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

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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. S. Dehaene et al., 2001; S. 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, 2010; Kouider, 2009; Seth, 2007). While 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), while still 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 reactivation 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 each case, beginning with establishing the subjective threshold of awareness.

Cheesman and Merikle (1984, 1986) first distinguished between subjective and objective thresholds. The subjective threshold is that level at which participants believe they are performing at chance in making some judgement, for example indicating whether a back-masked stimulus was a word or non-word; the objective threshold is that level at which their responses objectively are at chance performance. Cheesman and Merikle demonstrated that these thresholds were distinct, with some priming effects occurring below the subjective but not the objective threshold. The appeal of subjective thresholds is in part because they directly index phenomenal experience (Jack & Shallice, 2001; Merikle & Daneman, 2000; Merikle et al., 2001). However, the use of subjective thresholds has been criticised on the basis that apparently earnest denials of awareness may reflect low confidence rather than the true absence of awareness (see, e.g. Green & Swets, 1966, pp. 335–337; Holender, 1986; Macmillan, 1986; Merikle, 1982). Hence, some investigators have preferred to investigate subliminal effects at an objective threshold where forced-choice performance is at chance (e.g. Draine & Greenwald, 1998; Naccache & Dehaene, 2001; Snodgrass & Shevrin, 2006).

Even utilising objective methods the relationship between exposure and priming is not always straightforward, with some evidence that it can vary non-monotonically with SOA (Dagenbach, Carr, Wilhelmsen, 1989) and be subject to variations induced by the threshold setting tasks themselves (Carr & Dagenbach, 1990). While there has been substantial evidence for priming below the objective threshold for the most part effects have been smaller, difficult to attain and short lived (e.g. Draine & Greenwald, 1998; Klauer, Eder, Greenwald, & Abrams, 2007, though cf. Van den Bussche, Van den Noortgate, and Reynvoet (2009) who found no significant effect of using objective versus subjective thresholds in a meta-analysis of subliminal priming effects). Evidence that effects are generally weaker below the objective threshold has led to its use in assessing unconscious processing being heavily criticised for testing not just unconscious cognition but degraded unconscious cognition (Dienes, 2004, 2008; Lau & Passingham, 2006). We maintain that, where possible, the choice of threshold should be motivated by theory. In the present research we are seeking to test predictions of the GWT which itself motivates the use of subjective measures. Specifically, GWT holds that a stimulus is conscious if it exists within the global workspace and that anything within the workspace will be widely accessible, including accessible to report. Hence, the subjective threshold optimally identifies the stimulus intensity that falls just below this reportable, and hence conscious level as defined by GWT. The objective threshold would be non-optimal as it would typically require the stimulus to be degraded further than is necessary to remove conscious report, as judged by the theory we are testing. According to GWT, local unconscious processing would allow the discrimination required for a test of the objective threshold. Hence we are constrained to using the subjective threshold in this work precisely because we want to provide the *strongest* test of the conscious access hypothesis; the use of an objective threshold would be to adopt a weaker test that would not permit strong conclusions were learning not to be observed.

We adopt the use of confidence ratings to identify subjective thresholds of awareness, for example taking the absence of any confidence in being able to discriminate words from non-words as indicating the absence of a conscious state of knowing what the words are. While other

subjective measures, such as the perceptual awareness scale (PAS; Ramsøy, & Overgaard, 2004), usefully gauge different types of perceptual experience, where one is seeking to evaluate whether a specific state of knowledge is conscious then a confidence rating paired with an appropriate decision choice is the more suitable approach (Dienes, Scott & Seth, 2010; Dienes & Seth, 2010).

After identifying the relevant subliminal threshold(s), two different name-profession pairs are presented subliminally, one including a creative profession and one an uncreative profession. The test of unconscious associative learning follows immediately after the subliminal presentation; participants are required to perform a speeded classification of one of the two professions which is consciously primed by either the name with which it was subliminally presented (concordant pair) or the alternative (discordant pair). Thus evidence for unconscious associative learning would be provided by a systematic difference in reaction times between concordant and discordant test-pairs. The results of these experiments demonstrate unconscious associative learning both within and between sensory modalities.

Two further experiments were undertaken. Experiment 4 set out to examine the extent to which the associative learning might be more efficient with conscious perception. Experiment 5 sought to establish whether the unconscious cross-modal associative learning achieved in Experiment 3 could be replicated utilising non-linguistic stimuli. Experiment 4 found evidence that the task is approached in a very different way when stimuli are consciously perceived, while Experiment 5 successfully replicated the associative learning observed in Experiment 3 and thus extends our findings to include unconscious cross-modal associations between novel non-linguistic stimuli.

Our results demonstrate associative learning of novel pairs of subliminal stimuli presented in different sensory modalities, initially illustrated for linguistic stimuli and subsequently replicated with non-linguistic stimuli. These results present a challenge to GWT and the prevailing theoretical perspective that holds consciousness to be a requirement for the integration of multiple sensory inputs.

2. Experiment 1

2.1   Rationale

This first experiment sought to test whether the proposed paradigm would reveal unconscious associative learning in the auditory modality.

2.2   Method

2.2.1   Participants

Participants included 60 volunteers (37 female) with a mean age of 24 (SD = 8.95) recruited by direct approach on the University of Sussex campus. Volunteers participated in exchange for confectionary. All participants were native English speakers reporting normal binaural hearing and were naïve to the experimental hypothesis. Ethical approval, for this and the other experiments reported in this manuscript, was granted by the University of Sussex School of Psychology ethics committee and the studies conducted in accordance with the declaration of Helsinki.

2.2.2   Materials

The experiment was implemented in Matlab with the Cogent 2000 toolbox for enhanced timing accuracy and conducted on a laptop computer with a refresh rate of 60 Hz and the screen resolution set to 1024 x 768. All instructions were presented on-screen and the auditory stimuli presented through Dynamode HH-660MV stereo headphones. Auditory word stimuli were all uttered by the same male speaker, recorded at 32 bits and 44.1 kHz, and normalised to have the same peak volume; approximately 66 dBc when played at the native sound file volume. The word stimuli used included the numbers 1-30 together with 10 standard colour words for the auditory threshold finding task, and 16 profession names (8 creative, and 8 non-creative) together with 32 male names for the final test phase. All the words used are listed in Appendix A. The complete set of materials for all five experiments and the corresponding data has been made publically available on the Open Science Framework and can be retrieved from osf.io/4smbx.

2.2.3   Procedure

The study was conducted in a quiet room with the experimenter present at all times. The procedure consisted of four stages with instructions given on-screen.

Stage 1, Threshold identification. The goal of this stage was to identify the auditory threshold below which participants were unable to consciously discern individual words. On each trial participants were played a sequence of eight randomly selected number words between one and thirty with a single colour word inserted at a random position between the 1st and 7th number in the sequence. There was a 10 ms delay between words. The words were played into the right headphone only. Participants were instructed to listen carefully to the stream of words and to use the 'y' or 'n' key to indicate if they had heard a non-number word in the sequence. If they indicated that they had heard a non-number word they were then asked to type it in. The initial volume was that of the native sound file. This volume was then systematically increased on each subsequent trial by a multiple of .0005 times the initial volume until the participant correctly identified a non-number word. Once a non-number word was correctly identified the volume was then systematically decreased on subsequent trials by the same volume multiple until the participant reported being unable to discern the non-number word on six consecutive trials. The volume at which this was achieved was taken to be their initial subliminal threshold.

Stage 2, familiarisation with an attentional task. This stage was designed to familiarise participants with an attentional task which would be employed in the test trials. Two pairs of colour words, embedded in a sequence of number words as in the first stage, would be spoken in the right ear at the subliminal threshold previously identified. Each pair of colour words was made of two randomly selected from the ten colour words listed in Appendix A. Each pair were repeated twice separated by between two and five number words, for example, <2-5 number words> 'red yellow' <2-5 number words> 'red yellow' <2-5 number words> 'blue orange' <2-5 number words> 'blue orange' <2-5 number words>. Each word in the sequence was separated by a 10 ms pause as before. While the subliminal sequence was presented to the right ear a random sequence of the numbers 'one' and 'two', separated by a 300 ms delay, was played to the left ear. These were

played at a supraliminal volume corresponding to a volume multiple of 100 times that identified to be below the auditory threshold; this multiple delivered a comfortable volume easily audible by all participants. Participants were informed that their task was to listen to the sequence of ones and twos spoken in their left ear and to press the left arrow key in response to the number 'one' and the right arrow key in response to the number 'two'. The need for accuracy was emphasised and a dynamic error count showing the number of errors or omissions was displayed on-screen. At the end of each trial participants were asked if they had heard any non-number words. Where any words were accurately identified the presentation volume (the volume intended to be subliminal) was adjusted down by a further .0005 times the initial volume. The program proceeded to the next stage only when the participant had reported being unable to discern a non-number word on six consecutive trials.

Stage 3, familiarisation with the profession categorisation. On-screen instructions provided two lists of professions; eight labelled as 'creative' (relating to art or music) and eight as 'non-creative', see Appendix A. Participants studied the lists before beginning a reaction time task. On each trial, one of the 16 professions was spoken supraliminally through both headphones, at the identified supraliminal volume, with the participant required to indicate whether it was 'creative' or 'non-creative' using the left or right arrow key respectively. The trials included all 16 professions repeated three times in different random orders. The need for both speed and accuracy was emphasised and a dynamic display showed the participant's fastest reaction time so far and the number of errors made.

