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APPROACHES IN SYNESTHESIA RESEARCH: NEUROCOGNITIVE ASPECTS AND DIAGNOSTIC CRITERIA

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ABSTRACT

Synesthesia is a fairly rare phenomenon in which the subject in contact with certain stimulus in one modality experiences unusual extra sensations in other modalities, such as seeing or feeling colours while listening to music or personifying of letters and numbers. The phenomenon was long perceived to be merely a product of imagination and associations. Latest research, however, is based on a multidisciplinary approach, which includes first-hand synesthetic reports, neuroimaging and behavioural tests used in confirming and explaining the phenomenon's presence as well as its neurophysiological foundations. This article presents an overview of such investigations through the lens of cognitive and psychophysical paradigms, neural models and genetic studies of synesthesia.

KEY WORDS

synesthesia, research methods, cognitive, introspective reports, neural

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INTRODUCTION

Synesthesia is a phenomenon in which an otherwise normal person, while being stimulated in one modality experiences an emergence of sensations in other modalities. The original ancient Greek meaning is composed from two words: *syn* (joining) and *aisthēsis* (sensation).

Although it is only for the last 200 years that synesthesia has been scientifically defined, it has for a long time been very well known to the mankind through arts. What distinguishes it from the other mental states are its unvoluntarity and automacy.

Synesthesia was first described by Francis Galton, in "Visualized Numerals" [1], where he presented the types of synesthetic experience accompanying mathematical reasoning or the variations of polymodal experience of mathematical concepts, space and time.

As a proof of their distinctive eidetic memory, the synesthetes state their parallel feelings (for example "I know the result is 2, because it is blue."). Synesthesia can include the spatial dimension. This is particularly noticable in the case of so-called "number forms", where the spatial, formal and colour perceptions get synesthetically merged with semantically organized concepts such as alphabet, temperature, months etc. [2, 3].

In the past synesthesia was often dismissed as being exotic and unreliable simply because the state of synesthetic experience could be verified only via subject's first-hand mental state reports [3, 4]. Since there are no direct tests for synesthesia, everything else are mere interpretive tools. Current studies rely on indirect methods of recording brain activity as well as on some of the newer methods of synesthesia 'verification', which employ the observed 'typical features' characteristic of 'synesthetic' experience as their diagnostic criteria.

Probably the most common form is graphem-colour synesthesia. Particularly due to the availability of comparisons and combining of various methodological approaches, most of the studies and experiments are being adjusted to and focused on this type and its subtypes. The key areas of synesthesia research in the last 20 years are: cognitive and psychophysical studies/theories; neural models/ theories; gene studies and studies of localisation of the phenomena by fMRI and other neuroimaging techniques (MR, CT, etc.) [5].

COGNITIVE AND PSYCHOPHYSICAL PARADIGMS

The cognitive and the psychophysical paradigms in synesthesia research are similar in their approaches. They differ mostly in terms of openness and applicability. The behaviouristically grounded approaches have some problems with processing and verifying the synesthetes' introspective reports, as well as with the conclusions derived from them. Reliability of the reports, for example the ones about synesthetic colours, is sought to be confirmed by means of various experiments.

The most common one is the so-called *Revised Test of Genuineness*. It focuses on verifying or rejecting the assumptions that synesthetic associations differ from ordinary associations and that (perhaps also for that reason) the synesthetes possess a much better memory than non-synesthetes do. The test is based on verifying the automatic mnemonic capabilities or consistent ability of retrieving information (of words, sentences, colours). For synesthetes, this specific "information" acts also as a stimulus for the emergence of synesthetic sensations, which could be crucial for absolute remembrance [3, 5].

One of the oldest approaches is Stroop Color-Word Test of Interference. By manipulating the representations of graphems (words or numbers) it checks the reaction time of subjects over the specific stimulus and identifies the presence of automatic sensory response.

