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Synaesthesia quotient: operationalising an individual index of phenotypic expressivity of developmental synaesthesia

Abstract. The primary purpose of our current study is to develop a novel self-administered or/and interviewer-assisted instrument rating an individual degree of phenotypic expressivity of synaesthesia. A measurement index of such a degree is conceptualised as *Synaesthesia Quotient* (SynQ). This article will detail the initial stage of the scale development; i.e., conceptualisation, domains identification, item generation, and identification of rating values of the proposed scale. Ten preliminary domains are determined and related items are generated on the basis of empirical data from synaesthesia literature review, extant measures, and external neuroscientific results. Further work is underway to perform judgment-based item expansion (or reduction) informed by expert opinion and to assess the validity and reliability of the Synaesthesia Quotient inventory (SynQ-i). This paper is also intended to solicit post-publication feedback and generate specialist discussion.

Keywords: synaesthesia; Synaesthesia Quotient; individual degree of expressivity; measure scale; self-rating inventory.

Introduction

Implicit in the definitions and terminology in today's synaesthesia research are many premises regarding the *degree of manifestation* of the condition. Scientific literature is replete with notions and descriptions that, this way or another, emphasise varying *quantitative characteristics* of individual cases of developmental synaesthesia. Indeed, such characteristics of the phenomenon as *higher* and *lower* (Ramachandran and Hubbard 2001), *strong* and *weak* (Martino and Marks 2001) as well as *multiple* (e.g., Cytowic 2002; Day 2005) and even "*superior*" (Simner 2013) phrased in current scientific contemplations tacitly impart the idea of a certain measurability of synaesthesia across its individual cases. These widespread but non-conventionalised, assumptive aspects in the vernacular of neuroscience presuppose that not all synaesthetic brains are characterised by the same extent of synaesthetic manifestation. On the other hand, reported cases can be analysed as being highly distinct in the attributed number of inducer categories, degree of subjective intensity and prominence, test-retest consistency scores, proneness to age-dependent diminution and attrition, etc. (cf. Cytowic 2002; Dixon et al. 2004; Cytowic and Eagleman 2009; Simner 2012). As is clear, the specified propensities are not so much related to the qualitative aspects of experiential content in individual cases of the condition. Rather, due to the fact that most cases can be revealed to manifest synaesthesia to a varying extent, such manifestations can be characterised as *quantitatively* different.

However, to date no special methods of quantification of the expressivity of synaesthesia have yet been conceptualised or constructed within an explicit and empirical framework. As the capability of measuring a construct serves as a solid foundation to explore its empirical correlates and reveal its relation to other phenomena, a lack of psychometrically sound measures of synaesthesia might be a primary obstacle to a more profound understanding of the condition. In this paper, it is proposed that some previously identified content-neutral aspects can be methodologically explicated as a notion of *phenotypic* expressivity with its measurement index, *Synaesthesia Quotient*, abbreviated as *SynQ*. The latter can be understood as a cumulative sum of measurable values attributed to these aspects. Moreover, conceptualisation and operationalisation of SynQ will be additionally reinforced by revealing other content-neutral aspects derived from some objective results of neuroscientific studies (see also Sidoroff-Dorso 2012). As will be shown, owing to the fact that the field of synaesthesia research is developed unevenly and not all the aspects have been quantified, determined or even clearly identified, the foundations for SynQ scales are best derived from various empirical sources.

This paper will concentrate on how some data of neuroscientific research both general and synaesthesia-focussed can be exploited for constructing a *Synaesthesia Quotient Inventory*. We will describe the initial stage of designing the Synaesthesia Quotient Inventory (SynQ-i), a self-administered or/and interview-based rating measure of phenotypic expressivity of synaesthesia. We will outline the method and report the outcomes of *domain identification*, as well as *item and rating value determination* for the SynQ measurement instrument (as per *Standards 1.1, 1.4, 3.2, 3.6, 3.9, 3.11* in AERA, APA, NCME 1999; cf. Downing and Haladyna 2006; DeVellis 2003; Irvin and Kyllonen 2002).

In synaesthesia research, a plethora of expert and self-administered (online and paper-based) tests, questionnaires and interview scenarios has been developed and widely used for several purposes. The first group of assessment tools is *consistency*/genuineness tests (Asher et al. 2006; Eagleman et al. 2007; Baron-Cohen et al. 1993; Rothen and Meier 2010; Simner et al. 2009; Simner et al. 2006). Typically, such assessment is carried out on a test-retest basis whose sessions are spread in time with the repeat trial(s) completed without prior notification. The criteria in genuineness tests are precision and promptness of concurrent-related reactions within a single or across multiple sessions. Besides psychophysical measurements, questionnaires and interviews have also been applied to verify authenticity and consistency of the condition. Another type of experimental procedure is the one that strives to expose the structural and functional distinctions of the neuronal substrate, phenomenological differences and behavioural response patterns inherent in the phenomenon of synaesthesia and its multifarious varieties (e.g., Banissy and Ward 2007; Rouw and Scholte 2007; Skelton et al. 2009). A third type of subjective reports and objective tests might be called *contingency tests*, as they are targeted at revealing regular connections between synaesthesia and other psychological, neurophysiological and personality traits. Along the latter two lines of research, many experimental paradigms and self-report inventories have been borrowed from other major domains of neuroscientific research such as investigations into memory, attention, imagery, creativity, ability, etc. (e.g., Yaro and Ward 2007; Domino 1989; Barnett and Newell 2008; Glicksohn et al. 1999).

The Synaesthesia Quotient Inventory is a different type of assessment. The Synaesthesia Quotient inventory is an instrument that is designed to rate an individual degree of phenotypic expressivity of synaesthesia and sum it up as a measurement index conceptualised as *Synaesthesia Quotient*. It is to complement other inventories that are currently in use and, when and if required, capitalise on their results both for its construction/development and reliability/validation. On that account, the SynQ measurement tool is intended to be administered in alignment with or subsequent to other instruments that are validated and well-established to verify genuineness of someone's synaesthesia such as the TOG-R (Asher et al. 2006) or the Eagleman Lab Synaesthesia test (Eagleman et al. 2007).

Although a fully-fledged, validated paradigm is yet to be constructed, it will be demonstrated here that, at present, measurable SynQ-related cross-type invariants are analytically available and experimental techniques are feasible to give grounds for a sufficiently rigorous *Synaesthesia Quotient Inventory*. Investigation-wise, SynQ might be instrumental in establishing a framework with a view to revealing regularities between the degree of expressivity of developmental synaesthesia in an individual case and, for instance, peculiarities of the underlying brain structure, hypothetically co-occurring neurocognitive conditions (hypercalculia, dyslexia, autism, etc.) and psychological traits such as creative abilities, facilitation of memory and mental imagery, and other cognitive differences. In this regard, the proposed concept of *Synaesthesia Quotient* and the related measure scales can prove applicable in gaining a more systematic and predictive perspective on synaesthesia.

Conceptual framework for the Synaesthesia Quotient Inventory

Developmental synaesthesia can be defined as a statistically atypical but non-pathological condition in which perceiving or merely thinking of *a category-based* or, on a continuum of perceptual categorisation, *category-embedded entity* (a sensory standard, letter or speech sound, number, name of a person or place, etc.) triggers on a consistent, automatic and involuntary basis and,following the principle of supervenience, an additional, perception-like property (colour, taste, etc.) of endogenous, consciously impenetrable origin. For instance, hearing or aurally imaging somebody's name (or seeing or recalling his or her countenance) irresistibly and irrevocably makes a synaesthete experience a certain colour. Among 60-150 types of synaesthesia reported in scientific literature, the most frequent stimuli (called *inducers*) are graphemes, time units and music, while synaesthetic reactions (coined as *concurrents*) can include colours and colour patterns, haptic effects, spatial localisations, etc. (cf. Ward 2013; Day 2013; Simner

2012; Cytowic and Eagleman 2009; Hubbard and Ramachandran 2005; Grossenbacher and Lovelace 2001; Cytowic 1997).

Synaesthesia has been revealed to run in families, and there is solid evidence for a genetic component of synaesthesia as several genetic markers have been identified to be responsible for at least an initial neurobiological impetus for evincing the condition (Asher et al. 2009; Thompson et al. 2011). However, it was found out that, though being inherited, it is not the specific types of synaesthesia that appear to be passed on from generation to generation, which can be mutable and deferring to a varying extent between twins, siblings, and parent and child (e.g., Baron Cohen et al. 1996; Smilek et al. 2002; Barnett et al. 2008; Ward and Simner 2005).