Stage 4, test stage. Each test-trial consisted of two phases, see Figure 1. In the first phase participants were required to perform the attention task as described in Stage 2 above; responding to the words 'one' and 'two' spoken into the left ear. While performing the attention task two different name-profession pairs were played in the right ear at the identified subliminal threshold. Presentation timings were identical to those used for the pairs of colours words in stage 2. The two pairs always included one name paired with a 'creative' profession and one with a 'non-creative'

profession e.g. 'Mike Pianist' and 'Paul Accountant'. Each pair was repeated twice within a trial. The pairing of professions with the male names was separately randomised for each participant. At the end of the subliminal sequence participants were asked to report whether they had been able to discern any non-number words and if so to enter them. If they identified a non-number word the trial would be excluded from later analysis and the threshold further reduced for subsequent test-trials. The second phase of each test-trial required the participant to classify a supraliminal profession name, as in Stage 3 above. The profession name played would be one of the two profession names included in the immediately preceding subliminal presentation, half of the time this would be the profession from the first name-profession pair and half that from the second. In contrast to Stage 3 however, the profession name was preceded by the supraliminal presentation of one or other of the two male names included in the subliminal presentation followed by a 10 ms delay. Participants were told to ignore the spoken names and focus on classifying the professions quickly and accurately as before. On half of the trials the name would be that which had been subliminally paired with the target profession and on half it would be that which had been paired with the alternate profession; thus, creating concordant and discordant pairs respectively. There were 32 test-trials in total with each profession name as the target on two occasions and each male name serving as prime once.
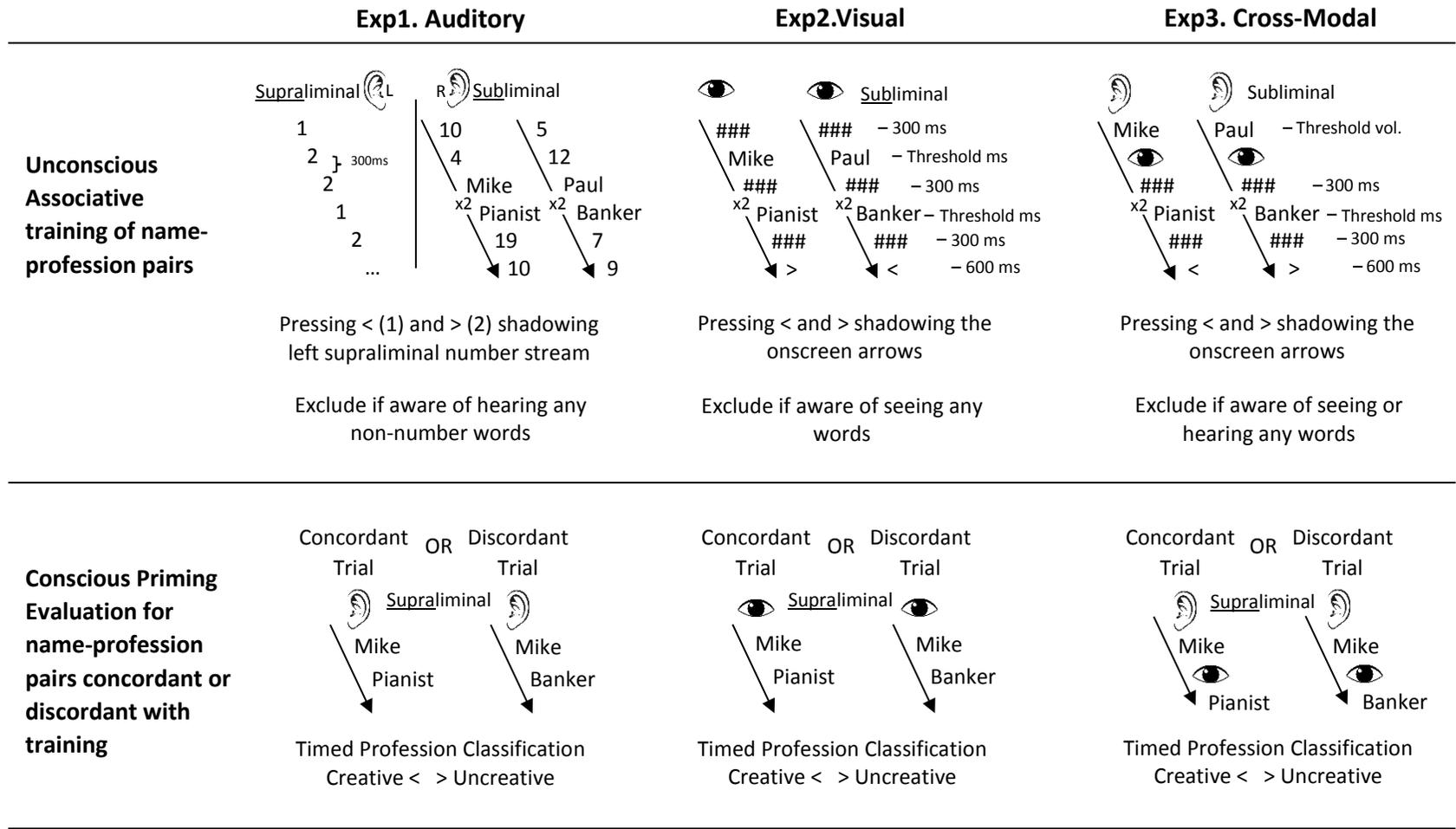
	Exp1. Auditory	**Exp2.Visual**	**Exp3. Cross-Modal**

Unconscious Associative training of name-profession pairs

Exp1. Auditory:
Supraliminal L — R Subliminal
1   10   5
2 } 300ms   4   12
2   Mike   Paul
1   x2 Pianist x2 Banker
2   19   7
…   10   9

Pressing < (1) and > (2) shadowing left supraliminal number stream

Exclude if aware of hearing any non-number words

Exp2.Visual:
Subliminal
— 300 ms
— 300 ms
Mike Paul — Threshold ms
— 300 ms
x2 Pianist x2 Banker — Threshold ms
— 300 ms
> < — 600 ms

Pressing < and > shadowing the onscreen arrows

Exclude if aware of seeing any words

Exp3. Cross-Modal:
Subliminal
Mike Paul — Threshold vol.
— 300 ms
x2 Pianist x2 Banker — Threshold ms
— 300 ms
< > — 600 ms

Pressing < and > shadowing the onscreen arrows

Exclude if aware of seeing or hearing any words

Conscious Priming Evaluation for name-profession pairs concordant or discordant with training

Exp1. Auditory:
Concordant Trial   OR   Discordant Trial
Supraliminal
Mike   Mike
Pianist   Banker

Timed Profession Classification
Creative <   > Uncreative

Exp2.Visual:
Concordant Trial   OR   Discordant Trial
Supraliminal
Mike   Mike
Pianist   Banker

Timed Profession Classification
Creative <   > Uncreative

Exp3. Cross-Modal:
Concordant Trial   OR   Discordant Trial
Supraliminal
Mike   Mike
Pianist   Banker

Timed Profession Classification
Creative <   > Uncreative

Figure 1. Illustration of two-phase test-trail procedure for the three experiment types. Note, Experiments 4 and 5 follow the same format as Experiment 3 but with different stimuli; supraliminal stimuli in Experiment 4 and non-linguistic subliminal stimuli in Experiment 5.

2.3   Results

2.3.1   Bayes factors

For hypothesis testing both p-values and Bayes factors will be reported. A Bayes factor, B, is a continuous measure of strength of evidence for an H1 versus H0 (Wagenmakers et al, in press; Dienes, 2014). While there are no sharp categories in Bayesian, by convention a B greater than about 3 can be taken as substantial evidence for H1 over H0; a B less than about 1/3 as substantial evidence for H0; and a B between 1/3 and 3 as indicating the data are insensitive in distinguishing H1 and H0 (Jeffreys, 1961). The advantage of this convention is that B > 3 and p < .05 will often match when the obtained mean difference is roughly that expected (Dienes, 2014; Jeffreys, 1961); B's can then disambiguate non-significant results as either indicating support for H0 or as indicating insensitive data. A Bayes factor determines how well the data are predicted by H1 relative to H0; thus a rough expected size of effect is needed in order to make predictions. Reber, Luechinger, Boesiger, and Henke (2012) utilized a paradigm similar in that after pairs of words had been presented together, participants were faster to indicate semantic relatedness for previously related rather than unrelated pairs, by about 50 ms. This rough estimate will form the basis of predictions for Experiment 1 (which will provide a better prediction for subsequent experiments). Following Dienes (2014), the predictions of H1 will be modelled as a Normal centred on zero with an SD equal to the rough expected effect size (B will be notated $B_{N(0,SD)}$ to indicate how H1 was specified). As RT's were transformed the expected value will be based on a transformed 50 ms effect around the midpoint of the obtained means.

2.3.2   Pre-processing and exclusion criteria

Note, the following pre-processing and exclusion criteria have been identically applied in all of the experiments. Participants were excluded where they perceived stimuli intended to be subliminal on greater than 25% of trials ($N = 0$), or where their mean difference in reaction times for concordant and discordant pairs was identified as an outlier by the SPSS boxplot function ($N =$

2). Individual trials were excluded where the participant reported detecting (in this case hearing) a word that resembled any word intended to be subliminal on that trial ($M = 0.5\%$, $SD = 1.3\%$), where the profession classification decision was incorrect ($M = 4.7\%$, $SD = 4.4\%$), or where the RT was shorter than 200 ms or greater than 2 SDs from the mean ($M = 4.4\%$, $SD = 2.4\%$). Overall, the mean percentage of excluded trials was 9.4% ($SD = 4.6\%$). As is common for RT data the distribution was non-normal; this was normalised by applying a reciprocal transformation (1 / RT).