The subjects are tested with a list of colour names printed in coloured ink. For example, the word BLUE is printed in congruent (blue) or incongruent (some other) colour [6]. The response time needed for naming the colour and reading the word is much slower in the incongruent conditions, than in the congruent ones. The Stroop test for synesthesia is conducted in the same way as the classical Stroop test, except that the combinations are adjusted to the synesthetes in the group. For a synesthete who sees the number 2 as blue, a 2 represented in blue would appear as congruent, whereas a 2 presented in any other color would appear to him or her as incongruent. The findings are similar: in case of inconsistency between the graphemes and synesthetic colours, the response times of synesthetes are also slower than in the congruent condition, which leads us to believe that the formation of synesthetic colours takes place automatically and involuntary [3, 6].

Albeit exposing the automacy of sensory perception in synesthesia, both of the tests do not contribute to answering the question, whether the synesthetic perceptions are of conceptual or sensory nature. In the last decade new paradigms are seeking to determine what exactly makes the difference between the perceptions of a synesthete and a non-synesthete.

Ten years ago, neuroscientist Ramachandran designed a popular experiment “pop-out” test, in which he presented to subjects the matrices with different graphemes, measuring afterwards the response time needed for recognizing the positions and numbers of specific graphemes in the matrix. Usually a matrix with number 5’s is used, in the middle of which a triangle composed of 2’s is situated. The control subjects have difficulties in recognising the difference and finding the triangle, whereas to the synesthetes this presents no problem [4, 5, 7].

GENETIC BASIS OF SYNESTHESIA

In his research Galton noticed that significant number of his subjects had relatives who were also synesthetic [1]. Later on nearly all the studies have been mentioning the hypothesis that synesthesia is hereditary. However up to 1990’s only few studies have attempted to determine the frequency of occurrence of synesthesia within a given population or to analyse the synesthetes’ family history [3]. There are major discrepancies in assessing the frequency of synesthesia, as well as in determining its connection to the family pedigree.

Galton, for example recorded high frequency of the phenomenon in a 1:30 ratio in men and 1:15 in women [1]. Studies that were made four decades later reported exactly the opposite. Synesthesia is estimated to be rather rare with the ability for such experiencing ranging to one person in 25 000 [3]. Due to significant variations, the latter mentioned studies possess a merely general informative value. One of the main reasons for their unreliability is inadequacy of the rated groups, which had been put together on the basis of reactions to an newspaper ad. The tests of last ten years estimate the frequency of synesthesia to be as high as 1 in 200 [4]. In spite of methodological rigidity all the past investigations have been confirming important information: there are two additional parameters within the frequency of synesthesia: the sex of the respondents and their family ties.

Modern research techniques have confirmed the assumption that synesthesia has a close genetic linkage. Up to 40 % of the synesthetes have at least one close relative (parent, sibling, offspring) with the same type of synesthesia, whereas in some families even more different types are present [8, 9]. It is estimated that synesthesia is more common in females than in males, however the direct linkage to X chromosome is not yet fully confirmed.

The two main arguments against the abovementioned assumption are imprecision of past methods as well as the comparative studies of monozygotic twins. Cognitive tests in the 80’s and 90’s of the 20th century were namely not focused on precise determination of the genetic

locus and were not considering the possibility of population often being unevenly represented in favour of women. The claim of X-chromosome dominance is being challenged also by some of the latest comparative studies of monozygotic twins, that were not both consistent for synesthesia, and by data which shows that the phenomenon may occasionally skip generations or can be inherited through male line [3]. High rate of synesthesia among family members points to inherited abilities, and may at the same time serve as an affirmative argument for physiological or neurological basis of synesthesia.

Genotype does indeed support and to a certain extent influence predisposition of an individual towards specific talents or personality traits. In a similar manner it also influences one's physical attributes.