Expressivity is a notion that implies the extent to which a genotype exhibits its phenotypic expression at the level of an individual. Individuals with the same genotype can show substantial differences in many aspects of their related phenotypes. A particular inherited trait is expressed to a different degree among individuals with the same genotype, which is described as *variable expressivity*. For example, individuals with the same allele for a gene responsible for a quantitative trait like body height can have large variance. At large, the degree to which a genotype is phenotypically expressed in individuals is measurable (e.g., Griffiths et al. 2000; Cummings 2010). For the purposes of this paper, *phenotypic expressivity of synaesthesia* is defined as the degree to which phenotypic expression of the condition of synaesthesia differs from individual to individual. Accordingly, synaesthetes with the same genotype can be considered to have measurably different degrees of the synaesthetic phenotype.

In this regard, *Synaesthesia Quotient* can be defined as an index of the quantitatively conceived degree of overall expressivity of synaesthesia in an individual case. Currently, SynQ is an operational construct substantiated by the data presented in scientific literature. The index is being constructed as capable of being identified along the reciprocally reinforcing lines of experiential (phenomenological), psychophysical (behavioural) and neurophysiological studies. A Synaesthesia Quotient of an individual case is supposed to be expressed as both a numerical indicator that will define its absolute position according to a *norm-referenced score interpretation* and/or a verbal ratio-scale descriptor with a view of placing each case on the spectrum between the low (through average) and high-level extrema of synaesthetic manifestation.

As is the case with other constructs in extensively used measurement tools (such as IQ or EQ), one of the key issues to be addressed at the initial stage of scale construction will be the scope or generality of the target construct (cf. Downing and Haladyna 2006; DeVellis 2003; Irvin and Kyllonen 2002). Regarding the issue of homogeneity or heterogeneity of the phenomenon of synaesthesia and, therefore, inclusion/exclusion of some of its types, all the solutions favouring the latter characterisation have been based on either first-person reports or theory-laden models that have been guiding empirical research of individual types grouped exclusively on the "content" of their inducer/concurrent pairings. However, no objective criteria have been proposed as to how to separate varieties of synaesthesia described as different primarily on account of subjective experience. To complicate matters, even in subjective descriptions it might sometimes be very difficult to draw a definitive line across types and, more importantly, within (taken to be) the same type of synaesthesia. Indeed, psychoactive substances, for instance, can expand someone's developmental synaesthesia onto other (categories of) inducers (Brang and Ramachandran 2008). The same has been demonstrated to be a result of short-term training (Mroczko 2009; Sidoroff-Dorso 2010). Additionally, heightened arousal can sometimes make music and sound-based types less distinct, while long-term moods can expand emotion-triggering types into "auric" varieties ("seeing" people in colour), etc. On the other hand, comparative data derived from the genetic and behavioural studies demonstrate that synaesthesia can be inherited as different types or some synaesthetes can develop or lose this or that type of experience (e.g., Baron Cohen et al. 1996; Bailey and Johnson 1997; Cytowic 2002; Ward and Simner 2005; Barnett et al. 2008; Simner 2012). It has also been demonstrated that clusterisation of synaesthetic manifestations informed by factor analysis (Novich et al. 2012) is not necessarily genetics-driven and is highly likely to be mediated through environmental influences (Sidoroff-Dorso 2012). These facts might suggest some resolution or at least alleviation of the dilemma of homogenous/heterogeneous characterisation of synaesthesia as an objectively identifiable aspect (for other issues in defining and quantifying synaesthesia see the *Discussion* section below).

Taking into consideration a crucial part that synaesthetes' self-reports play in informing preparation and implementation of experimental studies, the condition itself and its epistemic status in neurosciences entails a particularly articulated manner of investigation. Indeed, being almost neutral in behavioural terms, synaesthesia basically lends itself to analysing, researching and classifying solely via self-report. It has not once been suggested that progress in understanding the phenomenon should require a more thorough integration of empirical methods and first-person descriptions (cf. Smilek and Dixon 2002). Such a "synergistic approach" should be reflected in an appropriately selected mode and type of the constructed inventory. For this reason, for the

Synaesthesia Quotient Inventory the self-rating format is proposed in this paper as a method of data gathering and scaling. As a technique, besides the benefit of directly measuring the phenomenology of the respondent, self-rating has proved to present opportunities for rigorous standardisation, reliable comparison across various samples of interest, and a normative comparison that is facilitated by its efficient data gathering (Morey 2003). To compensate for the shortcomings of subjective evaluation, a supplementary appendage with an objectively verified estimate, if such is obtainable, can accompany each item (see a sample of the scale in *Exhibit 1*).

Although the intuitions and inferences scattered in scientific literature can be interpreted as preliminary evidence that self-reports and third person observations can cast new light on individuals' manifestation of the condition, until a rigorous measurement approach is developed, further exploration in this field will be constrained. With this purpose in mind, it seems insufficient, to found the definitional properties in the models of synaesthesia exclusively on self-report descriptions without translating these properties into objective quantifiable aspects. Though several aspects have been defined as 'gold standards' or 'signature' traits of synaesthesia across cases and types, no evidence for underlying mechanisms of many of them has been provided. Ergo, it is important to consolidate the theoretical basis of synaesthesia research and, in alignment with the conceptual framework of the current models of synaesthesia, determine what invariant dimensions might constitute the phenomenology and related neuronal basis of the phenomenon. To overcome this issue, we design the self-rating scale by deriving its domains from the bulk of empirical data both from inside and outside synaesthesia research as a literature review of independent studies into the relevant traits can also help to supplement data in the existing models and to include the obtained extrapolations into the constructed measure.

According to such an integrative data-driven approach, both identification of the domains and the rating values of synaesthesia expressivity to be associated with them are to be developed using empirical results from synaesthesia research and external neuroscientific literature. As the adopted approach to domain identification of the target construct and subsequent generation of relevant indicators is indirectly based on expert opinion, the rigour of the methods employed in the source studies partially contributes to resolution of the issue of defensibility of the content-defining process; i.e., it constitutes intermediate endorsement of the *face and content validity* of the proposed measure and, in so doing, enhances its immunity to the failure of being maximally independent on the assumptions of the author(s) of the inventory.

However, regarding the disparately unevenly researched fields of various synaesthesia types with multiple concepts yet under-defined and putative generalisations, exclusive reliance on pure "blind empiricism" (Meehl 1945) in scale development is difficult to endorse without some assumptions based on the *theoretical* or *deductive* method (Loevinger 1957; also Cronbach and Meehl 1955). Moreover, Loevinger emphasised that considering content issues while defining the domain is not insufficient; i.e., (as distinguished from "blind empiricism") it might mean that content validity must be established empirically: "If theory is fully to profit from test construction... every item [on a measure scale] must be accounted for" (Loevinger 1957: 657; also quoted in Clark and Watson 1995). Consequently, for the objectives of the current project, if objective evidence for resolving the content issues, i.e., item generation or/and identification of rating value, is not available directly from the field of synaesthesia research, it is extrapolated from comparably relevant empirical results from other neuroscientific investigations as "external anchors."

The integrative data-based approach propounded in this article is regarded as a major inroad to providing a substantiated foundation for domain identification, item generation and scale construction for the Synaesthesia Quotient Inventory. Although the initial stage focuses on domain identification, it should provide a generative framework so as to follow at later stages the principle first phrased by Loevinger: "*The items of the pool should be chosen so as to sample all possible contents which might comprise the putative trait according to all known alternative theories of the trait*" (Loevinger 1957, original italics). To ensure this, the definitional characteristics of synaesthesia (i.e., its "gold standards" such as involuntariness, consistency, categoricality, etc.) are analytically broken up into several dimensions so as to over-represent the target construct for further item generation and purification. What follows in the next section is detailed identification of the content domains of the construct of synaesthesia expressivity across individual cases (i.e., *feasible factors* writ large) as well as relative rating values of the corresponding indicators with Synaesthesia Quotient as their summative index.

Summing up our methodological perspective, our approach is threefold. First, regarding the fact that some characteristics of degrees of manifestation of synaesthesia with very few exceptions (e.g., *multiple* and *strong* types) have been implicated practically though in a non-conventional manner, these implicit magnitude estimations will be analysed in the context of results from synaesthesia-based and external neuroscientific studies of the relevant traits. Second, on the basis of some data drawn from synaesthesia research literature, additional aspects of synaesthesia will be demonstrated to be similarly significant for invariantly defining the condition and, at the same time, to be quantitatively different from case to case. Explication of both groups of characteristics will serve to elucidate the array of domains of the target construct of phenotypic expressivity of synaesthesia. Finally, following the same principle of data extrapolation and consolidation, the revealed characteristics will be assigned rating scale values or, more precisely, relative "direction of growth" within the identified content domains. All in all, we will expound the delineated aspects as *measurable manifestations* capable of reflecting *a degree* of synaesthesia expressivity in each individual case.