2.3.3 Analysis

The mean reaction times for concordant test-trials were longer than those of discordant test-trials, $t(57) = 2.81$, $p = .007$, $dz = 0.37$, $B_{N(0, 8\times10^{-5})} = 6.89$, see Figure 2a. The direction of this difference is consistent with inverse priming or what is more generally termed the negative compatibility effect (NCE; Eimer & Schlaghecken, 1998). This phenomenon is characterised by concordant primes facilitating reaction times relative to discordant primes when the delay between prime and target is short (typically less than 150 ms) and the relationship reversing as the delay becomes longer. While the effect has most commonly been studied in the context of masked priming (Bowman, Schlaghecken, & Eimer, 2006; Krueger, Klapoetke, & Mattler, 2011; Schlaghecken, Bowman, & Eimer, 2006), it has also been demonstrated in the absence of a mask, as is the case for the current paradigm, (Jaskowski, 2008; Machado, Wyatt, Devine, & Knight, 2007; Sumner, 2008). Machado et al. demonstrated that, in the absence of a mask, when the prime preceded the target by greater than a few hundred milliseconds response times were slower when the prime and target were associated with the same response. The effect is attributed to the response to the prime needing to be inhibited during the delay between prime and target and that inhibition needing to be overcome when the same response is subsequently required for the target. The size of the effect observed by Machado et al. (11-19 ms; Exp. 1) is comparable to that observed in the current experiment (14 ms). In the present study the prime (male name) has been associated with either the target profession presented for classification, or an alternate profession requiring the opposite classification. An extended delay between prime and target was unavoidable due to the

nature of auditory stimuli; the spoken names were typically around 600 ms in duration but were uniquely identifiable long before completion e.g. the name Thomas lasts approximately 625 ms but is uniquely identifiable after as little as 200 ms. As a result, the delay between the name prime being identifiable and the onset of the target would be upward of several hundred milliseconds, and hence consistent with timings previously shown to induce the NCE, albeit in a visual rather than auditory paradigm.
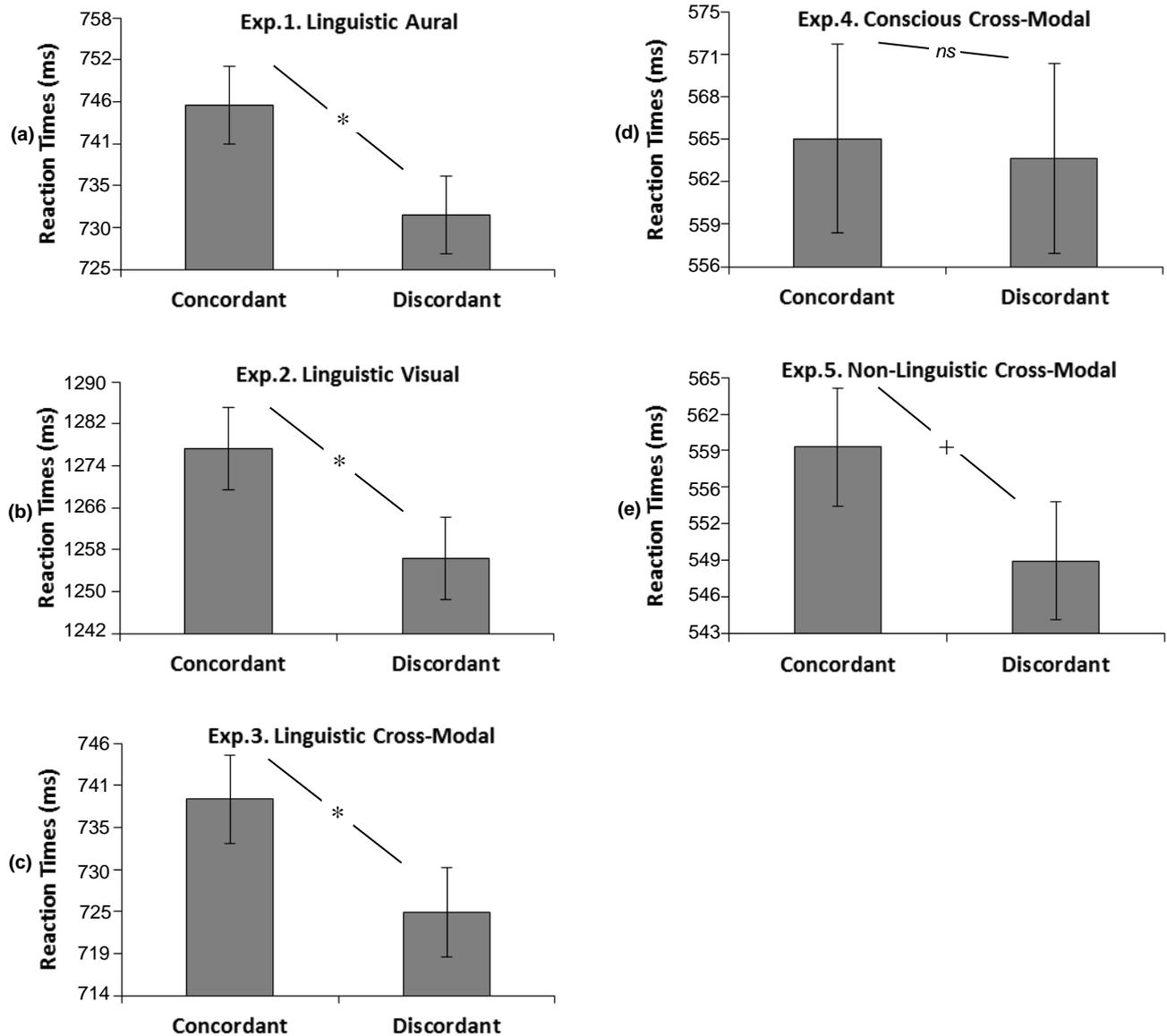
Figure 2. Mean reaction times for classification judgements by trial type and experiment (+/- 1 SEM diff).

Exp. 1, subliminal linguistic aural, $N = 58$; Exp. 2, subliminal linguistic visual, $N = 55$; Exp. 3, subliminal linguistic cross-modal, $N = 60$; Exp. 4, supraliminal linguistic cross-modal, $N = 57$; Exp. 5, subliminal non-linguistic cross-modal, $N = 52$. Note the scale reflects the difference in reciprocally transformed reaction times with the y-axis values converted back to milliseconds.

 * $p < .05$, + $p < .05$ one-tailed

2.4   Conclusion Experiment 1

The reliable difference in reaction times between concordant and discordant test-trials

demonstrates that associations were formed between the names and professions during their

subliminal exposure. Experiment 1 thus demonstrates unconscious associative learning in the auditory domain.

3.   Experiment 2

3.1   Rationale

Having found evidence for unconscious associative learning in the auditory modality, Experiment 2 sought to replicate this in the visual modality. A cross-modal evaluation would only be informative if reliable learning could first be demonstrated in both modalities.

3.2   Method

3.2.1   Participants

Participants included 60 volunteers (41 female) with a mean age of 22 (SD = 4.2) recruited by direct approach on the University of Sussex campus. Volunteers participated in exchange for confectionary. All participants were native English speakers reporting normal or corrected to normal vision and were naïve to the experimental hypothesis.

3.2.2   Materials

Materials were as for Experiment 1 with the following exceptions. Stimuli were presented in written rather than auditory form; Courier New font style, font size 25. The stimuli used for the visual threshold finding task consisted of equal numbers of three-letter words and three-letter non-words generated from random combinations of consonants (excluding 'y'), see Appendix A for word stimuli. During the subliminal presentation words were presented in light grey (0.9 on a black-white scale from 0-1; Luminance 158.8 cd/m^2) on a white background (Luminance 188.1 cd/m^2) and both forward and backward masked by randomly generated black and white block patterns where blocks were 3x3 pixels. The presentation of words in low contrast was a deliberate strategy intended to increase the duration that the stimuli could be presented without conscious perception.

3.2.3   Procedure

The study was conducted in a quiet room with the experimenter present at all times. The procedure consisted of the equivalent four stages followed in Experiment 1 but adapted for the visual modality.

Stage 1, Threshold identification. Each trial consisted of the following sequence of stimuli presented at fixation: a fixation cross (1000 ms), first mask (300 ms), low-contrast word or non-word (initially 600 ms), second mask (300 ms). After each sequence participants were required to indicate whether they thought a word or non-word had been presented and to indicate whether they had 'some confidence' in that judgment, or if it was a 'guess'.   They were instructed to indicate 'some confidence' if they had even the slightest idea and to only respond 'guess' if they genuinely felt they were responding randomly. The display time was reduced each time there was a correct response made with confidence. The reduction was initially 50 ms until a 'guess' response was made or the stimulus duration reached 50 ms, at which point the duration increased to the previous level and subsequently reduced in steps of a single screen refresh (16.67 ms). This process proceeded until the participant indicated guessing on six consecutive trials at the same display duration; that duration was adopted as their initial subliminal threshold.

