



## Personality and cognitive profiles of a general synesthetic trait



Romke Rouw<sup>a,b,\*</sup>, H. Steven Scholte<sup>a,b</sup>

<sup>a</sup> Department of Psychology, University of Amsterdam, Amsterdam, the Netherlands

<sup>b</sup> Amsterdam Brain and Cognition, University of Amsterdam, Amsterdam, the Netherlands

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### ABSTRACT

The recent sharp increase in studies on synesthesia has taught us a lot about this fascinating condition. Still, while we define synesthesia as ‘the mixing of senses’, the great majority of synesthesia studies focus on only one synesthesia type (in particular grapheme-color synesthesia). In this study, a large group of subjects are tested on the presence or absence of different types of synesthesia. Efforts to recruit a representative sample of the Dutch population, not related to or aware of synesthesia as a research topic, helped counter a selection bias or a self-report bias in our subject group. A sharp increase in synesthesia prevalence was found, at least partially due to including many different types of synesthesia in the synesthesia ‘diagnoses’. The five synesthesia types reported in the Novich et al (2011) study were obtained; Colored Sequences, Colored Music, Colored Sensations, Spatial Sequences, Non-Visual Sequelae, as well as an additional synesthesia type, Sequence-Personality. No differences were found between synesthetes and non-synesthetes in education level, handedness, age, and sex. The synesthetes showed increased intelligence as compared with matched non-synesthetes. This was a general effect rather than bound to a specific cognitive domain or to a specific (synesthesia-type to stimulus-material) relationship. The expected effect of increased “Openness” in synesthetes was obtained, as well as two unexpected effects in personality traits (increased “Neuroticism” and decreased “Conscientiousness”). We also found increased “Emotionality” (experiencing emotions) and increased “Fantasizing”, but synesthetes did not differ in cognitive appraisal of emotions (identifying/analyzing/verbalizing of emotions). The personality and cognitive characteristics were found related to *having* synesthesia (in general) rather than to particular synesthesia subtypes. This supports the existence of a general synesthetic ‘trait’, over the notion of relatively independent ‘types’ of synesthesia. In further support, exploratory analyses showed that a measurement of synesthetic strength (number of subtypes of synesthesia) correlates with stronger findings (increased “Openness”, “Fantasizing”, and “Emotionality”, and decreased “Conscientiousness”). In conclusion, results are in line with the notion of a general synesthetic ‘trait’, and this synesthetic trait is associated with particular personality traits and cognitive characteristics.

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### 1. Introduction

The past two decades have seen a steep increase in synesthesia literature. Accordingly, a lot has been learned about this fascinating condition. Yet, it would be just as valid to state that we hardly know anything at all about synesthesia. Almost all synesthesia research includes only one type of synesthesia, and the great majority of these studies are on one particular type, namely ‘grapheme-color’ (linguistic-color) synesthesia. Yet the definition of the condition stresses its broadness: the ‘mixing of senses’, and an important characteristic of synesthesia is that it includes a range of different subtypes (e.g., Cytowic and Eagleman, 2009; Novich

et al., 2011; Nicolai, Jennes, Stoerig, & van Leeuwen, 2012). Currently, we do not know the relationship between the general condition of synesthesia (the “Synesthetic Trait”), and the plurality of different subtypes (“Synesthetic Types”). We also know very little about the scope of the synesthetic characteristics we have acquired so far; are they general characteristics that apply equally to all different types, or are part of these findings in fact specific to the studied type (grapheme-color synesthesia) only? In order to learn about the trait ‘synesthesia’, larger-scale studies are needed that include many different types of synesthesia, and compare this diverse group of synesthetes with a group of controlled non-synesthetic subjects. In this project, we examine the ‘trait’ synesthesia by including a larger set with different synesthesia types. The current study was set up to find different types of synesthesia in a large sample of subjects. The second goal is to examine the general personality and cognitive characteristics of these synesthetes, as compared with non-synesthetes.

\* Corresponding author at: Brain and Cognition, Department of Psychology, University of Amsterdam, Weesperplein 4, 1018XA Amsterdam, The Netherlands.  
E-mail address: [r.rouw@uva.nl](mailto:r.rouw@uva.nl) (R. Rouw).