Domains and Scale Value Identification

The foundational definitions of synaesthesia in the current models analytically integrate both objective and subjective evidence. Even the most solid data of neuroimaging studies are straightforwardly guided by first-person descriptions regarding the criteria by which the investigated cases are selected and manipulated (cf. Smilek and Dixon 2002). Therefore, though synaesthesia's neurophysiological background has been rigorously established, in terms of its yet undetermined tenets that are crucial for uncovering its general mechanisms and identifying the scope of its typology, some characteristics attributed to the condition can still be regarded as *constructs*. Much in the same manner as memory's essential traits such as those used to divide it into types and functions and to measure its retentive specifications (cf. Trautwein 2006), the degree of expressivity of synaesthesia should also be, at least at the initial stages, conceptualised and operationalised through deriving its content domains. The procedure is best implemented on the combinatorial basis of theoretical and empirical models. In this section, content domains of expressivity of synaesthesia will be analytically delineated along the lines of extant data of synaesthesia-targeted and independent empirical research. This in turn will provide the fundamentals for generating a pool of items for the measurement instrument of *Synaesthesia Quotient*. The same or relevant evidence from other studies will be used to identify the rating scale values (relative "direction of growth") of the expressivity magnitude of synaesthesia.

Perhaps one of the earliest and most common mentions of inexplicit quantitative evaluation of the condition is the term *multiple synaesthesia* which implicates the developmental magnitude of the condition. In one of the earliest works on synaesthesia, Georg Sachs mentions several categories in one person (himself) (Jewanski et al. 2009) without specifically stating the importance of such multiplicity. Later on, Francis Galton reported that, among individual cases, one could find a certain overlapping of different varieties in "the character of the process itself [categories], so that it is by no means uncommon to find two very different forms concurrent [i.e., simultaneously found] in the same person" (Galton 1881: 649). Therefore, Galton used the argument of multiple synaesthesia as evidence for a certain continuity among its varieties.

As we suggested elsewhere (Sidoroff-Dorso 2012), among multiple synaesthesiae, some varieties should be further singled out as relatively more distant in terms of cognitive differentiation by labelling them *poly-aspectual*. Unlike multiple cases consisting of more than one category of inducers that can be characterised as more or less similar, such as letters and numbers or days of the week and months, poly-aspectual cases are those the *triggers* of which are functionally more distinct both cognitively and behaviourally – e.g., tastes and music, number forms and pain, smell and people's names, etc. In this respect, for instance, Sachs' case in which musical tones had colour and the colours were derived from the names of the notes not from their pitch and timbre *per se* (Jewanski et al. 2009) is a multiple synaesthesia while such drastically different inducers as in a taste-to-colour and a music instruments/ timber-to-colour types can be called *poly-aspectual*.

Nowadays, with a few exceptions, evincing multiple synaesthesiae is not addressed as an independent variable or, even, an informative aspect. However, some scientists do point out, though only in passing, the importance of the number of synaesthesiae in their subjects for experiment results. For instance, Simner (2013) equates a large array of synaesthetic forms observed in the same subject to a "superior" or *more extreme synaesthesia*, which, as per Simner, was a reason for contrasting results in two studies of mental rotation abilities in, to use now our terms, multiple and poly-aspectual synaesthetes. Simner concludes that better performance in imagery tasks might be related to more extreme synaesthesia (Simner 2013).

Taking into account some prominent empirical results of neuroscientific research into categorisation mechanisms (e.g., Goldstone 2000; Cohen and Lefebvre 2005; Bargh and Morsella 2008; Smith 2008; Seger and Miller 2010; Ashby and Maddox 2010; Nosofsky et al. 2012; Huth et al. 2012; Czigler 2013; Barsalou 2012; Barsalou 2013), there is substantial evidence that human brains have multiple category-learning systems that are functionally distinct at both cognitive and neural levels. However, although distinct types of category-learning and category-retention (perceptual vs. conceptual, declarative vs. procedural, implicit vs. explicit, rule-, examplar-, or prototype-based, etc.) can have distinct neuronal bases, and despite possible transfer and processing sharing, more categories would require more neural functional capacity or structural substrate to mediate them. Indeed, increased connectivity has recently been demonstrated to be not only relevant for identifying neurobiological bases of synaesthesia but also contrasting individual cases by positively correlating with their scores on synaesthesia tests. Heightened intrinsic network integrity has also been shown to differentiate several type-varieties of the condition by directly reflecting the strength of synaesthetic experiences (e.g., Rouw et al. 2011; Hupe et al. 2011; Davern et al. 2012; van Leeuwen et al. 2011; Zamm et al. 2013). On that account, it can be legitimate to conclude that developmental extension of synaesthetic manifestation should be considered as increasing from individual cases with single-category induction through multiple-trigger cases to poly-aspectual ones, with each extra category *raising its quantitative value*.

The number of types that a given case of synaesthesia consists of (e.g., multiple vs. singular) and their cognitive involvement (mono- vs. poly-aspectual) seems to form one content domain. However, *multiple synaesthesia* is likely to reflect cognitive selectivity of the underlying mechanisms while the characteristic of *aspectuality* implicates their cognitive diversity and range. For example, the same number of types within one case can be relatively similar (with stimuli being people's names, letters and some notions) or, in contrast, they can aggregate several distinct, functionally separate cognitive dimensions (e.g., taste, grapheme and music as triggers). In this respect, though the propensity of *poly-aspectuality* does seem to embrace that one of *multiplicity*, in the preliminary version of the SynQ instrument presented in this paper, these two characteristics are delineated as two discrete items (see Items #1 and #2 in *Exhibit 1*). Indeed, aspectuality (cognitive diversity of inducers) can additionally be a marker of ontogeny and ontology of those cognitive functions that synaesthesia supervenes on by showing how long was the critical period that it took to develop. Nevertheless, disentangling whether these two aspects constitute one, two or more domains should be a matter of further research.

Extension measure of manifestation of synaesthesia is not to be limited to inducers. In their definitions of synaesthesia, many neuroscientists point out that the versatility of concurrents in some synaesthetes can also encompass not one sensory modality but spread across many (thus, Dann coins a term "five-point" synaesthesia to describe the secondary sensations in Shereshevskii's case reported by Luria; Luria 1968; Dann 1998). Though less definitive than the number of induction categories, the perceptual versatility of concurrent sensations or *concurrent scheme* can also be *indicative* of a domain of measurable magnitude of developmental synaesthesia. Importantly, as was revealed in one of our studies, the number of categories in induction positively correlates with the number of concurrent modalities (Sidoroff-Dorso 2012). It should be taken into account as well that, in a concurrent system embedded within a single modality (e.g., vision), the growing degree of its complexity (e.g., colour with additional texture; Eagleman and Goodale 2009; Moos et al. 2013) can be taken as another indication of *growing strength* of its synaesthetic manifestation (see Item #3 in *Exhibit 1*).

In the long history of synaesthesia research, it has been not infrequently reported that, in some cases, synaesthetic manifestation is characterised by partial, selective or/and total *decrement* (Day and Sidoroff-Dorso 2013). The question whether the vivacity of synaesthesia diminishes with age was first raised by Cornaz (in Jewanski et al. 2011; Jewanski et al. 2012). Simner (2012) critically questions the gold standard of consistency of synaesthetic reactions in test-retest verification of the phenomenon by admitting a certain degree of qualitative alteration and quantitative diminution as a possible and sometimes irrelevant deviation. However, as was shown in a longitudinal study by the same author's team, neurocognitive modifications of maturation can strongly differentiate the quality and level of development (degree of presence) of synaesthesia from child to child (Simner 2009). In our view, such age-dependent individuation of the degree of synaesthetic expressivity testifies to relatively high or low active sustenance of an individual's synaesthetic endowments. In this respect, synaesthesia attrition as a function of natural, non-morbid processes of ontogenetic development (maturation and aging) can also be embraced as a domain to inform an item in a measurement inventory. More sustained synaesthetic expression is certain to be *more consistent over time and less likely to dissipate* with age or due to other natural causes (see Item #4 in *Exhibit 1*).