Let us take as an example a case of simple, yet specific inheritance of a sensory ability such as the ability to taste the PTC substance (present in pickles) as either bitter or tasteless. The proportion of non-tasters ranges from 20 % in African population up to 30 % in European descendants. The ability to taste PTC as bitter is highly specific in that the substance can be recognised by the "taster" only when dissolved in his own saliva and it is therefore not related to overall taste acuity [3]. Cytowic claims that it is not naive to seek a single-gene determinant for synesthetic ability. The argument for such an assumption are current cases, in which a specific gene determines the occurrence of a complex mental phenomenon, as for instance in Tourette's syndrome, in types of X-linked mental deficits, colour blindness and inherited deafness. Results of the tests done on twins suggest the high influence of the hereditary components on susceptibility for certain visual illusions, eidetic (photographic) memory, various optical illusions (afterimages), spatial orientation and for flicker fusion frequency [3]. Similar examples are certain strongly expressed talents. One of the talents that are supposed to be inherited is the musical ability. The family trees of world's famous musicians such as Bach, Mozart and Beethoven speak in favour of such claims. For this kind of inherited ability it is characteristic to emerge early in life, to improve steadily, and persevere among the gifted, independently from the circumstances. A similar development may be spotted in synesthetes as well in terms of possessing a memory of their trait that goes way back into early childhood and is perceived as a natural part of their perception (the latter applies to the developmental synesthesia but not to the acquired one) [3].

At this point we may establish an analogy between synesthesia and the perfect pitch. The latter phenomenon namely also shows high familial incidence, occurring more often in females and invariably manifesting itself at a very early age. Developmental synesthesia and perfect pitch share some further similarities as well, such as the absolute presence of phenomenon. In both cases the skill emerges naturally without the necessity to develop it trough practice [3, 10].

From neurological point of view the perfect pitch is believed to be located in the left planum temporale, more precisely in the auditory cortex [3, 10]. We shall see later on, the neural models of synesthetic perceptions point to the increased activity taking place exactly in the area of planum temporale during synesthetic experience.

NEURAL MODELS OF SYNESTHESIA

In the 19th century, the popular theories of undifferentiated neural activity suggested that synesthesia was caused by an immature nervous system. They linked synesthesia with the normal syn-kinesis (the joining of voluntary movements with involuntary ones), that can be observed in babies. When baby reaches for a toy, he exhibits a flow of involuntary movements of the body and extremities. With the maturity of corticospinal and cerebellar motor pathways and with acquired myelin insulation, a human being is capable of performing

the fine movements separately without transferring them over to other muscle groups. As synesthesia was for a long time considered to be essentially a mental impairment and an accidental perceptual response, the phenomenon was mistaken for some form of atavism or "sensory incontinence" [3].

Two broader theories of neural basis for synesthesia have been developed. They both derive from the confirmed assumption that synesthesia is a neurophysiologically localised phenomenon.

LOCAL CROSSACTIVATION

On the neurophysiological level the models of synesthesia differ according to their initial questions. The two basic questions from which they begin are namely whether synesthetic experience arises from and is conditioned by failed neural pruning or may there be some kind of inability of reducing the long-range disinhibited feedback from the visual system.

The regions that participate in letter and number recognition (the areas of parietal and central lobe) also lie close to the area that participates in colour processing (V4). Due to the close location of both areas there is a high probability of reinforced linking between the two, which can lead to the so-called crossactivation between the area for the grapheme recognition and V4. We may conclude that the extra-colour experience while seeing graphemes is indeed a consequence of crossactivation of V4 area [2]. As the main reason for crossactivation the pruning model points out failed development of synaptic pruning. The development process of pruning is one of the most important mechanisms of synaptic plasticity in which the connections between brain regions are partially curtailed and eliminated during the development. This insufficient pruning is suggested to be the cause of intensive activation of neural pathways between the brain areas, which in the case of a synesthete leads to increased entry of information and therefore to perceptual cross-wiring [5].