We also aim to address another issue in synesthesia research, which is sampling bias. In order to include as many synesthetes as possible, researchers are often forced to recruit synesthetes based on the subject's knowledge and recognition of this condition. This means that the tested subjects are most likely not a representative sample. For example, synesthetes have been proposed to show increased cognitive abilities (Brang and Ramachandran, 2011; Rothen et al., 2012). Yet testing this hypothesis might be problematic if a sampling bias in synesthesia studies favors subjects (e.g. with increased cognitive or meta-cognitive abilities) who find it easier to recognize their own condition. Furthermore, synesthetic subjects with a connection to a university (e.g. students) are contacted more easily by synesthesia researchers. Similarly, the female bias obtained in synesthesia has been explained as increased tendency in females, as compared with males, to self-report (Simner et al., 2006; but see Rich, Bradshaw and Mattingley, 2005). This means that some of the found characteristics of synesthesia might be influenced by this gender bias. Studies that recruit subjects on other characteristics and subsequently test these subjects on synesthesia show different prevalence and synesthesia characteristics as compared with the studies where subjects are recruited based on self-referral (Simner et al., 2006). Simner and colleagues (2006) found in a student population higher prevalence, and absence of the skewed male-to-female ratio, if biases in self-report were avoided.

In this study, we address two questions. First, which types of synesthesia are found and what is the prevalence of these synesthesia types in the normal population? We recruited a large (semi-) representative sample of the Dutch population. Recruiting of subjects was done without referring to (or knowledge of) synesthesia. These subjects were then presented with a set of questions probing for the (possible) presence of synesthesia. As we explain in the methods section, the five types of synesthesia obtained in the Novich et al. (2011) study were taken as a starting point, and we included additional questions to explore the possible presence of other types of synesthesia. The second question is whether synesthetes differ from non-synesthetes in their general personality or cognitive profiles. As far as we know this is the first study where different types of synesthesia are searched in a large group of representative subjects (diminishing self-reference or sampling bias), and subsequently tested with a set of personality questionnaires and cognitive tests. We tested three different domains: cognitive ability (intelligence), personality characteristics ('big five'), and emotional/cognitive style.

### 1.1. Cognitive ability and Intelligence

Previous reports have shown increased IQ in the synesthete subjects (Simner et al., 2009; Paulesu et al., 1995). Zamm et al., (2013) found increased connectivity in white matter tracts related to color-music synesthesia, and proposed a possible link between synesthesia and other populations characterized by enhanced local white matter connectivity, such as individuals with absolute pitch, high cognitive intelligence, high emotional intelligence, and high creativity, but also patients with hallucinations and subjects with autistic spectrum disorders (see also Ramachandran and Hubbard, 2001). The current project tests the hypothesis of generally increased intelligence in synesthetes as compared with non-synesthetes (Experiment 1).

Synesthetes have also been found to differ from non-synesthetes in having superior memory ability (though normally not as extraordinary as the famous case of Solomon Shereshevsky from Luria in 1968, for a review see Rothen et al., 2012). Superior memory for word lists has been found in grapheme-color synesthetes, where the graphemes in the words are assumed to elicit colors that subsequently aid memory performance (Radvansky

et al., 2011; Mills et al., 2006; Smilek et al., 2002; Yaro and Ward 2007). Grapheme-color synesthetes have also been found to score above average (but still within normal range) in the concurrent domain (visual as compared to verbal memory). Such advantage in visual memory performance has been found for grapheme-color synesthetes, in different types of memory tasks and even extending to abstract (thus not inducing synesthesia) visual stimuli, (Terhune et al., 2013; Pfeifer et al., 2014; Pritchard et al., 2013; Rothen and Meier, 2010a; Ward et al., 2013). However, superior memory was not always obtained in grapheme-color synesthesia, and case-study findings may be influenced by selection bias or the particular strategic use of synesthesia as a mnemotechnique (see Rothen and Meier, 2009). There are few studies on the memory abilities of other types of synesthesia. Ward et al. (2013) showed that the increased visual memory performance obtained in grapheme-color synesthesia was not found in a non-visual synesthesia type, namely lexical gustatory synesthesia. Sequence-space has a visuospatial component (the concurrent is a spatial configuration). Accordingly, enhanced visual or visuospatial memory has been obtained (Hale et al., 2014; Simner et al., 2009). However, Rothen et al., (2013) found no memory advantage in sequence-space synesthetes for memory of letters or symbols.