Related to decremental tendencies in synaesthesia is a domain that embraces the subjectively experienced varieties of the phenomenon distinctly characterised as *associator vs. projector* types. The former is experienced as a persistent and immutable knowledge-like impression, while the latter manifests itself as an additional overlay either as shapeless blobs, blurred patches or stencil-like semi-transparent coatings over the (mentally retrieved) stimulus-objects. These two different varieties were proposed to constitute a continuum of *depleting subjective presence* (cf. Ward et al. 2007). Particularly, in colour-grapheme synaesthesia, resultant Stroop effects revealed that evoked experience in the projector type interferes more strongly with perceiving real objects (mostly their colours), with reaction time in projector synesthesia being earlier than in associator synesthesia (Dixon et al. 2004; see also Ward et al. 2007). Moreover, greater anisotropic diffusion (i.e., more coherent white matter) was found to be stronger in the inferior temporal cortex in projector-synaesthetes relative to associator-synaesthetes (Rouw and Scholte 2007). Dynamic causal modelling for fMRI revealed that cross-activation in V4 during synaesthetic reaction was induced via a top-down pathway in associators, whereas via a bottom-up pathway in projector synaesthetes (van Leeuwen et al. 2011). Therefore, *on par* with the distinct phenomenologies of the projector/associator varieties, the empirical findings cumulatively presuppose not only a stronger perceptual presence of synaesthetic concurrents but also a more substantial neural basis in projector *vis-à-vis* associator types. Additionally, Ward et al. (2007) suggests further dividing the associator type into "know-associators" and "see-associators", while also splitting the projectors into "space-projectors" and "surface-projectors." Although this more intricate distinction seems to apply mostly to the distal sense modalities (for reasons that we contemplate below), it can be tentatively concluded that synaesthetic expressivity *gradually increases from associator to projector* (see Item #5 in *Exhibit 1*).

Regarding the stimulus selectivity, individual cases can be distinguished as manifesting a certain spectrum from all-modality or comprehensive types to relatively more selective, i.e., more cognitively involved types, which might be called *domain of cognitive involvement* (or *induction scope)*. While both variations of triggering are category-based, the all-modality types are more sensory-grounded and more likely to emerge at a younger age with their categorisation consolidating from within the trigger-source modality ("parcellated"; cf. Karmiloff-Smith 1996; Seger and Miller 2010; Ashby and Maddox 2010). In contrast, more selective types are more loosely related to unmediated ("raw") sensory activity, these types being more category-based and, likely, of ontogenetically later origin. Although the extremas of this continuum of varying induction scopes are sufficiently distinct, the demarcation line is getting more blurred towards intermediary types. Indeed, such highly selective types as name-to-colour and spatial sequences will stand in clear opposition to sound-to-colour and taste-to-touch synaesthesiae. However, this distinction is less definite with the types *induced* by orgasm, pain or emotion, for the reason that these experiences can be considered as separate instantiations of broader sensory modalities or "modes" (broad practical spheres).

The measurement scale for the item of induction scope might be established according to the possible time of development (from younger to more mature age), increasing degree of necessary activation of bottom-up processing ('cognitive load' or dependence on voluntary attention) in synaesthetic induction from type to type, and relative degree of automaticity/immediacy. Experientially, synaesthesia reveals *compound perceptual* properties; the phenomenon seems to develop as part of the process of perceptual and covert or overt cognitive categorisation. Depending on its type, synaesthesia's cognitive realm straddles higher-level or/and lower-level perception, embracing the spectrum of cognitive calibration from modularisation to differentiation to global-to-basic categorisation (cf. Karmiloff-Smith 1996; Goldstone 2000; Quinn and Johnson 2000; Huth et al. 2012). Therefore, within the domain of cognitive involvement/stimulus selectivity/induction scope, *increasing expressivity of synaesthesia* can be delineated as follows: from all-modality induction to more immediate perceptual (music, language, face/social perception, etc.) to more symbolic, mediated types (letters, numbers, etc.) to primarily abstract (names, notions, swimming styles, etc.) (see Item #6 in *Exhibit 1*). However, individual variation of cognitive involvement, experience complexity and period of category attainment should be additionally taken into account.

It is a statistically substantiated fact that, from individual to individual, synaesthetic inducers are distributed unevenly across modalities with most cases being triggered by visual stimuli and fewest by pain, kinaesthetics, smell and emotion (Day 2013). Though primarily hypothesised as being determined genetically, synaesthesia appears to be a multi-factorial phenomenon and inclusion of other causes, such as cultural and developmental influences, cannot be ruled out (cf. Sur et al. 2004). Indeed, the genetic/essentialist frameworks fall short of explaining the revealed regularities and "cognitive asymmetry" between the existing inducer/concurrent pairings in synaesthesia. For instance, more "basic" (protopathic) inducers, i.e., nociceptive, gustatory or olfactory stimuli, have not been identified to evoke such relatively more cognitively loaded concurrents such as spatial sequences/coordinates or personification types. On the other hand, names of the months, number concepts or geometric shapes (rather late cognitive formations) almost never become coupled with (supervened on) reactions in the visceral and proximal sensory modalities. Additionally, while the senses of taste, touch and hearing are quite often found to be the substrate for all-modality types, vision *per se* represents a highly selective, object-centred host-modality for synaesthetic inducers (cf. Day 2005; Day 2013). All in all, inducer/concurrent pairings seem to replicate both evolutionary and ontogenetic, experience-dependent calibration of the sensory/cognitive interrelations. The specificities of such calibrations can be included as a content domain into a measurement tool of Synaesthesia Quotient.

The bearing of such calibration on the sensory domain has been parsimoniously conceptualised as the classical neurophysiological dichotomy of *protopathic and epicritic* sensations (Rivers and Head 2008; Head and Holmes 1911; Walshe 1942; review in Semmes 1969). Although Head and Rivers' distinction was fiercely criticised right after its introduction and is not so widely received today, recently it has been shown to be anatomically relevant for the neuronal pathways of pain (see Price 2000). Moreover, recordings from single sensory neurons have partly reaffirmed separation of highly differentiated sensations from other types. Hugely reworked and reformulated, the distinction still exists in various models of, for example, cortical modulation of thalamic sensibility, higher-level integration of sensory experience and hierarchical cognitive mediation of explicit and implicit perceptual learning. The distinction still has its proponents in neurosciences (cf. Haggard et al. 2013) and might prove valuable for explicating synaesthetic mechanisms. Indeed, linguistic-colour synaesthetes, relative to non-synaesthete controls, have been found to manifest early sensory-perceptual differences in the visual evoked potential (VEP) in response to simple non-synaesthetic stimuli that oppositely bias magnocellular and parvocellular response, which suggests a differential effect on these two pathways (Barnett et al. 2008). As parvocellular neurons have been previously demonstrated, roughly, to be sensitive to colour, more capable of discriminating fine details (higher contrast and frequency), have greater spatial but lower temporal resolution than their magnocellular counterparts (see Ungerleider and Mishkin 1982), it can be concluded that a protopathic/epicritic distinction (or a very similar system) can be involved in synaesthetic perception.

According to later versions of the epicritic/protopathic division, these extreme characteristics of the relative degree of differentiated sensibilities can apply on equal footing to the sensory realm well beyond somatic sensation to other senses (Parsons 1927; Stanley-Jones 1967; Chin et al. 1976; Pribram 1971). Thus, protopathic sensations (dyscritic in Parsons 1927; protocritic in Pribram 1971) are mostly diffuse, objectless, *en masse* experiences that are characteristically dependent on the quantity (intensity) of the stimulus or, more often, inner states and processes. Protopathic sensitivities are more elementary and primordial, and lean to being devoid of any discriminatory capacities (localisation, categorisation, etc.). In contrast, epicritic sensations are both *phylogenetically later and ontogenetically younger*, with more discriminative power, being more refined and object-specific systems upon which judgement is exercised and discrete behaviour is contingent (cf. Luu et al. 2001). Furthermore, each sensory modality can be characterised differently by its development-expectant degree of epicritic/protopathic components, with pain and touch being mostly the latter while vision and hearing (distal senses) the former.

On the whole, the measurable degree of expressivity of synaesthesia can be distributed progressively *within the domain of discriminative power across the induction-related sensory modalities* from earliest to latest formative periods of the inducer system. More protopathic systems (touch, pain, taste) involved in synaesthetic induction will indicate a *higher* score, while epicritic (more knowledge-based) sensations as inducers will presuppose a *lower* score. It should be noted that, based on the relative characteristics of experience-related differentiation, more epicritic modalities can also include more or less protopathic synaesthesia-triggering sensations. For example, (perceived) motion-to-X types will be characterised as less epicritic (more protopathic) than letter-to-X types but as more epicritic (less protopathic) than touch-to-X; therefore, with a SynQ comparatively *decreasing* in the types based on touch to motion to vision-based graphemes as inducers (see Item #7 in *Exhibit 1*).

