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Bridging the gap: Synaesthesia and multisensory processes

1. Introduction

Although the study of multisensory processes and the study of synaesthesia both represent burgeoning fields of inquiry, there has been little attempt to bridge between these two research topics. This is somewhat surprising, as these two are undoubtedly heavily interrelated from both a psychological and neuroscience perspective. The goal of the present issue is explore these interrelationships, and focus on the state-of-the-field within these closely connected research domains.

Synaesthesia is a fascinating phenomenon in which perception of different senses are mixed. For synaesthetes, specific sensory stimuli (automatically) trigger additional perceptual experiences that are not normally perceived by non-synaesthetes (e.g. letters elicit colours or words elicit tastes). Theories about the cause of this condition range from altered pruning and changes in anatomical connectivity to the disinhibition of typical feedback mechanisms common to all of us. The study of synaesthesia by itself has yielded many valuable insights over the past few decades (e.g. Ward, 2013), but a more current question in the field is how synaesthesia relates to other processes such as multisensory integration and crossmodal processing.

The field of multisensory processing is in a period of rapid growth. Although the behavioral and perceptual benefits attributable to having information available from multiple senses has been long known (Welch and Warren, 1980; Sumby and Pollack, 1954), only recently has there been a concerted effort to better understand the psychological phenomena associated with multisensory functions and to link them to their neural correlates (Stein, 2012; Murray and Wallace, 2012). It is now well established that information from each of the senses converges at many sites within the brain, and that the product of this convergence is often a response that looks very different from the sum of the responses to the individual senses. Recent strides within this area have extended our understanding of the neural correlates of multisensory integration from the single cell to more distributed neural representations, have begun to provide evidence on the role of dynamic binding mechanisms in multisensory processing (e.g. Cappe et al., 2009, 2012; Carriere et al., 2008; Maier et al., 2008; Royal et al., 2009; Senkowski et al., 2007) and started to establish strong functional links between neural activity profiles and changes in behavior and perception (e.g. Murray et al., 2016). It is such a context that research into synaesthesia has become a focus for some interested in multisensory processes.

With regard to relating the fields of multisensory processing and synaesthesia, one of the important issues that is being discussed is whether synaesthesia can be regarded as an extreme manifestation of typical sensory integration (e.g. Bien et al., 2012; Cohen Kadosh and Henik, 2007; Martino and Marks, 2001; Ward et al., 2006), or not (Deroy and Spence, 2013). Deroy and Spence (2013) have argued that synaesthetic associations are arbitrary and cannot be equated with crossmodal correspondences, which have their origin in the statistical properties of the world around us (e.g. pitch-brightness correspondences). On the other hand, Martino and Marks (2001) have proposed that intuitively driven associations can be considered as 'weak' synaesthesias (e.g. metaphors in language), whereas more perceptual experiences (e.g. pain that elicits colour) could be regarded as 'strong' synaesthesia. This latter view suggests that 'strong' synaesthesia lies on a continuum with crossmodal correspondences, which are present also in non-synaesthetes (e.g. Rouw et al., 2014; Van Leeuwen et al., 2016), and therefore implies that synaesthesia is merely an extreme form of typical multisensory processes. Several papers in the current issue touch upon the question whether this is indeed the case. A schematic of both accounts is given in Fig. 1.

Other studies that have already bridged the gap between multisensory processing and synaesthesia have investigated multisensory processing *in synaesthetes*. Are synaesthetes extreme sensory integrators? Indeed, several studies have found evidence for enhanced crossmodal processing in synaesthetes in tasks unrelated to their synaesthesia (Brang et al., 2012; Lockwood et al., 2016). Others, however, have observed no difference or worse performance in synaesthetes compared to nonsynaesthetes (Neufeld et al., 2012; Sinke et al., 2012b; Whittingham et al., 2014). Possible factors to explain the discrepancies between studies are the ages of the participants or the type of synaesthesia under investigation, but more research is definitely warranted in this field.

Although the studies mentioned above are clear examples of research that bridges the gap between multisensory processing and synaesthesia, the main topics in the multisensory and synaesthesia research fields remain quite separate. We believe that the overlap in interests and possible anatomical and functional substrates calls for more integration between the two research fields. For instance, one could think of systematic comparisons between possible forms of synaesthesia and tendencies in crossmodal integration. Questions of interest include: 1) whether those associations that also manifest as synaesthesia are actually more intuitive crossmodal associations for nonsynaesthetes than those who do not manifest as synaesthesia? 2) what do synaesthetic associations suggest about typical sensory integration mechanisms? 3) does multisensory integration transpire in a different way in synaesthetes? 4) are the same brain areas implicated in integration of the concurrent experience with the inducer in synaesthesia and in similar multisensory combinations in non-