Stage 2, familiarisation with an attentional task. Each trial consisted of the subliminal presentation of two pairs of colour words, each pair presented twice, with each presentation separated by the supraliminal presentation of a left or right arrow to which participants were required to respond by pressing the corresponding key. Thus a trial would consist of: fixation cross (1000 ms), mask 1 (300 ms), colour word 1 (subliminal threshold duration), mask 2 (300 ms), colour word 2 (subliminal threshold duration), mask 3 (300 ms), left or right arrow (600 ms), repeated twice for two different pairs of colour words i.e. four sequences in total. After the full sequence participants were required to indicate if they had been able to make out a word. If a word was correctly identified the word duration was further reduced by a single screen refresh. The

program proceeded to the next stage only when the full sequence had been completed six times without a colour word being detected.

Stage 3, familiarisation with the profession categorisation. The procedure was identical to that of Experiment 1 with the exception that the professions were presented visually for each categorisation trial rather than verbally. That is, they performed speeded classifications of visual presentations of each profession name as either creative or non-creative. Each of the professions were presented three times in different random orders.

Stage 4, test stage. The procedure for each test-trial included visual equivalents of the same two stages comprising test-trials in Experiment 1. In the first phase participants performed the attention task, as described in Stage 2 above, while two name-profession pairs were presented subliminally (repeated twice). The timing of the presentations was identical to that of the colour word pairs describe in stage 2 namely: fixation cross (1000 ms), mask 1 (300 ms), name (subliminal threshold duration), mask 2 (300 ms), profession (subliminal threshold duration), mask 3 (300 ms), left or right arrow (600 ms), repeated twice for each of the two different name-profession pairs, i.e. four sequences in total. This was again followed by a test of awareness with participants asked to indicate using 'y' or 'n' if they had been able to make out a word. If they indicated perceiving a word the trial was excluded from analysis and the display duration reduced by a further screen refresh (16.67 ms). In the second phase participants had to perform the timed classification of a supraliminal profession name; one of the two which had been subliminally presented. This classification proceeded in the same manner as Stage 3 above with the exception that each profession name was preceded by the supraliminal visual presentation of one of the two male names included in the subliminal presentation; the name was presented for 300 ms in greyscale value 0.9 followed by a blank screen for 200 ms before the profession name started to appear. The profession name was initially presented in very low contrast (greyscale value 0.995, where 1 = white) and faded up to a contrast of 0.9 over a period of 950 ms, with increments occurring on every third screen refresh (50 ms). The delay between prime and target was purposely long with the aim of

creating an effect in the same direction as that which had been observed in the auditory paradigm i.e. inverse priming.

3.3 Results

3.3.1 Pre-processing and exclusion criteria

Participants and trials were excluded according the same criteria as in Experiment 1. Participants were excluded where they perceived stimuli intended to be subliminal on greater than 25% of trials ($N = 3$), or where their mean difference in reaction times for concordant and discordant pairs was identified as an outlier by the SPSS boxplot function ($N = 2$). A total of 5 participants were excluded. Individual trials were excluded where the participant reported detecting (in this case seeing) a word that resembled any word intended to be subliminal on that trial ($M = 4.4\%$, $SD = 5.7\%$), where the profession classification decision was incorrect ($M = 8.4\%$, $SD = 7.0\%$), or where the RT was shorter than 200 ms or greater than 2 SDs from the mean ($M = 5.0\%$, $SD = 2.1\%$). Overall, the mean percentage of excluded trials was 16.8% ($SD = 8.7\%$). The RT data was again subjected to a reciprocal transformation. The representation of H1 for the Bayes factor was based on the effect size from Experiment 1; i.e. a Normal with a mean of zero and an SD set to the transformed mean difference (2.62×10^{-5}).

3.3.2 Analysis

The mean subliminal threshold was 133 ms ($SE = 14$ ms), consistent with our strategy of using low contrast word stimuli with high contrast masks to permit longer exposures without resulting in conscious perception. The mean reaction times for concordant test-trials were longer than those of discordant test-trials, $t(54) = 2.68$, $p = .010$, $dz = 0.36$, $B_{N(0, 2.62 \times 10^{-5})} = 5.86$, see Figure 2b. The direction of the difference was again consistent with inverse priming.

3.4 Conclusion Experiment 2

The unconscious associative learning observed in the auditory modality in Experiment 1 was replicated in the visual modality in Experiment 2.

4.   Experiment 3

4.1   Rationale

Experiments 1 and 2 found reliable evidence for unconscious associative learning in the auditory and visual modalities respectively. Experiment 3 therefore sought to evaluate whether unconscious associative learning could be achieved cross-modally between auditory and visual stimuli. The experimental design was adapted such that names were presented in the auditory modality and professions in the visual modality; any unconscious associative learning would thus require cross-modal binding. Because learning was observed in each modality independently, either the presence or reliable absence of learning in this cross-modal experiment would be informative.

4.2   Method

4.2.1   Participants

Participants included 60 volunteers (34 female) with a mean age of 22 ($SD = 5.6$) recruited by direct approach on the University of Sussex campus. Volunteers participated in exchange for confectionary. All participants were native English speakers reporting both normal or corrected to normal vision and normal binaural hearing. All participants were naïve to the experimental hypothesis.

4.2.2   Materials

Materials were identical to those used in Experiments 1 and 2. The word stimuli used in the test trials consisted of the 32 spoken names as used in Experiment 1 and the 16 visually presented professions as used in Experiment 2.

4.2.3   Procedure

The study was conducted in a quiet room with the experimenter present at all times. The procedure consisted of five stages following the same format as Experiments 1 and 2.

Stage 1, visual threshold identification. This stage established the visual threshold using the same stimuli and procedure as Stage 1 of Experiment 2.

Stage 2, auditory threshold identification. This stage established the auditory threshold using a simplified version of the procedure used in Stage 1 of Experiment 1. The colour words were presented alone rather than embedded in a sequence of number words.

Stage 3, familiarisation with an attentional task. This stage introduced an attentional task of the same form as used in Experiment 2 with one key difference; where in Experiment 2 the pairs of words were presented visually here the first word in each pair was presented auditorily (at the identified subliminal threshold) and the second word presented visually (at the identified subliminal threshold). Thus each trial consisted of the following sequence: Fixation cross (1000 ms), first mask presented while word 1 was spoken (duration of the spoken word, > 600 ms), word 2 visually presented (subliminal threshold duration), second mask (duration of the spoken word), left or right arrow (600 ms), repeated twice for two different pairs of colour words i.e. four sequences in total. After the full sequence, participants were required to indicate if they had either heard or seen a word using the 'y' and 'n' key in each case. If they indicated hearing or seeing a word the corresponding threshold (volume or presentation duration) was adjusted as in Experiments 1 and 2. The program only proceeded to the next stage when the participant had reported being unable to hear or see any words on six consecutive trials.

Stage 4, familiarisation with the profession categorisation. The procedure for familiarising with the profession categorisation task was identical to that of Experiment 2 i.e. professions were presented visually for speeded classification.

Stage 5, test stage. The procedure for each test-trial included a combination of the auditory and visual equivalents of the same two phases used in Experiments 1 and 2. In the first phase participants were required to perform the attention task as described in Stage 3 above. The subliminal stimuli included two different name-profession pairs (one including a creative profession and one an uncreative profession) with the names presented auditorily (at the identified subliminal threshold) and the professions visually (at the identified subliminal threshold); each pair was repeated twice. This was again followed by a test of awareness to ensure that trials were excluded

where stimuli were consciously perceived and permitting the display duration or volume to be further adjusted if necessary. The second phase of each test-trial was identical to that of Experiment 2 with the exception that the name prime occurring prior to the profession was presented auditorily rather than visually and the target profession was not faded up but presented in greyscale 0.9 from the outset.

4.3   Results

4.3.1   Pre-processing and exclusion criteria

Participants and trials were excluded according the same criteria as the previous experiments. Participants were excluded where they perceived (either heard or saw) stimuli intended to be subliminal on greater than 25% of trials ($N = 0$), or where their mean difference in reaction times for concordant and discordant pairs was identified as an outlier using the SPSS boxplot function ($N = 0$). Individual trials were excluded where the participant reported detecting (in this case seeing or hearing) a word that resembled any word intended to be subliminal on that trial ($M = 0.6\%$, $SD = 2.0\%$), where the profession classification decision was incorrect ($M = 8.0\%$, $SD = 7.6\%$), or where the RT was shorter than 200 ms or greater than 2 SDs from the mean ($M = 5.0\%$, $SD = 2.4\%$). Overall, the mean percentage of excluded trials was 13.1% ($SD = 8.4\%$). The RT data was again subjected to a reciprocal transformation. The Bayes factor was calculated in exactly the same way as for Experiment 2.

4.3.2   Analysis

The mean subliminal threshold for the visual stimuli was 178 ms ($SE = 17$ ms), again consistent with the low contrast word stimuli combined with high contrast masks permitting longer exposures without conscious perception. The mean reaction times for concordant test-trials were significantly longer than those of discordant test-trials, $t(59) = 2.56$, $p = .013$, $dz = 0.33$, $B_{N(0, 2.62\times10^{-5})} = 6.27$ see Figure 2c. The direction of the difference was again consistent with inverse priming.

In each of Experiment 1, 2, and 3, test trials were excluded if the participant reported seeing or hearing a word that even remotely resembled any word intended to be subliminal on that trial.

