. Olfactory-visual emotion integration based on subthreshold negative olfactory and visual cues has been found to facilitate subthreshold visual perception of negative emotion (Novak, Gitelman, Schuyler, & Li, 2015). And while cross-modal associations between tones and odours have recently been demonstrated during sleep (Arzi et al., 2012), the sleep state does not preclude the existence of conscious contents, which are known to be present both during REM and NREM stages (Tagliazucchi, Behrens, & Laufs, 2013). As such, a rigorous evaluation of unconscious cross-modal cognitive integration in a waking state, where conscious contents can be reliably determined, is of vital theoretical importance (Mudrik, Faivre, & Koch, 2014).

A very recent study provides the first evidence that such unconscious multisensory cognitive integration is indeed possible. Faivre, Mudrik, Schwartz, and Koch (2014), employ a form of congruency priming to demonstrate that auditory and visual representations of the same number or letter can be integrated without awareness. Priming with the simultaneous subliminal presentation of auditory and visual representations of same or different numbers facilitated conscious same-different judgments of simultaneous presentations of same or different letters. While this demonstrates a form of unconscious integration it is limited to the re-activation of pre-existing, consciously acquired associations, namely between the auditory and visual representations of the same concept. Wolf Singer (Singer, 1998) argues that we should distinguish between routine bindings of this sort, where neurons code for a specific combination of sensory inputs, and novel, unanticipated combinations with only those novel bindings potentially dependent on a conscious brain state. Here we sought to evaluate the potential for unconscious cross-modal binding of that latter form by evaluating the potential for associative learning of novel stimulus combinations. Drawing on the strengths of successful uni-modal unconscious associative learning (Duss et al., 2011) and cross-modal priming (Lamy et al., 2008) demonstrations, we devised a novel paradigm intended to permit a sensitive test of associative learning that could be evaluated both within auditory and visual modalities independently, and cross-modally between them.

Failure to observe unconscious cross-modal learning would be uninformative without first demonstrating that equivalent learning can be achieved within each modality independently. Accordingly, we start our investigation with three experiments exploring the unconscious associative learning of word-pairs; first for auditory-auditory pairs (Experiment 1), then for visual-visual pairs (Experiment 2), and finally for auditory-visual pairs (Experiment 3). The approach is the same in