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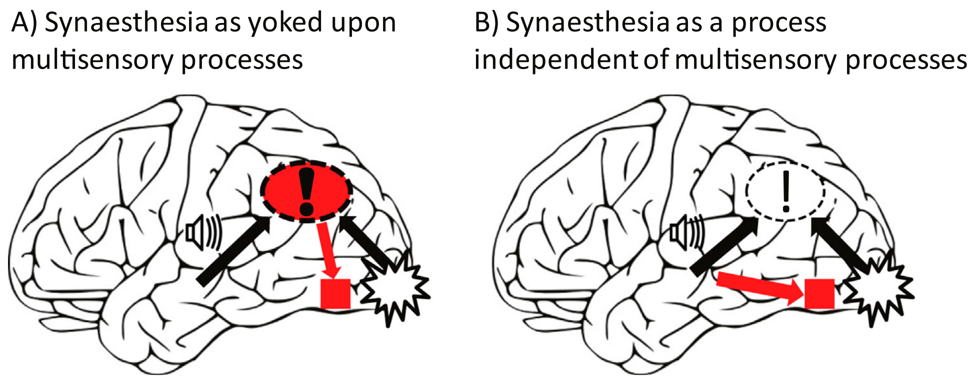

Fig. 1. Does synaesthesia belong on a continuum with multisensory processes? If so (A), synaesthetic experiences (in red) might be superimposed on multisensory pathways and convergence zones. Moreover, multisensory processes in synaesthetes might be stronger than in non-synaesthetes. By contrast, if synaesthesia is independent of multisensory processes (B), inducer-concurrent relationships in synaesthesia can be accessed via distinct pathways/representations. We would note that extrema are represented here and that these possible mechanisms need not be mutually exclusive.

synaesthetes? We reasoned that by learning about the work from both the synaesthesia and multisensory fields, it would be easier for researchers from the two fields to connect with each other and that this would promote collaborations on mutual interests.

With this in mind, a symposium “Synaesthesia in Perspective: Development, Networks, and Multisensory Processing” was organized that took place in Hamburg, Germany on February 28 and March 1, 2014. The meeting sought to present synaesthesia in a wider perspective, bringing together researchers from the field of multisensory processing and the field of synaesthesia. It was organized by Tessa van Leeuwen, Sina Trautmann-Lengsfeld, Peter König (University of Osnabrück, Germany), Jianwei Zhang (University of Hamburg, Germany) and Andreas Engel. The symposium took place at the Department of Neurophysiology and Pathophysiology of the University Medical Centre Hamburg-Eppendorf. It was funded by grants from the German Research Foundation (DFG Collaborative Research Centre SFB 936 “Multi-site communication in the brain” and DFG International Graduate Research Group GRK 1247 “Cross-modal interaction in natural and artificial cognitive systems”) and by the European Research Council (ERC Advanced Investigator Grant ERC-2010-AdG-269716 MULTISENSE “The merging of the senses: understanding multisensory experience”).

The current Special Issue in *Neuropsychologia* entitled “Bridging the Gap: Synaesthesia and Multisensory Processes” is a follow-up to this highly successful symposium and is meant as a means by which researchers from both fields of study can become acquainted with each other's work. We have collected papers from a wide variety of contributors and there is a lot of breadth in the topics that are being discussed. We envision that this issue will inspire new work that can build on mutual interests. We briefly introduce each paper below.

2. The issue

In the first section of the issue, we focus on synaesthesia. Gould van Praag et al. (2016) show that synaesthetic phenomenology, namely the phenomenological localisation and automaticity of synaesthetic concurrents, is related to activity in colour areas in the brain. The paper is complemented by the contribution from Colizoli et al. (2016) in which non-synaesthetes were trained to associate letters with colours by reading books with coloured letters. Colizoli et al. show that activity within area V4 after training correlates with the subjective appearance of the trained colour associations. This is comparable to the findings by Gould et al. but is now demonstrated in non-synaesthetes. Despite the different approaches, both papers stress the importance of phenomenological individual differences for the neural correlates of (synaesthetic) perception, and highlight that in both synaesthetes and non-synaesthetes crossmodal associations may be based on similar brain mechanisms.

Synaesthesia-like experiences have been previously reported during the use of the psychedelic drug LSD (Luke and Terhune, 2013; Sinke et al., 2012a), which has prompted researchers to suggest that no special anatomical connections are necessary to elicit synaesthesia (e.g. Grossenbacher and Lovelace, 2001), i.e., that we are all synaesthetes in a way. However, a systematic placebo-controlled study of synaesthetic experiences under the influence of LSD was missing until now. Here, Terhune et al. (2016) find that people do report more synaesthesia-like experiences when under the influence of LSD compared to placebo, but that these experiences lack the consistency and specificity that set synaesthesia apart from hallucinations.

In the paper by Rouw and Scholte (2016), synaesthesia is described as a phenomenon that gives rise to specific personality traits and cognitive characteristics. Analyzing together synaesthetes with different forms of synaesthesia, Rouw and Scholte focus on general synaesthete characteristics and conclude that synaesthetes are special as a group.