Self-reports reveal that induction in some individual cases can be *attention-dependent*, with attended stimuli triggering relatively more vivid secondary sensations and unattended ones producing less or no explicit experience of concurrents. Such first person data have not yet been explicated in relation to the neural correlates of experiencing synaesthesia while (not) exercising selective attention. However, results of several independent studies suggest that attention and awareness (consciousness) interact at the behavioural level but operate independently at the neural level (i.e., Kentridge et al. 1999; Lamme 2003; Tse et al. 2005; Koch and Tsuchiya 2006; Tsuchiya and van Boxtel 2013). Manifestations of this independence are extremely multifarious and include psychophysical and neurophysiological (topographical and temporal) variances. For example, some authors suggest that visual awareness and attention contribute independently to a third category of neural activity called “a perceptual threshold about the presence (or absence) of a stimulus.” This implies that there is more than one type of “perception,” one related to visual awareness and one related to conscious report (van Gaal and Fahrenfort 2008; also Wyart and Tallon-Baudry 2008). It has been suggested that large-scale interactions between high-level (executive) and low-level (perceptual) areas are crucial for rendering perception reportable (Rees et al. 2002; Lamme 2003; Dehaene et al. 2006). As is shown in an EEG study, access awareness was selectively correlated with increased gamma-coupling between anterior and posterior brain areas (Melloni et al. 2007; see also Bor and Seth 2012). Moreover, a MEG-study showed that, whether attended or not, consciously seen stimuli induced increased mid-gamma activity (54–64 Hz) 240–500 ms over the contralateral visual cortex, whereas attended versus unattended stimuli caused a significant increase in high-gamma range (76–90 Hz) with a slightly delayed latency (350–500 ms) and was uniquely modulated by attention (not by conscious experience). Single-trial parametric analysis confirmed that the awareness-related mid-frequency activity drove the seen–unseen reports but also revealed a small influence of the attention-related high-frequency activity on the reports (Wyart and Tallon-Baudry 2008).

Cumulatively, this evidence suggests that, regarding specific mechanisms that might facilitate development of synaesthesia, the degree of its expressivity (i.e., SynQ) might be considered as *reversely related to the faculty of attention* and gradually progressing from attention-loaded (more demanding functionally) to attention-neutral (less functionally demanding, more structure-based) induction. However, as the neural correlates of attention and awareness can be dissociated and specifications of such dissociation have been shown to be intricately dependent on subjective significance, task-related settings, prior experience, endogenous/top-down and exogenous/bottom-up components of attention, concentration characteristics, inter-modal effects of attention on consciousness, mode of attending to invisible stimuli, etc. (cf. Tsushima et al. 2006; Bahrami et al. 2007; Chun and Marois 2002; Keller 2011; Marchetti 2012; Rees 2013; Baars 2013; Tsuchiya and van Boxtel 2013), the attention-based scaling item in the SynQ measurement inventory is highly provisional and further experimental disentanglement of relations between synaesthetic induction and endogenous attention/concentration within the stimulus/response event will be needed (see Item #8 in *Exhibit 1*).

Involuntariness of reactions *per se* in synaesthesia is yet another gold standard for many scientists to prop up their definitions of the phenomenon. Nevertheless, a certain *degree of controllability* over some aspects of concurrents is also widely debated and, though not unanimously, accepted. Indeed, it is the extent of deliberate mutability of concurrent experience that literally blurs the line and leads to interpreting synaesthesia as having perceptual characteristics, i.e., fixed and immediate, alongside those of mental imagery, although being quite distinct from both (Craver-Lemley and Reeves 2013; also Intons-Peterson and McDaniel 1991; Giusberti et al. 1992). Besides the examples in self-reports that provide data regarding synaesthetic subjects’ abilities of panning, scanning, rotating and zooming in on their "number form" concurrents, other cases are also known to manifest a certain amount of possible voluntary modulation, expansion and detailisation (Cytowic and Eagleman 2008; Craver-Lemley and Reeves 2013).

It is yet unclear to what extent, or whether at all, possible voluntary modification of synaesthetic concurrents activates pre-existing substrate determinants in the brain or implements new, emergent formations in ongoing subjective experience (similar to mental imagery). In many studies, synaesthetes have demonstrated scoring higher on mental imagery tests (Barnett and Newell 2008; Spiller and Jansari 2008; Price 2009). This was hypothesised as being an orthogonal aspect to synaesthetic perception, both of which, when overlapping, result in two distinct types of synaesthetic experience: projectors and associators (Simner 2013). Importantly, both associator/projector division (Ward et al. 2007) and degree of controllability (Richardson 1969) are hardly discrete and, more likely, represent multifarious continuums whose (in)dependence is yet to be empirically revealed.

However, if top-down modulation of underlying neurophysiological activity is to be understood as *more integrative* and more demanding and, hence, with more delayed latencies, more large-scale, cohesive and anterior (towards parietal cortex and prefrontal cortex) (cf. Frith and Dolan 1997; Engel et al. 2001; Gilbert and Sigman 2007; Baluch and Itti 2011), the outcome phenomenon will be characterised as *relatively less reliant* on the initial structural specifications of the brain and/or *less implemented* in the first-epoch, non-recurrent processing; i.e., *less correlated* with feedforward and 'horizontal' activation. Thus, regarding the imagery-like intentional changeability of synaesthetic concurrents, it would be legitimate to interpret the comparative, case-to-case degree of expressivity of synaesthesia as *increasing* from those having fewer controllable aspects to the ones that manifest more features liable to calibration and modification (see Item #9 in *Exhibit 1*).

On the side of synaesthetic stimuli, another domain for the synaesthesia inventory can be derived from the degree of *dependence of induction* upon the presence/absence of a real physical stimulus, which possibly arises from interaction between top-down and bottom-up processes (Mechelli et al. 2004; also Ganis et al. 2004; Bartolomeo 2008). Synaesthetes often self-report that their synaesthesia is evocable by imaginal as well as actually presented stimuli (e.g., Frith and Paulesu 1997; Ramachandran and Hubbard 2001), which was partly supported by the studies using Stroop tests (Smilek et al. 2002; Elias et al. 2003; Jansari et al. 2006). In particular, Spiller and Jansari (2008) have empirically shown that, in some grapheme-colour cases, synaesthetic experience can be triggered not only by a directly perceived inducer but also by its mentally retrieved image, and it was also emphasised that there are important individual differences in imagery-induced synaesthesia. In a modified Stroop paradigm with congruent/incongruent backgrounds, the mentally evoked stimuli yielded insignificant (N = 2) or opposite camouflage effects: facilitating (N = 2) or interfering (N = 2). The contrast might be explained by the reported effect being a function of interference caused by vividness of the retrieved stimuli and/or concurrents varying from participant to participant (Spiller and Jansari 2008).

It is, though, unclear from the description of the setting of the experiment whether the mental formations that were practically utilised by the synaesthetes and (or hypothetically considered as a contrast to physical triggers) were, in fact, endogenously generated imagery, outcomes of a learning-limited model, short-term memory recall or still another strategy. However, this does not compromise the general conclusion empirically supported by Spiller and Jansari (2008) and originally phrased by Grossenbacher and Lovelace (2001) that "synaesthesia can occur with incomplete activation of the entire cascade of sensory signalling normally propagated during perception" (p.38). Important for measuring SynQ along these lines might be not the origin or vividness of the mental image but its necessary and sufficient status (whether perceptual or cognitive; cf. Smilek et al. 2002; Mroczko 2009; Nikolić 2009) for triggering synaesthetic experience. Moreover, such top-down, stimulus-independent induction in this sub-variety of synaesthesia still presupposes a full-pass cascade activation leading to synaesthetic experience with qualitatively the same subjectivity, whereas it is almost unlikely that synaesthesia can be triggered by imagery alone with no possibility to be similarly evoked by corresponding physically presented triggers. Therefore, parsimoniously, synaesthesia is best interpreted to be *relatively more strongly expressed* in subjects who are capable of self-triggering their concurrents through mental retrieval in an equally vivid manner as through immediately perceived stimuli in contrast to, thusly, less strongly manifested cases that are exclusively dependent on external inducers (see Item #10 in *Exhibit 1*).

Summing up, as some aspects of synaesthesia including the degree of its expressivity can be regarded as *theory-guided constructs*, in this section, it has been attempted to specify the content domains of the latter. Capitalising on empirical evidence from synaesthesia research literature as well as extrapolating the relevant supplementary data from external neuroscientific studies, ten domains have been derived within which possible overall rating values (scoring scheme tendencies for SynQ) have been determined. The identified content domains of the magnitude of synaesthesia expressivity include: multiplicity (number of possessed types within an individual case), aspectuality (functional difference among inducer systems), sensory versatility of concurrents, attrition (decremental proneness), extent of perceptual presence or veridicality of concurrents, cognitive involvement (selective complexity) of inducers, descriminative power of the sensory modality of induction (protopathic or epicritic sensations as a basis of inducers), attention-dependence of induction, controllability of concurrents, and stimulus-dependence of induction.