We hold this to be a suitably sensitive approach for excluding cases of conscious awareness, however a still more stringent criterion might exclude any trial where the participant believed that they saw or heard a word irrespective of whether what they reported in any way resembled the subliminal stimulus. Conducting this additional analysis revealed the same pattern of results with a difference in concordant versus discordant reaction times again achieved in all three experiments: Auditory, $t(57) = 2.67$, $p = .010$, $dz = .34$, $B_{N(0, 2.62\times10^{-5})} = 7.93$; Visual, $t(54) = 2.19$, $p = .033$, $dz = .29$, $B_{N(0, 2.62\times10^{-5})} = 2.47$; Cross-Modal, $t(59) = 2.55$, $p = .013$, $dz = .31$, $B_{N(0, 2.62\times10^{-5})} = 6.18$.

4.4   *Conclusion Experiment 3*

The associative learning observed between subliminal stimuli in the auditory and visual modalities independently was replicated where the associated stimuli were presented in alternate modalities. Experiment 3 therefore provides evidence for unconscious associative learning of novel stimulus pairs between auditory and visual modalities.

5.   Experiment 4

5.1   *Rationale*

Experiment 3 demonstrated that subliminal stimuli presented in two different modalities can become associated. The fact that such associations can be achieved without conscious perception raises the question as to what advantage conscious perception provides; specifically, might the associations acquired be stronger than those from unconscious exposure? Experiment 4 sought to evaluate this by replicating Experiment 3 with the crucial change that the stimuli would now be presented supraliminally. For auditory stimuli this was achieved by individually identifying a volume where participants could reliably identify the stimuli. For visual stimuli we sought to keep the duration of exposure approximately equal to the average exposure duration used in Experiments 2 and 3, while achieving conscious perception by adjusting the contrast i.e. presenting the words in black on a white background rather than presenting them in grey as in the previous Experiments.

Our prediction was that under conscious conditions the same direction of effect would be attained i.e. negative priming, but that the size of the effect would be greater due to stronger associations between names and professions.

5.2   Method

5.2.1   Participants

Participants included 60 volunteers (37 female) with a mean age of 23 (*SD* = 3.6) recruited by direct approach on the University of Sussex campus. Volunteers participated in exchange for confectionary. All participants were native English speakers reporting both normal or corrected to normal vision and normal binaural hearing. All participants were naïve to the experimental hypothesis.

5.2.2   Materials

Materials were identical to those used in Experiment 3.

5.2.3   Procedure

The study was conducted in a quiet room with the experimenter present at all times. The procedure was the same as Experiment 3 with the following key exceptions. The visual words were presented in black, rather than grey, on a white background. This was done in an attempt to permit conscious perception while keeping the duration roughly equivalent to the mean duration in the previous subliminal experiments. The two threshold finding stages were adapted to ensure the stimuli were supraliminal rather than subliminal. The visual threshold task started with an initial exposure duration of 150ms and this duration only increased if participants were unable to reliable identify the words. The threshold was considered to have been established once they had accurately reported the words on six consecutive trials at the established duration. The auditory threshold task similarly involved increasing the volume of the words until participants accurately reported them on six consecutive trials at the established volume.

5.3   Results

5.3.1   Pre-processing and exclusion criteria

Unlike the previous Experiments the stimuli were intentionally presented above the conscious threshold and as such there were no exclusions based on their unintended perception. In all other respects the pre-processing and exclusion criteria were applied as before. Participants were excluded where the mean difference in reaction times for concordant and discordant pairs was identified as an outlier using the SPSS boxplot function ($N = 3$). Individual trials were excluded where the profession classification decision was incorrect ($M = 12.5\%$, $SD = 9.3\%$), or where the RT was shorter than 200 ms or greater than 2 SDs from the mean ($M = 5.6\%$, $SD = 3.3\%$). Overall, the mean percentage of excluded trials was 17.3% ($SD = 9.8\%$).

5.3.2   Analysis

The mean exposure time for the visual stimuli was 151 ms ($SE = 0.73$ ms), closely approximating the mean exposure time in the subliminal experiments. In contrast to those experiments however, the mean reaction times for concordant test-trials were not significantly longer than those of discordant test-trials, $t(56) = 0.21$, $p = .833$, $dz = 0.03$, $B_{N(0, 2.62\times10^{-5})} = 0.66$ see Figure 2d. The Bayes Factor of 0.66, being both less than 3 and greater than 1/3rd, indicates that the analysis lacked sensitivity and thus prevents any strong conclusions regarding the failure to observe significant learning.

To explore how the approach to learning may have differed from that adopted with subliminal stimuli we contrasted the reaction times and percentage of classification errors made in the present supraliminal paradigm with those of the equivalent subliminal version (Experiment 3), see Figure 2. The mean classification reaction time in the present study was shorter than that of the subliminal equivalent, $t(115) = 6.40$, $p < .001$, $d = 1.18$, $B_{N(0, 2.62\times10^{-5})} = 18.18$, and a greater percentage of classification errors were made, $t(108.34) = 2.88$, $p = .005$, $d = 0.55$, $B_{N(0, 3.03)} = 9.30$. The larger proportion of errors will have reduced the power to detect an effect in the present study by increasing the number of excluded trials. The combination of shorter reaction times and greater classification errors clearly indicates that participants performed the task differently in the presence of supraliminal versus subliminal stimuli. It seems plausible that participants were attempting to

consciously anticipate the required classification responses based on their knowledge of how the primes had previously been paired with professions; something that was not possible in the subliminal conditions. However, given that precisely half of the targets in the test phase were deliberately discordant with their prime overall such anticipatory responses will have reduced classification accuracy, i.e. producing a speed accuracy trade off.
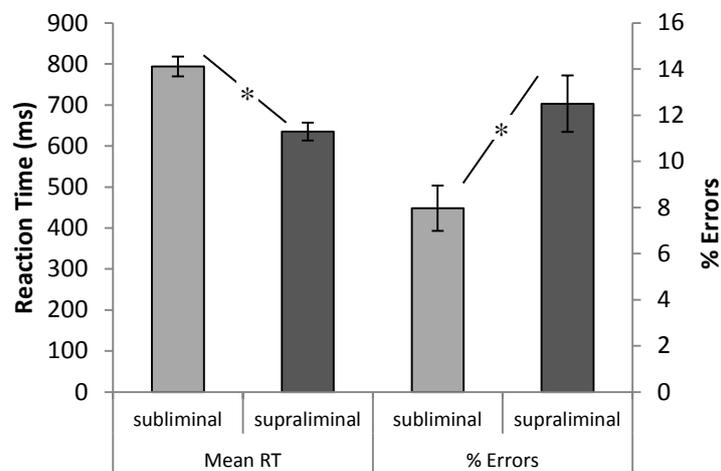
Figure 2. Mean reaction times and percentage of profession classification judgements which were incorrect i.e. creative professions classified as uncreative or vice versa, for the subliminal (Experiment 3) and supraliminal (Experiment 4) cross-modal experiments (+/- 1 SEM). Exp. 3, $N = 60$; Exp. 4, $N = 57$. * $p < .05$.

5.4 Conclusion Experiment 4

Experiment 4 demonstrated that conscious perception of the stimuli changes the approach to performing this task. In the presence of supraliminal stimuli participants responded significantly faster, and made significantly more classification errors. A plausible explanation is that participants were unable to avoid anticipating the classification judgments based on their conscious knowledge of the prior pairing between the names and professions.

6.   **Experiment 5**

6.1   Rationale

The paradigm adopted in the previous experiments utilised word-based stimuli; either written or spoken words.   Words were chosen both for the ease of adapting the same paradigm to auditory and visual modalities, and for the likely strength of verbal concepts.   The stronger a given concept the more readily it can support associations (Anderson, 1983; McLaren & Mackintosh, 2000; Scott & Dienes, 2010), therefore adopting highly familiar words was desirable so as to maximise the likelihood of learning.   However, the use of words does limit the generalizability of our findings.   In educated adults, where reading is a highly practiced skill, written words automatically generate phonetic representations and to a lesser extent spoken words prime visual representations of the written equivalent (Perre, Pattamadilok, Montant, & Ziegler, 2009).   As such, while Experiment 3 demonstrated that new associations can be formed between subliminal stimuli presented in two different modalities this could conceivably be limited to situations where those stimuli have a pre-existing automatically generated representation in the opposing modality. Experiment 5 sought to evaluate this possibility by adapting the paradigm to use non-linguistic stimuli.

6.2   Method

6.2.1   Participants

Participants included 60 volunteers (42 female) with a mean age of 24 ($SD = 6.1$) recruited by direct approach on the University of Sussex campus.   Volunteers participated in exchange for confectionary.   All participants were native English speakers reporting both normal or corrected to normal vision and normal binaural hearing.   All participants were naïve to the experimental hypothesis.

6.2.2   Materials

Sequences of 12 non-alphanumeric symbols took the place of the written professions used in the test phase of the linguistic experiments. Eight of the sequences were asymmetrical e.g. '[[[[ ]]]] – – – –' and eight were symmetrical e.g. '[[[[– – – –]]]]'. All symbols were presented in Courier New font style, font size 25, as was used for the profession names in the previous experiments. Symbol sequences were also employed in the threshold finding task where they were either made up entirely of one symbol e.g. e.g. ']]]]]]]]]]]]' or were made up of two symbols e.g. ']]]]]] + + + + + +'. None of the sequences used in the threshold finding task were used in the test phase.

Auditory sequences of four tones took the place of the spoken names used in the linguistic experiments. The tone frequencies were 220.00 Hz (A3), 246.94 Hz (B3), 261.63 Hz (C4), and 293.66 Hz (D4). Tone sequences consisted of randomly ordered sets of four tones, always including at least two different tones. Tones were 300 ms in duration each separated by a 20 ms silence. None of the tone sequences used in the threshold finding task were used in the test phase. In addition, symmetrical tone sequences were excluded from the test phase.