The same model might be applied to other forms of synesthesia. Lexical-Gustatory synesthesia, for instance, could emerge due to increased pathways between areas in the depths of lateral sulcus which participates in processing of taste information and is located next to the frontal lobe and thus next to the areas in charge of processing the auditory information [5, 7]. However, it is crucial to point out that the crossactivation model is a hypothetical one which cannot explain all the forms of synesthesia.

LONG-RANGE DISINHIBITED FEEDBACK

The second theory is based on studies which defend the hypothesis that the causes of synesthesia may be attributed to the disinhibited feedback from a "multisensory nexus", such as temporo-parietal-occipital junction [2]. The principle of disinhibited feedback has been established for a long time already. Its main idea is that the information does not only travel from the primary sensory areas to association areas (i.e. the parietal lobe), but that it also travels in the reverse direction, therefore from "high ordered" cortical regions to basic sensory areas. In cases of ordinary responses there is a balance of excitatory and inhibitory postsynaptic potentials. When, however, the response is not appropriately inhibited, the signals from later stages of processing might influence the earlier processing stages [3].

This process might possibly explain why the activation of visual cortical areas in synesthetes is more intense than in non-synesthetes, when listening to sound tones, for example.

The reports about temporary synesthetic-like experiences as a result of psychedelic drug consumption, also speak in favour of this model [3].

DIAGNOSTIC CRITERIA FOR SYNESTHESIA

Synesthesia has a lot of different combinations and types, which differ in the way of development, as well as in their nature and intensity. Due to the heterogeneity and subjective experiences, it is hard to verify synesthesia in the individual. Research is further complicated by the fact that most synesthetes do not even know that their sensory experience is a surveyed and named phenomenon. A scale of certain common general properties that are said to be characteristic for the experience of individuals with so-called idiopathic synesthesia was developed during the 1980's on the basis of the earlier discussed clinical methods and tests. The table describes following characteristics:

SYNESTHESIA IS INVOLUNTARY AND AUTOMATIC

Synesthetes claim that synesthesia can not be hold back or prevented, neither it can be imagined by using humour. Synesthetic response occurs immediately, regardless of their readiness, as an automatic response to an appropriate stimulus [2, 3, 11]. Thus, for example, even if the presented numbers are masked and poorly visible, they still will provoke synesthetic experience. Strong focus of the tested person's mind on something results in weakening of synesthesia. If, however, the person is consciously aware of the stimulus and is at the same time in a relaxed state, the synesthetic perceptions may become more vivid.

Many synesthetes also report their ability of "going back" to a perception or a particular part of the perception that attracts their attention. In this respect we can speak of a kind of manipulation of attention, which can direct the intensity of synesthesia, however this is not the creation of the phenomenon as such. The automatic synesthetic response to stimulus is characterized by the already mentioned phenomenon of perceptual grouping and "pop-out". Individuals with the same type of synesthesia seldom agree on features of their perceptions (number 2 can be for one synesthete yellow and blue for the other), but what they all have in common is the auto-response to the present stimulus in the appropriate conditions.

SYNESTHETIC PERCEPTIONS ARE CONSISTENT AND SIMPLE

One of the key features of synesthesia, allowing for the authenticity of the phenomenon at the individual level to be easily checked, is continuity of synesthetic responses. Associations are established in childhood and remain constantly present throughout life.

These characteristics are also the basis for the aforementioned Baron–Cohen's ***Revised Test of Genuineness***, a clinical method that has been in use for two decades now and requires direct involvement of the test person. The test is commonly drawn as a questionnaire with 130 examples of letters and words. It involves nine synesthetes and nine control subjects who have to describe the colour associations by means of a given word list. The entire test group is homogeneous in terms of IQ, memory skills, gender and age. Control subjects reconsider the cases of a word list a week later and the testing of the entire group is repeated after about one year. Matching of the two tests can confirm or rule out the condition of synesthesia in individuals. The level of matching responses between the control group and the whole group stands at 92 % and it can thus be assumed that synesthetic associations are not merely result of memorization, but a memory of a different kind, since the memorized words remain stable even after such a long time as a period of one year [5].