In particular, a person *with a higher Synaesthesia Quotient* will be (1) a multiple and (2) poly-aspectual rather than a singular-type synaesthete. (3) Their concurrents are inclined to exhibit more sensorial characteristics, and (4) their synaesthetic experience is more consistent over time and less likely to dissipate with age or for other non-morbid reasons. A high SynQ case is (5) a projector type rather than associator with (6) inducers, more likely, constituting an all-modality, more comprehensive rather than selective, category-embedded type of synaesthesia. They will have a trend of (7) having protopathic rather than epicritic sensory modalities embedding the inducers which will trigger synaesthesia (8) relatively more independently of top-down attention. A greater magnitude of synaesthesia expressivity will manifest itself as (9) less controllable experience of concurrents (thus, being more structure-based and less function-dependent) and (10) less reliant on the presence of physical stimuli (being capable of self-triggering by merely imagining the inducer).

Discussion

Quantification of phenotypic expressivity of synaesthesia depends on the resolution of at least three mutually entangled issues: (a) homogeneity and scope of the phenomenon, (b) operationalisation of the degree of expressivity in individual cases through (c) identification of its proper content domains. Although the adopted approach does not modify the general assumption of objective synaesthesia research, according to which the condition is considered to be a manifestation of a certain neurophysiological substrate that is pre-determined genetically and manifests itself through subjective experience on a directly relational basis. However, such an understanding overlooks the modifying influence of the environment and learning and, therefore, results in "paradoxes of nativism" such as "inborn music" and "brain-wired letters". With the aim of overcoming the pertinent theoretical issues, it is proposed to alter the perspective from experiential (content-oriented) to ontogenetic (development-oriented). Consequently, the issue of homogeneity and scope is addressed by adopting a view that synaesthesia types can be subject to both malleability and heritability (like IQ) and that they can have both unique and common genetic determinants with individual types being phenotypic variance instantiated through learning and experience as qualitatively different subjectivities.

Furthermore, quantification of synaesthesia is compounded by the fact that, in the majority of cases, *none of the experiential propensities* of the phenomenon, either of its inducers/concurrents or their correspondences, seems to be of gradable nature (as they are not *prothetic* in Stevens' terms), which renders synaesthetic correspondences their characteristic arbitrariness. Prothetic aspects of stimuli are described as changeable quantitatively (e.g., loudness, brightness, etc.), while *metathetic aspects* are thought to vary in terms of quality (e.g., colour or pitch). Prothetic sensations are best assessed with ratio scales whereas metathetic sensations are best judged with category scales; and, hereupon, direct magnitude estimation (DME) is not possible for psychophysical measurement of the latter. Importantly, to distinguish prothetic from metathetic, it was suggested that perceptual ratings from a category-related scale should be regressed onto ratings derived from a ratio scale (Stevens 1975). Therefore, a major task to accomplish at the initial stages of constructing the SynQ-i is to adopt a framework that can methodologically transform the experiential, mostly metathetic features of the synaesthetic experience in the respondent's case into measurable dimensions. For example, in Items #4 and #7 (see also *Domains and Scale Value Identification*), it is achieved by extrapolating the metathetic features into the ontogenetic perspective and, thereby, tracing down their statistically probable developmental histories. Generally, a greater magnitude of expressivity is shown to manifest itself across the identified domains as earlier appearance, stronger veridicality, a greater number of types and lower selectivity of induction.

Additionally, to date, definitions of synaesthesia, whether unifying or disjunctive, have been conventionally based on theory-driven inferences from first person data. Indeed, it is still too difficult to find *empirical* evidence either against or in favour of homogeneity of synaesthesia types, which is further complicated by the fact that all types, to a greater or lesser extent, manifest stimulus selectivity (hence, their latent conceptuality). Therefore, it might be methodologically sounder if synaesthesia is characterised differently at different levels of analysis. Immediate experiential examination reveals its *inexplicably compound perceptual* properties, whereas ontogenetically the phenomenon seems to develop as part of the process of covert or overt cognitive categorisation. To specify the latter, across most reported types, synaesthesia straddles higher-level or/and lower-level perception, embracing the spectrum from category-engrained/all-modality to category-based; i.e., scopes of modularisation-differentiation-categorisation that can be based, broadly, on the process of *unitization* (cf. Karmiloff-Smith 1996; Goldstone 2000; Huth et al. 2012). As we demonstrated elsewhere (Sidoroff-Dorso 2012), the aspects of meaning of inducers in various types of developmental synaesthesia can be considered *as ontogenetic markers* with the "semiotic content" serving as implicit indicators of: (1) the *sensitive periods of development* of these types of synaesthesia (cf. Cytowic and Eagleman 2008); (2) the *specific cognitive tasks* and, specifically, intra- and inter-subjectively constructed situations/functions that these types are contingent on; and (3) the *related structures and functions of the CNS* that implement these dynamic characteristics. In much the same vein as genetic determinants contemplated above, such an understanding of synaesthesia implies *both* similar and different neuronal substrates that might be involved in evincing distinct types of the phenomenon. Primarily, it is the relevant similarity across idiosyncratically manifested cases that the Synaesthesia Quotient inventory is intended to elicit and record.

It might seem open to controversy that, in the related domains, concurrent-hosting sensory modalities are reduced on the items with different rating scores. Specifically, Item #7 rates vision lower than touch or pain. Besides the empirically based conclusions provided in the *Domains and Scale Value Identification* section (see above), it should be noted that such relations among the sensory modalities as concurrent receptacles should be very scrupulously specified on the bases of the individual's developmental history, perceptual enskillment, dominant inter-sensory interaction, functional hierarchy of the senses in the sensorium of the background culture, etc. In particular, in visually challenged synaesthetes, a different functional hierarchy can be expected.

The same is the case with the rating of the degree of cognitive involvement, abstractness or selectivity/inclusion of inducers (Item #6). One of the possible putative solutions would be that, in a more dominant modality with more discriminatory power (epicritic), one can distinguish between the experiential types of associator and projector (as well as more discrete intermediate varieties), while, in less functionally differentiated senses, such discrimination is either absent or considerably reduced. These two variables (associator/projector discriminability and protopathic to epicritic differentiation) were demonstrated to correlate positively, if loosely

(Sidoroff-Dorso 2012), which can partly facilitate delineation of the domains and more sensitive quantification. These issues can be further addressed at later stages by introducing a more precise weighting scheme for the items in point, following experts' feedback and consequent validation.

Some items of the SynQ-i can be criticised for being formulated as if targeting a singular manifestation type within a certain case. For instance, Item #5 requires the respondent to describe his or her synaesthetic reactions as either projector or associator on a 1 to 5 grading scale, with the surface-projector type being rated as most prominently manifested. Though the respondent is asked to assess his or her "most typical type," due to the similarly perceived prominence of the experienced varieties, the most representative one might be rather difficult to select. A slightly time-consuming but more precise way to estimate the degree of synaesthesia expressivity for such items would be to find a mean of the total score for all the types of inducer/concurrent categories in the respondent's case. The same scoring rule can be applied to practically all the items in the inventory if the respondent has synaesthesia of a multiple type.

Having inferred the relative degree of synaesthesia expressivity within the domains, we have formulated these inferences, for illustration, as ten item stems with correspondingly scaled response sets to solicit the domain-related information. These in turn have been assembled into a sample of a preliminary version of the Synaesthesia Quotient Inventory, one item for each domain, in the format of an ordinal scale (see *Exhibit 1*). Arguably, the derived domains do not exhaust the whole content scope of the construct of synaesthesia expressivity; however, they represent the most prominent and fundamental aspects that have been recognised explicitly or implicitly in synaesthesia research to date. Although some of these domains may also seem overlapping and, therefore, over-representative of the target construct, this should be taken as a benefit at the initial stages of scale construction (cf. Downing and Haladyna 2006; DeVellis 2003). It is to note, however, that, in the current version of the SynQ-i, the results of the elicited response add up to a *summative index* (i.e., SynQ) only at its minimum, and further content differentiation and instrument construction are needed for generating and purifying a pool of scale items, establishing their validity, and implementing weight assignment based on, among other techniques, independent specialists' feedback, which is planned for the next stage of our project. The presented framework as well as the designed inventory is currently intended to elicit post-publication commentary from synaesthesia experts and prospective respondents. In order to fulfil this objective, the questionnaire has been sent to external scholars for open peer-review.