A full list of the tone sequences and symbol sequences used in both the threshold finding task and the test phase is provided in Appendix B.

6.2.3 Procedure

The procedure consisted of the same five stages as the linguistic equivalent (Experiment 3) with minor alterations due to the change of stimuli.

Stage 1, visual threshold identification. This stage established the visual threshold following the same procedure as Experiment 3 with one minor exception. Rather than being asked whether a word or non-word had been displayed participants were asked whether the sequence of symbols had been made up of one type or two types of symbol. Participants were then asked to report if they had some confidence in that judgment or whether it was a complete guess. If they were accurate in their judgement and reported some confidence then the display duration was shortened following the same procedure as in the previous experiments. As before, their threshold

of awareness was considered to have been found when they reported having no confidence on 6 consecutive trials.

Stage 2, auditory threshold identification. Because the tone sequences are more readily discernible than spoken words the subliminal presentation of tone sequences made use of a white noise mask. The white noise was set at a constant volume (approximately 68 dBc), preceded the tone sequence by 100 ms and continued until 100 ms after the tone sequence had ended. The volume of the tone sequences (native sound file volume of 77 dBc) was adjusted in the same way as in the previous Experiments. Specifically, the volume was first increased on each trial by .0005 times the native sound file volume until the participant was able to confidently report whether the last two tones of a given sequence were the same. On subsequent trials the volume was then systematically reduced by the same multiple on each trial until the participant was unable to report whether the last two tones were the same. Their threshold of awareness was considered to have been found when they reported having no confidence on 6 consecutive trials.

Stage 3, familiarisation with an attentional task. This stage introduced the same attentional task as used in Experiment 3 with minor changes relating to the stimuli. Each trial consisted of two symbol sequence – tone sequence pairs, each repeated twice. One of each pair always included a symmetrical symbol sequence and the other an asymmetrical symbol sequence. The stimuli presentation was as follows: Fixation cross (1000 ms), mask (presented while the tone-sequence was played, duration 1460 ms), symbol sequence (for the subliminal threshold duration), mask (duration 1460 ms), left or right arrow (600 ms), repeated twice for each of the two different pairs. Participants were required to press the arrow key corresponding to the direction of the arrow and error tones were generated for delayed or incorrect responses as before. After the full sequence was complete (each pair had been presented twice) participants were asked to indicate if they had seen any symbol sequences (y/n), and whether they had heard any tone sequences (y/n). If they reported having seen or heard any sequences the display duration or volume was reduced in the same manner as in each of the previous Experiments; no attempt was made to establish the accuracy of their

perceptions. The program only proceeded to the next stage when the participant had reported being unable to see or hear any sequences on six consecutive trials.

Stage 4, familiarisation with the symmetry categorisation. The procedure for familiarising with the symmetry categorisation followed the same procedure as that for the profession categorisation in the previous experiments. On-screen instructions provided two lists of symbol sequences; eight symmetrical and eight asymmetrical, see Appendix B. Participants studied the lists before beginning the reaction time task. On each trial, one of the 16 symbol sequences was presented onscreen with the participant required to indicate whether it was symmetrical or asymmetrical using the left or right arrow key respectively. The trials included all 16 symbol sequences repeated three times in different random orders. The need for both speed and accuracy was again emphasised and a dynamic display showed the participant's fastest reaction time so far and the number of errors made, as before.

Stage 5, test stage. The procedure for each test-trial was identical to that of Experiment 3 with the exception that the auditory names and written professions were replaced with the tone sequences and symbol sequences respectively.

6.3   Results

6.3.1   Pre-processing and exclusion criteria

Participants and trials were excluded according the same criteria as the previous experiments. Participants were excluded where they perceived stimuli intended to be subliminal on greater than 25% of trials ($N = 5$), or where the mean difference in reaction times for concordant and discordant pairs was identified as an outlier using the SPSS boxplot function ($N = 3$). A total of 8 participants were excluded. Individual trials were excluded where the participant reported perceiving (in this case seeing or hearing) any stimuli intended to be subliminal (6.3%), where the classification decision was incorrect (14.7%), or where the RT was shorter than 200 ms or greater than 2 SDs from the mean (4.3%). In total 24.0% of trials were excluded. The RT data was again subjected to a reciprocal transformation.

6.3.2   Analysis

The mean subliminal threshold for the visual stimuli was 64 ms (SE = 4.7 ms). The mean

reaction times for concordant test-trials were longer than those of discordant test-trials, $t(51) = 1.94$,

$p = .029$ (one-tailed), $dz = 0.27$, $B_{N(0, 2.62 \times 10^{-5})} = 2.05$, see Figure 2e. Note that the direction of the

difference in RTs for concordant versus discordant pairs was consistent in all four of the prior

experiments.

6.4   Conclusion Experiment 5

Experiment 5 replicates the unconscious cross-modal binding observed in Experiment 3 and

extends that result to novel pairs of non-linguistic stimuli, thus demonstrating that it is not reliant on

stimuli having a pre-existing automatically generated representation in the opposing modality.

Notably, associations were formed despite the novel stimuli inevitably having weaker individual

representations than the linguistic stimuli used in the previous experiments.

7.   General Discussion

Our results demonstrate associative learning of novel combinations of subliminally presented

stimuli both within the same modality and crucially between two different modalities. The

observed effects were of a comparable size and showed a consistent pattern in each of the four

subliminal experiments. The results of Experiments 1 and 2 replicate previous research findings

showing the acquisition of associations between unconsciously perceived stimuli presented within a

single modality (Atas, et al., 2014; Duss, et al., 2011; Henke, et al., 2013). This was then extended

to cross-modal associations between audition and vision; in Experiment 3 this was demonstrated

with linguistic stimuli and in Experiment 5 it was replicated with non-linguistic stimuli. Experiment

4 found that conscious perception of the stimuli changed participants' approach to the task, with

conscious anticipation seemingly interfering with the accuracy of classification judgements.

In each of the subliminal experiments the time taken to classify a target was significantly longer when preceded by a prime with which it had been subliminally paired than when preceded by a prime that had been paired with a target requiring the opposite classification. This inverse priming, occurring in the absence of masking, is consistent with prior literature exploring the negative compatibility effect, (NCE; Jaskowski, 2008; Machado, et al., 2007; Sumner, 2008). In relation to the NCE, the key differences between our paradigm and that of, for example, Machado et al., is that in the experiments presented here the response associated with the prime was unconsciously acquired, and the prime and target were sometimes presented in different sensory modalities. Both the delay between prime and target and the magnitude of the observed difference in reaction times are, however, directly comparable.

Where the findings of Faivre, Mudrik, Schwartz, and Koch (2014) demonstrate integration through the reactivation of a consciously acquired association, the present results extend this to include the acquisition of new associations. This imposes a strong constraint on theories of consciousness. In particular, our results challenge what we call *integration theories* of consciousness: any theory that is committed to the *Conscious Access Hypothesis* (or CAH; Baars 2002). The CAH can be expressed as the conjunction of the following claims:

1. There are numerous distinct processing areas/brain functions that are normally separate and independent; and

2. Consciousness is required for integration of these areas.

Note that integration theories, as we use the term, assert that consciousness is *necessary* for integration; theories that merely claim that consciousness is *sufficient* for integration are consistent with our findings.

In its strongest, unrestricted form, the CAH denies all informational/functional integration of distinct processing areas in the absence of consciousness. But since there are several senses of the term "integration" relevant to theories of consciousness, there are correspondingly weaker integration theories that only claim the necessity of consciousness for some, but not all, of these

kinds of integration. A recent review (Mudrik, et al., 2014) identifies four claims corresponding to four dimensions along which the CAH may be weakened:

- *Claim 1: consciousness is necessary for long-range but not short-range spatiotemporal integration*

- *Claim 2: consciousness is necessary for high-level but not low-level semantic integration*

- *Claim 3: consciousness is necessary for multisensory integration*

- *Claim 4: consciousness is necessary for novel but not for previously learned integration*

It is worth noting, then, that our results challenge not just the strongest, unrestricted version of the CAH, but also some of the weaker claims just described:

- Claim 2, one could argue, is challenged by experiments 1, 2, 3 and 5, in that they demonstrate unconscious semantic processing that goes beyond mere categorical knowledge by involving conceptual knowledge and associative learning. However, evaluation of this issue requires careful consideration of the high-level vs. low-level semantic processing distinction, which is not our goal here, nor were our experiments designed for this purpose.

- Claim 3, however is clearly challenged by experiments 3 and 5, in that they demonstrate unconscious integration of the auditory and visual modalities.

- Claim 4 is challenged by experiments 1, 2 and 3. Further, experiment 5 challenges Claim 4 using non-linguistic stimuli, specifically to address the concerns of those who suspect that pre-existing associations between auditory and visual representations of words in experiments 1, 2 and 3 might somehow allow an interpretation of what subjects are doing in those experiments that falls short of learning new cross-modal associations.

Global Workspace Theory (Baars 1998; hereafter "GWT") is the paradigmatic example of an integration theory, which should come as no surprise, given that the author of the CAH, in terms of which we are defining integration theories, is also the originator of GWT. According to GWT, perceptual signals are first processed in (and confined to) modality-specific, localised areas of the brain. When signals remain localised, the associated sensations are not perceived consciously. It is only when a signal wins access to the global workspace and is thereby broadcast to a wider network of neurons across much of the cortex that it can be integrated with signals in another modality area. Thus, according to GWT, "consciousness is needed to integrate multiple sensory inputs" (Baars, 2002).