Of course, the stability of the association does not necessarily mean the bringing up of the same associations, as these differ from synesthete to synesthete. The subjective report of Baron-Cohen and other authors of 'genuineness test' also show that synesthetic colour associations are not random. For example, the option that letter A is red, is generally much higher than the same letter in blue or golden colour. Although such descriptions are not new, we

do not have explanations for them [4, 9]. There is also a connection between the continuity and automacy of synesthetic performances. They represent the most important criterion for the authenticity of the phenomenon and go together hand in hand. Synesthetes often label their colours as "strange", ones that we ourselves would not have deliberately chosen [11].

A part of the second criterion is the simplicity of synesthetic perceptions that is connected to the latter's non-obtrusive character. In such associations simplicity means that in various tasks synesthetes are "making a choice" within narrowly limited set of associations. A set of synesthetic responses is limited and simple at the same time, because such response is not a complex perception, but rather an unspecified discernible shape.

Synesthetic perceptions always consist of simple flat shapes, because if they went beyond basic shapes, they would become similar to figurative hallucinations [2].

Unobtrusiveness of synesthetic associations refers to a characteristic of a particular stimulus. This means that the association is never separated from the perception of the stimulus, nor does it completely overshadow it. We recognize the sound of the violin because of its distinctive sound, which is different from, for example, the sound of a drilling machine [3, 11]. Forms which a synesthete sensea are part of synesthetic perception itself, meaning that in our case the violin produces a sound of certain shape.

SYNESTHESIA IS MEMORABLE

We have already mentioned that many synesthetes have very good, and sometimes even a 'photographic' memory. Both, the continuity of synesthetic association, as well as a strong ability of their visualization, contribute to this trait. If one asked synesthetes about the positive traits of synesthesia, they would certainly mention that synesthesia helps them "to remember". "Remembrance" as one of the criteria for authenticating synesthesia, is of course here not meant merely as a generally exceptional memory, but it also means ways for retrieving the stimulus. Synesthetic perceptions are in fact semantically empty and do not bear the emotional content by themselves, which might be the reason why they are easier and more vividly memorable, sometimes even more than the original stimulus [3, 4, 7, 10].

Hypermnesia (exceptionally increased capacity for remembering) and synesthesia are mutually connected, since precisely the additional (synesthetic) information is said to enable the precise remembering and recollection of the sequences such as telephone numbers, names, letters, as well as faces and situations. These memories are clear and "vivid" and to the synesthete appear as equally true as the things directly perceived from the environment.

SYNESTHESIA IS SPATIALLY EXTENDED

Synesthetic associations also differ from the imaginary (imagined) ones in the "projection". "The projection" of synesthetic perception means that percept is assumed to actually exists "out there", and not in the imagination. We have already mentioned that the synesthetes visualize the perception, whereby the synesthesia gets "projected" in front of the person as if it was played on a "screen" put in front of the face or body [3, 11].

The main feature of experiencing projected synesthesia is also the "closeness" of performance itself. Synesthetes are often accompanied by a feeling that the association is very close, "at his/her fingertips", so to speak.

The same is also typical for the "weak synesthetes", i.e. those who are sensing synesthesia with their "inner eye". Again, here the synesthetic association also differs from an ordinary illusion or imagination by the presence of a Euclidean space. Therefore, in synesthesia a strong sense of the physical space of the performance itself is present and exposed [3].

The spatial dimension of synesthesia is particularly outstanding and unusual in the perception of the so-called "number forms" in which there is a synesthetic joining of perceptual qualities of spaciousness, shapes, sounds and colours with different semantically regulated entities such as numbers, months, parts of the day, the amount of voice, temperature, alphabet and so on [3].