Applications and implications

The Synaesthesia Quotient Inventory is being designed with an ultimate goal of offering an individual quantitative profile of phenotypic expressivity of developmental synaesthesia via recording the subjectively manifested magnitude of several content domains of the target construct. It is intended to be administered either as a self-rating or interviewer-assisted measure for experimental use or personal identity. The instrument's construction, therefore, embraces at least a twofold task: to conceptualise the notion of synaesthesia expressivity and operationalise its variables as an index (i.e., Synaesthesia Quotient). The theoretical foundation of the procedure is based on the assumption that, as a psychophysiological phenomenon, synaesthesia is positioned more generally in the taxonomy of cognitive processes and embraces its specific types (e.g., domain-general as opposed to domain-specific functions and types of memory; cf. Trautwein 2006). One of the explicit premises of the approach is that the phenomenon of synaesthesia has both a common aggregation of neuronal mechanisms as its invariant implementation core *as well as* its specific variations as functional extensions for individual types. It must be emphasised that the SynQ-i is the first attempt at developing a measure reflecting a generalised view of synaesthesia on a quantifiable basis. Therefore, rather than a definitive scale, the SynQ-i is best considered as a preliminary estimation tool with related ensuing controversies, which ultimately makes it open for other investigators to discuss, pre-test and refine it.

Regarding the inherently complex and empirically underdetermined characteristics of synaesthesia, any investigative project of the phenomenon is likely to necessitate a synergistic combination of subjective and objective data for reciprocal validation and iterative augmentation (cf. Smilek and Dixon 2002). Therefore, our choice of the Likert-type rating scale format is informed by its well-established usability for a self-administered inventory with the aim of recording first-person data. Despite the strictures of subjective methods, both the administration mode of self-report and the Likert-type format are most capable of tapping into the cognitive and perceptual components of subjective experience and quantifying the obtained results (Nisbett and Wilson 1977; Bowling 1997; Meyer et al. 2001; Fernandez-Ballesteros 2002; see also Jack and Roepstorff 2003). In the provisional version of the Inventory (see *Exhibit 1*), each of the ten identified content domains gets delineated as an item stem (closed-ended question), with corresponding response alternatives spanning five options. The sequence of the items is arranged according to the degree of their comprehensibility–from general and introductory to more detailed and elaborated. The response format is not unified but consists of verbal descriptors with numerical values that pre-code each individual item and reflect the increasing degree of synaesthesia expressivity as was evidentially determined for the related domain. These ordinal scales' measure in the form of multiple choice is not supposed to be limited to the number of either item stems or response options, the assembled sample of the Inventory being presented here as an illustration for further pre-testing and discussion. To compensate for the shortcomings of subjective measurement, each item stem or a domain-related group of items might later be accompanied with a checklist box to indicate empirical validation, if such is available at the time of administration.

The summative index of Synaesthesia Quotient is provisionally defined to be a total of all the domain-based indicators, with each of them being assigned a number of points ranging from one to five. As pre-coded in the options, an increasing score reflects an increasing magnitude of synaesthesia expressivity; though, in later versions, the scoring rule for some of the items will be modified and, specifically, can be reversed to avoid "one direction" bias. Putatively, the weighting formula is expected to reflect the significance of individual items on *a relative basis* within the summative index. Therefore, the assigned value of the scoring and the spread space between each option does not hold any intrinsic meaning (quasi-logarithmic scaling); i.e., a transition from point one to point two might not be equivalent to that from four to five. Theory-wise, these scores should be interpreted as discriminative, with each item being keyed to an empirically informed variable, and are supposed to be utilised for positioning an individual case on the continuum between the identified extremas of the degree of manifestation of synaesthesia. Additionally, as the SynQ-i is not designed to authenticate an individual's genuineness of synaesthesia, it is only in high-stakes settings that a time limit, requirement for test-retest consistency and other restrictions might need to be introduced.

Worthy of note here is that the concept of *Synaesthesia Quotient* reflecting the individual degree of expressivity of the phenomenon implies certain neutrality towards the idiosyncratic experiential "content" on both sides of the stimulus-reaction event. Indeed, while drawing on the respondents' answers regarding the peculiarities of their synaesthetic experience, the SynQ measurement tool is being designed to quantify the condition's expressivity by transforming the obtained data into numerical indicators (regressing the metathetic sensations). Though the cognitive aspects of synaesthesia and its stimulus selectivity do pose a question of heterogeneity of its types and varieties, such a content-neutral paradigm can be demonstrated to be not very much different from those designed to study memory, emotion, intelligence or other cognitive capacities and neurophysiological processes (Nisbett and Wilson 1977; Meichenbaum and Buttler 1979; Jack and Roepstorff 2003; Craver 2008; Trautwein 2006). Psychological phenomena can be studied and taxonomised at various levels of generalisation, which not only tends to be a subject of scientific debate but, as some of such methodological schisms will do, offers novel practical avenues.

Conclusions

This paper describes the initial stage of construction of the Synaesthesia Quotient Inventory (SynQ-i), a novel self-administered/interviewer-assisted rating measure of an individual degree of phenotypic expressivity of synaesthesia with its index conceptualised as *Synaesthesia Quotient*. Following the implicit characterisations of synaesthesia in terms of magnitude of its expression found in specialist literature (e.g., *strong* vs. *weak*, *multiple* or *superior*), the initial stage concentrates on *conceptualisation*, *domain and item identification, format selection* and *rating value determination* for the Synaesthesia Quotient Inventory. The procedure draws extensively on the results and paradigms of the existing synaesthesia research and inventories both for development and validation. Therefore, the SynQ-i is intended to be administered solely in alignment with these tools as it is not a stand-alone instrument to verify genuineness of synaesthesia. The administration mode of self-report and the Likert-type format were designated for the SynQ-i as most capable of tapping into the cognitive and perceptual components of subjective experience with their subsequent quantification. A Synaesthesia Quotient of an individual case is a summative index and is supposed to be expressed as a numerical indicator according to a *norm-referenced* score interpretation as well as a verbal ratio-scale descriptor with a spectrum of *low, average* and *high* levels of manifestation.

Typically, the foundational definitions of synaesthesia are derived from analytical combination of reciprocally reinforcing lines of experiential, psychophysical and neurophysiological evidence (“synergistic approach”) and characterise the condition with an underlying neurophysiological substrate that is pre-determined genetically and manifests itself through subjective experience on a directly relational basis. The framework adopted for the SynQ-i does not modify the common premise of objective research; however, it does alter the perspective from experiential (content-oriented) to ontogenetic (development-oriented). Whereas immediate experiential analysis reveals synaesthesia's *inexplicably compound perceptual* properties, ontogenetically the phenomenon appears to develop as part of the functional spectrum of modularisation-differentiation-categorisation, with its individual instantiations uniquely straddling higher-level or/and lower-level perception. This leads to a proposal that it might be methodologically more rigorous to understand synaesthesia *per se* as more general and embracing in the taxonomy of cognitive processes in relation to its specific types (cf. domain-general as opposed to domain-specific mechanisms of memory).

One of the practical implementation of such a *systems approach* is a model of synaesthesia according to which the phenomenon is understood as having both a common aggregation of neuronal mechanisms as its invariant core alongside specific functional extensions for its individual types which might involve *both* similar and different neural substrates. In much the same vein, it will be sounder to consider synaesthesia as both heritable and malleable (like other theory-guided quotient-related constructs) and having common as well as unique genetic determinants with phenotypical variance individually evinced as qualitatively different subjectivities. All in all, synaesthesia should be more exhaustively characterised at different levels of analysis as both unified (general) and different (specific). Primarily, it is this relevant similarity across idiosyncratic cases that the Synaesthesia Quotient Inventory is being designed to elicit and record.

As the concept of *Synaesthesia Quotient* implies certain neutrality towards the idiosyncratic content on both sides of the stimulus-reaction event, a major task to accomplish at the initial stage of constructing the SynQ-i was to adopt a measurement method that can reliably regress the experiential, mostly metathetic (qualitative) features of the phenomenological profile of the respondent's synaesthesia into measurable dimensions. In particular, owing to the fact that not all aspects of synaesthesia have been equally investigated, a pool of items for SynQ scales are best derived from various combined empirical sources. First, in synaesthesia research, some characteristics of manifestation degrees of the condition, with very few exceptions (e.g., *multiple* and *strong* types), are implicated practically though in a non-conventionalised manner. In this paper, these implicit magnitude estimations have been explicated in the context of results from independent synaesthesia-based and external neuroscientific studies of the relevant propensities. Second, on the basis of results drawn from research literature, additional aspects of synaesthesia have been demonstrated to be similarly significant for invariantly defining the condition and, at the same time, to be quantitatively different from case to case. Explication of both groups of characteristics served to delineate the range of content domains of the target construct of phenotypical expressivity of synaesthesia. Finally, following the same principle of data extrapolation, the elucidated characteristics were assigned rating scale values or, more precisely, relative "direction of growth" within the identified domains. All in all, the adopted approach has expounded these aspects as *measurable manifestations* capable of reflecting *a degree of synaesthesia expressivity* in each individual case. As these aspects have been directly or indirectly revealed through empirical research, this constitutes intermediate endorsement of the *face and content validity* of the constructed inventory.