In the contribution by Deroy and Spence (2016) it is specifically addressed whether conscious experiences in synaesthesia and non-synaesthetes lie on a continuum, or not. The authors conclude that synaesthetic experiences are not continuous with typical conscious experiences, making the case that synaesthesia and crossmodal correspondences in the non-synaesthete population should be regarded as separate phenomena.

After the focus on synaesthesia we turn to multisensory processing. Slocombe et al. (2016) explore the multisensory nature of food-tasting by assessing the influence of visual and tactile cues on the taste of foodstuffs. Finding those crossmodal influences, they state that their findings are in line with the view that cross-modal associations in non-synaesthetes share underlying mechanisms with synaesthesia. This is opposite to the view of Deroy and Spence (2016), where synaesthetes and non-synaesthetes are explicitly regarded as separate populations. Systematically performing multisensory studies such as the one by Slocombe et al. that tune in on synaesthesia-like experiences may help to clarify this issue.

Another crossmodal task that speaks to synaesthetic associations in this respect is the pitch-size correspondence task reported by Krugliak and Noppeney (2016), which was completed by non-synaesthetes. Systematic pitch-brightness and magnitude-brightness correspondences have also been reported to be present in synaesthetic associations, e.g. in music-colour and digit-colour synaesthesia (Cohen Kadosh et al., 2007; Ward et al., 2006). For pitch-size this is not (yet) the case, although it is a common crossmodal correspondence in non-synaesthetes.

Hillock-Dunn et al. (2016) discuss the effects of age on the McGurk effect and the temporal binding window within which this illusion can occur. They report the width of the binding window is not constrained by age (although the number of illusion percepts does differ). This is a particularly interesting finding since age is an important factor in multisensory integration processes; a finding also reported for multisensory integration in synaesthetes (e.g. Neufeld et al., 2012; Whittingham et al., 2014). It is important to study the development of multisensory processes in order to understand crucial steps in establishing proper multisensory integration. Do synaesthetes follow the same developmental trajectory as non-synaesthetes?

The manuscripts from Krueger Fister et al. (2016) and from Nidiffer et al. (2016) focus on the so-called principles of multisensory integration, and illustrate the strong interdependencies that take place across the dimensions of space, time, and effectiveness in dictating how human subjects -respond to various multisensory combinations. Building off of this, the contribution from Retsa et al. (2016) highlights the presence of a compensatory mechanism for estimating stimulus duration under cross-modal circumstances, and suggest that this effect is the result of shifts in spatial attention. Further examination of the interactions between attention and multisensory processing are described in the contribution from Misselhorn et al. (2016) who have developed a unique cross-modal matching paradigm across the senses of vision, hearing and touch. This work shows a differing pattern of performance benefits (and decrements) that depend upon modality, attentional allocation and stimulus congruence. Collectively, this section of the issue that focuses on multisensory interactions has important implications for both the design and interpretation of synaesthesia experiments, in particular in better elucidating the spatiotemporal architecture of multisensory interactions and the interplay between low-level (i.e., sensory statistics) and higher-level (e.g., attentional, contextual) factors in influencing human performance and perception.

Multisensory integration can be especially beneficial for weak stimuli that would otherwise – in a unisensory channel only – not be perceived. Regenbogen et al. (2016) demonstrate super-additive multisensory integration for peri-threshold stimuli using a model that combines reaction time and accuracy. Here we can raise the question whether synaesthetes would benefit in a similar way from the sub-threshold multisensory cues, or whether they have an advantage or disadvantage. If synaesthetes' multisensory detection thresholds are lower, perhaps this can be a mechanism by which synaesthesia comes about?

Salomon et al. (2016) discuss how body-related tactile input can influence conscious visual experiences. This can be regarded as an artificial form of synaesthesia where touch enhances the visual experience.

We conclude our issue with the contribution from Newell and Mitchell (2016). The authors propose a model for the origin of synaesthetic associations that reconciles connectivity and innate ability models of synaesthesia with the influence of learning and crossmodal statistical regularities in the world around us. Although the authors acknowledge that innate connectivity plays a role in synaesthesia, they furthermore propose that innate biases in synaesthetic associations can, during development, be influenced by the environment and top-down information. Regarded in this way, the specific synaesthetic associations of each synaesthete are the result of a dynamic, lifelong shaping and learning process. This model provides an explanation for the common finding that synaesthetic associations adhere to crossmodal biases that are present in nonsynaesthetes as well, while clearly maintaining that synaesthetes are innately different from nonsynaesthetes.

To conclude, the diversity of topics and approaches in this issue provide many opportunities for researchers to become acquainted with current trends in both multisensory and synaesthesia research. We hoped to inspire new research built on mutual interests between the two fields. Overall conclusions that can be drawn from the issue are the synaesthetes are likely 'special', but that they are nonetheless also subject to crossmodal associations that are common to all of us. Whether synaesthetes are integrating information from different senses in a completely different way (unrelated to their synaesthesia) remains to be explored. Specific forms of synaesthesia may also inspire new multisensory research. For the future, the model that is proposed by Newell and Mitchell may provide a testable framework for research on the boundaries of multisensory integration and synaesthesia.

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