Putting the point another way, according to GWT, processing dependent on the broadcast to a wider network should not occur without conscious awareness. In particular, integration of sensory modalities is dependent on broadcast in this way. Thus, GWT asserts that processing dependent on inputs in more than one sensory modality can only occur if there is conscious awareness of the input in at least one of the involved modalities. It follows that, according to GWT, unconscious cross-modal associative learning should not be possible, a point which does not seem to have been missed by the author of GWT himself, who explicitly claims that unconscious input processing is limited to sensory regions (Baars, 2002).

This way of applying the CAH to cross-modal sensory integration is not unique to Baars. A comparable view is put forward in (Palmer and Ramsey 2012, p 363):

"At least in the domain of multisensory integration, our results suggest a simple yet fundamental principle regarding the function of consciousness – cross-modal effects can occur in the absence of consciousness, but the influencing modality must be consciously perceived for its information to cross modalities."

Indeed, prior to the results presented here, there was no empirical basis for questioning these views; (Mudrik, Faivre & Koch 2014) report that no study to date has observed cross-modal integration in awake subjects (p 493):

"Thus far, it has only been shown that the processing of an invisible stimulus is affected by the processing of congruent and incongruent consciously perceived stimuli in the auditory, tactile, proprioceptive, or olfactory modalities. This, by itself, can be accommodated within the global access hypothesis: information about the supraliminal stimulus spreads to all modules, including the unconsciously activated visual one, enabling its comparison with the invisible stimulus. Thus, only an experiment where both stimuli are unconsciously presented can truly probe unconscious MIW [multisensory integration windows]. Such unconscious integration of tones and odors was reported during sleep, when unconscious association of these stimuli produced behavioral conditioning. However, no study to date has manipulated awareness of multimodal stimuli in awake subjects, where stringent measures of awareness can be obtained."

However, our studies have made precisely this manipulation, and thus question the general integrationist picture expressed by the researchers quoted above.

Rather than leave the issue there, it is worth considering how integration theorists might proceed in the light of our findings. Giving up on the Conscious Access Hypothesis would be a high price to pay for theories such as GWT in which the CAH is central, possibly leading to rejection of GWT itself. Are there alternative responses?

Alternatives could come in one of two forms: either push back, by somehow denying the data presented here or the implications we have drawn from them; or attempt to accommodate our results by modifying the CAH and/or theories based on it, such as GWT.

An example of the former line of response would be to challenge our interpretation of the data by rejecting the subjective criterion for consciousness that our studies employ. Specifically one could

challenge our assumption that lack of reportability implies lack of consciousness. Although this may be a feasible, even attractive possibility for some theorists (e.g., Lamme, 2010), it is not a viable option for GWT. Specifically, the notion of unreportable conscious experience is *prima facie* inconsistent with GWT, since at the heart of that theory is the idea that consciousness implies availability to all modules, including the speech/reporting systems.

We have already blocked another way some might be tempted to set aside the results of Experiment 3: claiming that CAH does not apply because of the linguistic stimuli used. The idea would be that linguistic stimuli constitute a special case, since with linguistic stimuli, there are pre-learned ("routine") associations between the visual and phonetic representations: a kind of multi-sensory integration (Singer 1998; Dehaene 2014). This, it might be proposed, is what gives the appearance of unconscious cross-modal learning of novel associations. But again, such a move is not in the spirit of integration theories such as GWT: "Consciousness is needed to integrate multiple sensory inputs, presumably by mobilizing specialized functions like syntax, semantics, high-level visual knowledge, problem solving and decision making" (Baars 1992, p 48, emphasis added). Nevertheless, we did consider the question worth asking: were the results observed in Experiment 3 limited to linguistic stimuli? Experiment 5 was designed to ask this question, and the answer was "no".

If pushing back on our results is not a viable option for the integration theorist, what about altering integration theories to accommodate our findings? Note that although our experiments demonstrate unconscious multisensory integration, they do not demonstrate unconscious global access. Specifically, the subliminal perceptual information (and learned associations involving that information) cannot be accessed by introspective/reporting systems. Accordingly, it might be tempting for integration theorists to accommodate our results by retaining the connection between consciousness and global accessibility, but allowing that there can be multisensory integration without global access. This seems like a reasonable move, but again it is unclear whether such a change can be made without undermining much of the empirical support that has been offered for

integration theories. Specifically, one GWT empirical strategy is to emphasize the normal independence and isolation of, e.g., sensory modules, and enshrine global broadcast as the sole means of overcoming this encapsulation, so that any evidence of integration would thereby also be evidence of global access and thus consciousness. Another, more serious, problem with the proposed revision to GWT is this: If unconscious "partial broadcast" (sharing information across module boundaries in the absence of consciousness) is possible, what stops unconscious information being shared with the introspection/reporting systems? A virtue of GWT as it stands is that it can give a principled explanation for why consciousness and reportability go hand in hand. Once partial broadcast is permitted, there is no longer an explanation in place for why unconscious items cannot be reported. To work, this line of accommodation would require a substantial addition to GWT as it stands.

Another accommodating approach is to retain an emphasis on integration being central to consciousness, but reject the CAH, the idea that consciousness is required for integration, as the way to capture that centrality. That is, an integration theorist could look for something other than "making integration possible" as the primary role for consciousness. A conservative way of doing this would be to move from the categorical to the probabilistic. Thus, consciousness doesn't make integration "possible", just "more likely".

But if we have to withdraw the integrationist hypotheses that consciousness is primarily about making integration possible or probable, what can we put in their place? One way to move on from integrationist theories as they stand is this hypothesis: consciousness enables information (integrated or not) to be more structured/more flexibly deployed. In particular, it might be that consciousness allows information to be used in a wider range of contexts, or over a longer temporal scale; it might facilitate representations with more sophisticated logical structure, variables, etc.; or it might permit higher-order informational states. None of these are supported by our data, but we mention them here for those wondering where to turn if the integrationist view is abandoned.

We close our discussion with some remarks about method. While previous studies have found evidence for unconscious associative learning within individual modalities even that more straightforward objective has proved challenging. It is therefore worth considering what aspects of the current design may have contributed to its success. We initially exploited linguistic stimuli reasoning that, in keeping with associative theories of perceptual learning (e.g. McLaren & Mackintosh, 2000), the strong individual representations would facilitate the formation of associations between stimuli (Scott & Dienes, 2010). Only in Experiment 5 did we move away from word stimuli, where this was done specifically to evaluate whether our result would generalise beyond linguistic stimuli for which there is a pre-existing automatically generated representation in the opposing modality. All familiar stimuli are typically given a name of some form, so the desire to avoid linguistic tags necessitated the use of novel stimuli. While the expectation was that using novel stimuli would reduce the likelihood of associations being acquired, in the event, the replication proved successful despite the novelty of the stimuli used.

Another important aspect of our design is the trial-by-trial test of awareness; subliminal thresholds were identified for each individual and tested throughout the experiment. We anticipated that taking advantage of individual differences in perceptual thresholds in this way, rather than applying an arbitrarily low threshold to all participants, would maximise the likelihood of unconscious learning. Importantly, the results remained robust even excluding any test trial where a participant thought they had seen or heard a stimulus regardless of their ability to report it. A related feature of the design involved the use of a method previously found to be effective in subliminal word presentation (Armstrong & Dienes, 2013; Lamy, et al., 2008) whereby word stimuli are presented in low contrast. It has been suggested that the capacity of unconscious processing may have been underestimated in back-masking studies as a result of the short exposure durations, typically in the order of 30 ms. In the present study, subliminally presented word stimuli appeared in light grey on a white background preceded and followed by high contrast black and white masks. This low-contrast presentation resulted in a mean subjective threshold of approximately 150 ms,

substantially longer than that typically observed using standard masking procedures. This extended unconscious exposure could feasibly have played an important role in aiding the formation of associations.

Finally, our paradigm purposely sought to minimise the time delay between subliminal exposure to each stimulus pair and testing of that association. Each test-trial included a subliminal exposure phase, where pairs of stimuli were presented, immediately followed by a test of whether an association had been acquired. This contrasts with more typical designs where multiple exposure trials for different stimuli are completed before a sequence of multiple test trials evaluates learning. We anticipate that the short time delay in the present study will have contributed to achieving a sensitive test of learning.

A recent challenge to GWT is the finding that information can be maintained in working memory although presented subliminally (e.g. Soto, Mäntylä, & Silvanto, 2011; King, Pescetelli, and Dehaene, 2016). If working memory is taken to be the global workspace, then the result directly contradicts the claim that a mental content being conscious is the content being in the global workspace. Soto et al. found that when a Gabor patch was rendered subliminal by subjective measures (i.e. a measure of subliminality that would be endorsed by global workspace theory), an accurate discrimination could be made five seconds later. The fact that accurate information was maintained for so long is the evidence for its being in working memory. While intriguing, one can still ask, to what extent do these results really challenge GWT? Stein, Kaiser, & Hesselmann (2016) argued that people could make an initial guess on first being exposed to the subliminal stimulus, and then keep the guess in working memory as a conscious experience (albeit the experience as of a guess). This plausible process would indeed save global workspace theory, because only conscious states need be maintained in the workspace to explain the results, despite the stimulus being genuinely subliminal. On this line, our challenge to GWT presented in this paper remains an important one. It should be noted, however, that the Stein, Kaiser, & Hesselmann line of argumentation is itself under dispute, with both behavioural and neural studies providing evidence

against it (Soto & Silvanto, 2016; Soto, 2017; Trubutschek, Marti, Ojeda, King, Mi, Tsodyks, & Dehaene, 2016). But even if the Stein, Kaiser, & Hesselmann defense of GWT (from the data establishing the working memory maintenance of subliminally presented items) fails, the results of the current paper constitute independent, novel evidence against GWT.