The most famous are examples of "mental maps" for time, where each day of the week or month of the year associated with the specified colour and shape (corresponding to the synesthete) while experiencing spatially embedded forms. Of course, the colour-design-space forms are unique for every synesthete. These "numeric forms" are often coloured and create simpler forms such as circles, spirals, twists, as well as a variety of curved schemes.

SYNESTHESIA IS IMBUED BY EMOTIONS

While experiencing synesthesia, synesthetes are accompanied by a feeling of authenticity, a kind of "Heureka!" feeling and with a sense of knowledge, with a firm conviction that what they perceive is true. They rely on their synesthetic perceptions and usually find them pleasant (in rare cases, the feeling is physically uncomfortable) [11, 12].

Everyday assignments (for example, calculating, counting, remembering phone numbers or reading) are imbued by brief, but strong emotions, and are experienced either as "very nice" or seem – when being inconsistent with perceptions – "like biting a rusty metal". Let us take for example a synesthete, who associates days of the week and months of the year with colour-form schemes that include tactile experience. Images of the synesthetic nature contain not only colour but also affects. Synesthetic mental scheme is also required to bear specific emotions and feelings of physical and mental comfort or discomfort [12]. In the discussed case this manifests itself by the units in the represented temporal system each having its own colour and emotion, as for instance:

"…Tuesday is a bluish-grey, sky-colour like diluted copper-sulphate solution. Wednesday is a "soft" shade of brown like that of high-grade chocolate. Thursday is coloured similar to Tuesday, but is more highly saturated. Friday consists of shades of red, blue and yellow. The colours are opaque and pigmented. Saturday is brown, like allspice, with a strong tint of yellow" [12].

In other words, Sunday and Friday stand out in the form and therefore represent more emotional experience to the synesthete than do the other days of the week.

CONCLUSIONS

During the early development of scientific thought synesthesia stood mostly in the focus of humanities and only partially within the domain of natural science. Research was being based above all from the theories on metaphores and associations. Another path of development was opened much later when neuroscience was formed.

Due to its inherently subjective nature, synesthesia was for a long time being pushed aside on part of behaviorists and the interest for the phenomenon was thus to be rekindled only in the last two decades of the previous century. During the past two decades it has become possible to speak of a trend of increased interest in synesthesia, that was fostered by increasingly popular focusing on sensoric experience established in cases of synthetic drugs use, rapid development of informational science, growing interest in methodic brain research by means of mesuring devices and – last but not least – by the invention and development of widely avaliable diagnostics in brain research.

One thing is clear: synesthesia is very heterogeneous phenomenon, with multiple causes and varieties of experience. Therefore understanding of synesthesia can provide us a better insight

into cognitive theories in awareness, automaticity, crossmodality, the role of emotions and numerical cognition.

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PRISTUPI ISTRAŽIVANJU SINESTEZIJE: NEUROKOGNITIVNI ASPEKTI I DIJAGNOSTIČKI KRITERIJI

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SAŽETAK

Sinestezija je rijetka pojava u kojoj subjekt, u kontaktu s određenim stimulusima koji djeluju na jedan način, doživljava neuobičajene dodatne osjete, poput vida ili osjeta boja tijekom slušanja muzike ili personificiranja slova i brojki. Ta je pojava dugo bila smatrana samo posljedicom imaginacije i asocijacija. Međutim, zadnja istraživanja temeljena su na multidisciplinarnom pristupu, koji uključuje izvješća u prvom licu o sinesteziji, oslikavanju neuroloških procesa i testovima ponašanja korištenima za potvrđivanje i objašnjavanje prisutnosti pojave sinestezije i njenih neurofizioloških temelja. Rad analizira takva istraživanja sa stajališta kognitivne i psihofizičke paradigme, neuralnih modela i genetskih studija sinestezije.

KLJUČNE RIJEČI

sinestezija, metode istraživanja, kognitivno, introspektivna izvješća, neuralno