The integrative method has enabled ten content domains to be derived and, within each of them, possible overall rating values (scoring scheme levels for SynQ) to be determined. The identified domains of the magnitude of synaesthesia expressivity include: multiplicity (number of types within an individual case), aspectuality (functional dissimilarity among inducer systems), sensory versatility of concurrents, attrition (decremental tendencies), perceptual presence of concurrents (veridicality), cognitive involvement of inducers (selective complexity), descriminative power of the inducer sensory modality (protopathic or epicritic sensations as a basis of inducers), attention-dependence of induction, controllability of concurrents, and stimulus-dependence of induction. Generally, a greater magnitude of expressivity is shown to manifest itself across the identified domains as earlier appearance, stronger veridicality, a greater number of types and lower selectivity of induction. In the preliminary version of the Inventory (see *Exhibit 1*), each of the ten identified content domains has been delineated as a closed-ended question (item stem) with response alternatives spanning five options. The summative index of Synaesthesia Quotient is provisionally determined to be a total of all the domain-based indicators, with each of them being assigned a number of points ranging from one to five.

It must be emphasised that the inventory presented in this paper is the first attempt at developing a measure reflecting a generalised view of synaesthesia on a quantifiable basis. Therefore, rather than a definitive scale, the SynQ-i should be considered as a preliminary version of an estimation tool with related empirical implications and ensuing controversies, which ultimately makes it open for other investigators to discuss, pre-test and refine it.

To specify, from the perspective of synaesthesia research, such a content-neutral paradigm might prove efficient to further reveal characteristics common to all types of synaesthesia. Individuals with higher SynQ estimates can be contrasted to low-scoring subjects who, in turn or simultaneously, could be compared with non-synaesthetes. While compartmentalising synaesthesia varieties can result in providing findings causally attributable to the properties of the stimulus or consequential effects, SynQ-based frameworks could be more fine-tuned to identify the invariance of neuronal and genetic correlates of synaesthesia proper. For instance, a SynQ-focussed paradigm will make it plausible to hypothesise *heritability of Synaesthesia Quotient*, not specific types of synaesthesia. Such studies can be based more on systems views (epigenetic, contingent models) and can ultimately contribute, for instance, to solving the *paradoxes of nativism* (e.g., "inborn music" or "brain-wired letters") that many current projects of synaesthesia research are fraught with. The notion of SynQ can also be instrumental in revealing connections between synaesthesia and other psychological traits and it might help reveal more intricate, age-dependent interrelations, interferential, incremental or facilitative, between synaesthesia and, for example, memory, creativity, attention (cf. *ontogenetic equivalency* of synaesthesia types in Sidoroff-Dorso 2012) and other individual cognitive differences and conditions. Last but not least, besides psychometric studies, the notion of Synaesthesia Quotient can be referenced on an everyday basis by synaesthetes themselves as part of their identity and self-understanding. Therefore, being both supplementary and complementary to the content-specific, disjunctive frameworks already in practice today, the unifying notion of Synaesthesia Quotient as an index of synaesthesia expressivity can, at best, be a foundation for an array of innovative studies and, at least, should be taken into account as one of the pivotal characteristics in each individual case of synaesthesia. It is our aspiration that it will open up a new methodological perspective.

Exhibit 1. The Synaesthesia Quotient Inventory (SynQ-i)

Synaesthesia is thought to be an inheritable phenomenon. The following questions are designed to find out how strongly synaesthesia manifests itself in your case. Your answers will help to identify your Synaesthesia Quotient (SynQ). Remember that the questionnaire is not to prove the authenticity of your synaesthesia. For that, you should take other tests.

Do not skip questions – answer all the questions as best as you can.

Read each item and mark the number of the option which comes closest to your synaesthetic experience.

Do not select more than one option per question.

If you have several types of synaesthesia about which you can answer differently, describe your most typical one.

Please pay close attention to whether the question targets the triggers (inducers) or the reactions (concurrents) in your synaesthesia.

We would appreciate your feedback and kindly ask you to send us your experiences and suggestions regarding the content or completion of this questionnaire to: anton.dorso@gmail.com

1. How many types of synaesthesia do you have?
   (1) One type. (2) Two types. (3) Three types. (4) Four types. (5) More than four types.

2. How different are the categories/sets that trigger the individual types of your synaesthesia?
   (1) Almost similar. For example, letter and number graphemes or, alternatively, names of the months and days of the week.
   (2) Rather similar. In the way they feel or what they mean, like pain and emotion or, in a different case, coloured smell and taste.
   (3) Somewhat different but still have something in common, like coloured music and phonemes, or spelling of names and letters.
   (4) Very different. Because my stimuli belong to two different senses, e.g., music and graphemes, or taste and music.
   (5) Drastically different. My stimuli belong to more than two different senses *and* concepts, e.g., names and smell, or numbers and pain.

3. How many sensory elements or qualities do your synaesthetic reactions have?
   (1) They are plain and unblended. For example, sensations of pure colour or just taste.
   (2) They have two properties in one sensory modality. For example, colour is localised.
   (3) They have several properties in one modality. Say, colour, texture and location.
   (4) They spread across two modalities. For example, vision *and* tactility.
   (5) They spread across more than two modalities.

4. Have your synaesthetic reactions changed over lifetime?
   (1) Yes, almost disappeared.
   (2) Yes, they have become vague and/or frayed.
   (3) Yes, some of my stimuli have stopped triggering synaesthesia or/and have become somewhat dimmer.
   (4) Yes, depending on the situation or state I am in, they become less distinct or/and disappear.
   (5) Nothing has changed or changes at all.

5. How do you experience your synaesthetic reactions? (Describe your most typical ones.)
   (1) As persistent knowledge.
   (2) As a sensorial presence in my mind.
   (3) As a sensory impression half in my mind half as a "sensory overlay."
   (4) As an indefinitely located but almost physically tangible sensation/"sensory overlay."
   (5) As a physically tangible sensation located over or emitted by the inducing stimulus.

6. How inclusive/selective are your synaesthetic triggers?
   (1) Very selective because my "triggers" are abstract (notions, names, symbols, etc.).
   (2) They tend to be somewhat selective, not very often present (for example, music, pain, etc.).
   (3) They are very frequent as I encounter them almost constantly (language, people, noise, etc.)
   (4) They are rather broad and embrace almost the entire modality with some exceptions (for example, *almost* all sounds, tastes, or tactile sensations).
   (5) They are very broad and embrace the entire modality with no exceptions (all what I hear, taste, or touch).

7. Which sensory modality or several modalities do your synaesthetic triggers belong to?
   (1) They do not belong to any modality because it does not matter what way I perceive them.
   (2) They are mostly related to vision and hearing.
   (3) They are mostly related to emotion.
   (4) They are mostly related to smell and/or taste.
   (5) They are mostly related to pain, touch or/and inner feelings.

8. Do your synaesthetic reactions appear when you *do not* pay attention to their triggers?
   (1) No, because I definitely need to recognise the trigger first for synaesthesia to appear.
   (2) Hardly, but sometimes my reactions help me tell one trigger from another.
   (3) Difficult to say because my reactions and what triggers them are indiscriminately fused.
   (4) Yes, sometimes. I can experience my reactions without recognising what evoked them.
   (5) Yes, they quite often spring out, even before I recognise their triggers.

9. To what extent can you control or change your synaesthetic reactions?
   (1) Totally, because I can suppress them altogether.

(2) Considerably, though I cannot suppress them but I can noticeably change their qualities: tints of their tastes or shades of their colours, etc.
(3) Partly. I can change their intensity, zoom them in and out, expand them, etc.
(4) A little. I can change them only slightly: dim them a bit down, fuse them with the surrounding, etc.
(5) In no way. My reactions are completely uncontrollable.

10. Are you able to evoke your synaesthesia by merely thinking about the corresponding triggers;that is, without directly sensing the triggers?
(1) No, I need to experience the external triggers for my synaesthesia to appear.
(2) It depends on the type of my synaesthesia, the situation and/or state that I am in.
(3) Yes, but it produces very weak reactions, almost like distant recollections.
(4) Yes, but in such cases my synaesthesia is *not* as pronounced as with immediate stimuli.
(5) Yes, and when I do so, my synaesthesia is as strong and vivid as when I actually experience the triggers externally.

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