Broadly speaking there are two classes of theories which seek to distinguish between conscious and unconscious content, integration theories and higher order thought (HOT) theories (Seth, Dienes, Cleeremans, Overgaard, & Pessoa, 2008). Integration theories hold that conscious contents are widely available or distributed in the brain and so either directly or indirectly align with the conscious access hypothesis. In contrast, HOT theories hold that a state is conscious when we are aware of being in that state (Carruthers, 2000; Rosenthal, 2005). By this approach conscious contents are determined by the presence or absence of the complementary higher-order content (HOT) rather than global accessibility (Lau & Rosenthal, 2011; Timmermans, Schilbach, Pasquali, & Cleeremans, 2012; Weiskrantz, 1997). In challenging the global access hypothesis our results question the framework adopted in many integration theories but do not directly speak to the validity of HOT theories. HOT theories are free to postulate connections between perceptual representations in different modalities that occur independently of consciousness. Rosenthal (2010) postulates that independently of any mental state being conscious, one is aware of objects by sound by an auditory quality space; and, separately, one is aware of objects by vision with a visual quality space. Yet people can learn to calibrate (or integrate) the spaces in ways that do not require conscious mental states (p 378). What is needed now on the HOT theory side is the development of testable predictions for any constraints on cross-modal unconscious learning.

The present study has demonstrated that novel associations can be formed between unconsciously perceived stimuli presented in different sensory modalities. This finding directly contradicts any account that holds that consciousness is necessary to perform multisensory integration and as such presents a challenge to many of the prevailing theories of consciousness that embrace this key tenet of the global access hypothesis. However, our findings should not be taken

to indicate that consciousness does not play an important role in integration. There are a variety of ways in which consciousness may make critical contributions to the integration process, for example, by permitting associations over greater temporal separation, by integrating in ways that go beyond associating, or in ways that facilitate a range of responses. We look forward to further conjectures about the role of consciousness as testable and strong as the original global access hypothesis.

8.   Acknowledgements

9. References

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Appendix A: Word stimuli employed in Experiments 1-4

Auditory threshold (Experiments 1, 3 & 5)		Visual threshold (Experiments 2, 3 & 5)					Test-phase (Experiments 1, 2, 3 & 5)		
Numbers	*Colours*	*Three letter words*					*Names*	*Creative Professions*	*Uncreative Professions*
One	Red	ace	dad	gum	log	ply	tad	Jack	Artist	Dentist
Two	Green	act	dam	gun	lot	pod	tag	Harry	Pianist	Solicitor
Three	Blue	add	day	gut	low	pop	tan	Alfie	Guitarist	Banker
Four	Yellow	age	den	guy	mad	pot	tap	Joshua	Musician	Accountant
Five	Orange	ago	dew	gym	man	pro	tar	James	Saxophonist	Pilot
Six	Brown	aid	did	had	map	pry	tax	Lewis	Composer	Engineer
Seven	Purple	aim	die	ham	mat	pub	tea	Ryan	Painter	Plumber
Eight	Pink	air	dig	has	max	pun	ten	Dylan	Illustrator	Electrician
Nine	Black	ale	dim	hat	may	pup	the	Joseph		
Ten	White	and	dip	hay	men	put	tie	Jake		
Eleven		ant	dog	hem	mix	rag	tin	Max		
Twelve		any	dot	hen	mob	ram	tip	Tyler		
Thirteen		ape	dry	her	mop	ran	tit	Ben		
Fourteen		are	due	hid	mud	rap	toe	Matthew		
Fifteen		ark	dug	him	mug	rat	ton	Archie		
Sixteen		arm	dye	hip	mum	raw	too	Riley		
Seventeen		art	ear	his	nab	ray	top	Oliver		
Eighteen		ash	eat	hit	nag	red	tot	Charlie		
Nineteen		ask	egg	hoe	nap	rib	tow	Thomas		
Twenty		ate	ego	hog	net	rig	toy	Daniel		
Twenty one		axe	elf	hop	new	rim	try	William		
Twenty two		bad	end	hot	nib	rip	tub	George		
Twenty three		bag	eon	how	nil	rob	tug	Ethan		
Twenty four		ban	era	hug	nip	rot	two	Samuel		
Twenty five		bar	eve	hum	nod	row	urn	Liam		
Twenty six		bat	eye	hut	not	rub	use	Jacob		
Twenty seven		bay	fab	ice	now	rug	van	Callum		
Twenty eight		bed	fad	icy	nub	rum	vat	Luke		
Twenty nine		bee	fag	ink	nun	run	vet	Jayden		
Thirty		beg	fan	inn	nut	rut	wag	Adam		
		bet	far	ion	oak	rye	wan	Alex		
		bid	fat	jab	oar	sad	war	Conner		
		big	fed	jam	oat	sag	was			
		bin	fee	jar	odd	sap	wax			
		bit	fen	jaw	oil	sat	way			
		bow	few	jet	old	saw	web			
		box	fib	job	one	say	wed			
		boy	fig	jog	orb	sea	wee			
		bra	fin	jot	our	set	wet			
		bum	fir	joy	out	sew	who			
		bun	fit	jug	owe	she	why			
		bus	fix	jut	owl	shy	wig			
		but	fly	keg	own	sin	win			
		buy	foe	key	pad	sip	wit			
		bye	fog	kid	pal	sir	woe			
		cab	for	kit	pan	sit	won			
		can	fox	lab	pat	six	wow			
		cap	fry	lad	paw	ski	wry			
		car	fun	lap	pay	sky	yak			
		cat	fur	law	pea	sly	yap			
		con	gap	lay	peg	sob	yes			
		cop	gas	led	pen	sod	yet			
		cow	gay	leg	pet	son	you			
		cox	gel	let	pew	spa	zag			
		coy	gem	lid	pie	sty	zap			
		cry	get	lie	pig	sue	zen			
		cup	gig	lip	pin	sum	zig			
		cut	gin	lit	pip	sun	zip			
		dab	got	lob	pit	tab	zoo			

Appendix B: Non-word stimuli employed in Experiment 5

Auditory threshold		Visual Threshold		Test-Phase		
Final 2 same	*Final 2 diff*	*One Symbol*	*Two Symbols*	*Tones*	*Asymmetrical*	*Symmetrical*
BDCC	ABBA	[[[[[[[[[[[[	[[[[[[******	CADA	[[[[]]]]----	[[[[----]]]]
DBBB	ACCA	]]]]]]]]]]]]	]]]]]]++++++	ABAA	===={{{{}}}}	{{{{===={}}}}
CADD	ADDA	------------	------||||||	ADCC	))))((((****	))))****((((
DDBB	BAAB	============	======######	CCDD	\\\\////^^^^	\\\\^^^^////
ACCC	BCCB	************	******oooooo	CCCB	++++}}}}{{{{	}}}}++++{{{{
ABCC	BDDB	++++++++++++	++++++{{{{{{	CBCD	>>>><<<<||||	>>>>||||<<<<
CACC	CAAC	||||||||||||	||||||}}}}}}	BCBB	####]]]][[[[	]]]]####[[[[
ADAA	CBBC	############	######((((((	BAAC	(((())))oooo	((((oooo))))
BBDD	CDDC	oooooooooooo	oooooo))))))	DCDC		
BCDD	DAAD	{{{{{{{{{{{{	{{{{{{^^^^^^	DBCA		
BAAA	DBBD	}}}}}}}}}}}}	}}}}}}<<<<<<	DBBA		
AACC	DCCD	((((((((((((	((((((>>>>>>	DBAC		
BCCC	DCDB	))))))))))))	))))))\\\\\\	DBDD		
ABDD	CCCA	^^^^^^^^^^^^	^^^^^^//////	CACA		
ABBB	CADB	<<<<<<<<<<<<	<<<<<<[[[[[[	AABC		
ACBB	BCDC	>>>>>>>>>>>>	>>>>>>]]]]]]	DBCC		
ADDD	BDAD	\\\\\\\\\\\\	\\\\\\------	CDCD		
DADD	BDAB	////////////	//////======	BDDD		
ACDD	BBAD	[[[[[[[[[[[[	[[[[[[******	BBCB		
DDCC	CBAB	]]]]]]]]]]]]	]]]]]]++++++	ADCB		
CABB	CBDA	------------	------||||||	CAAA		
CCBB	DCDA	============	======######	BACC		
CBBB	AABA			BCAA		
CBDD	CCDA			BDAC		
BDAA	BACB			AADA		
DACC	ABCB			ADCA		
DCDD	BDCA			ADBC		
CDDD	DABD			DDAA		
CCAA	DCBD			DBDC		
CDCC	BCDA			ADAC		
BBAA	DDBD			DCAB		
BDBB	DADA			BABA		
BADD	CCAB					
ADBB	BADB					
CBCC	CABC					
AABB	CCCD					
CDBB	ADCD					
DCAA	CCBC					
DABB	DACD					
BABB	DDAC					
AADD	ABCA					
DBAA	ACDA					
CBAA	ACBC					
BBCC	BCCD					
ACAA	ADAB					
DCBB	DCCB					
DCCC	BABD					
CDAA	ACAD					
DAAA	BCBC					