Similarly to these 'memory' findings, Meier and Rothen (2013) examined 'cognitive style' and found both effects specifically for certain combinations of stimuli types-to-synesthesia type, as well as general effects. In particular, a large sample of synesthetes containing four different types (grapheme-color, sound-color, lexical-gustatory, and sequence-space) was examined with the VVQ Verbalizer-Visualizer-Questionnaire (Richardson, 1977; Kirby, Moore, and Schofield, (1988). The 'verbalizer' style preference (a preference for verbal representations and an enhanced ability to work with verbal materials) was found related to grapheme-color synesthesia, but not to the other types of synesthesia. In contrast, vivid imagery visualizer style (a preference to let the mind wander and the ability to generate vivid mental images, particularly related to dream imagery) was marginally significant for sequence-space synesthesia, and significantly related to all other types of synesthesia.

Thus, some studies have shown generally increased cognitive performance associated with synesthesia. However, other studies obtained specific effects related to the specific inducer or concurrent of the examined synesthesia type. In the current study, we test the hypothesis that synesthesia is related to increased intelligence. Furthermore, based on the premise that there is such a thing as a *general* trait of synesthesia, rather than only a collection of independent different types of synesthesia, we hypothesize that general effects can be obtained. In particular, we expect to find a general increase of intelligence, regardless of synesthesia type. In addition to such a general factor, possible particular advantages related to congruency between stimulus type and synesthesia type (e.g. grapheme-color to verbal stimulus) are also explored.

### 1.2. Personality and the "Big Five"

Banissy et al., (2013) tested if the atypical experiences of synesthesia are associated with atypical personality profiles. Personality was assessed with the "Big Five Inventory" (BFI, John, Donahue, and Kentle, 1991). Respondents indicated, on a five point Likert scale, the extent to which statements related to the 'big five' personality traits (Extraversion, Agreeableness, Conscientiousness, Neuroticism, and Openness) best describe their own characteristics. Two measures of empathy were also administered, the Inter-Personal Reactivity Index, (IRI; Davis, 1980) and the empathy quotient (EQ; Baron-Cohen and Wheelwright, 2004). A large group (N=81) of synesthetes who all had (minimally) grapheme-color synesthesia was compared with age-

sex matched controls (N=112). The synesthetes were recruited from a database of volunteers at the University of Sussex, while the controls were recruited from the student population and via acquaintances. Banissy and colleagues predicted increased scores for synesthetes on “Openness to Experience”, based on findings of increased artistic inclination in synesthetes (Rich et al., 2005; Ward et al., 2008; Rothen and Meier, 2010b). As ‘Fantasizing’ (a sub scale of the IRI empathy questionnaire) can be construed as conceptually related to Openness to Experience, the authors also predicted increased Fantasizing in synesthetes as compared with non-synesthetes. Banissy et al. (2013) did indeed obtain differences in the personality characteristics of synesthetes and non-synesthetes. As predicted, synesthetes showed increased “Openness to Experience”. In addition, a non-expected decrease in ‘Agreeableness’ was obtained. Furthermore, synesthetes reported higher levels of “Fantasizing”. No general increase in empathy was found.

In the current study, we examine the ‘big five’ personality traits in synesthetes as compared with non-synesthetes. In line with the theoretical arguments put forward by Banissy and colleagues, we predict increased “Openness” and increased “Fantasizing” in the synesthetes. One important difference with the previous study is that several different types of synesthesia are included. However we expect that the same findings are obtained in this group of synesthetes. Openness has been found to correlate with intelligence measurements (Ackerman and Heggestad, 1997; Ashton et al., 2000; DeYoung, 2011; Farsides and Woodfield, 2003), thus the prediction of increased openness is not unrelated to the prediction of increased intelligence. For the other four personality traits (Extraversion, Agreeableness, Conscientiousness, Neuroticism) we have not found clear theoretical connections with synesthesia, and therefore these characteristics will be examined in an exploratory analysis. This analysis also explores if Banissy’s unexpected finding of decreased “Agreeableness” is replicated. As we will explain in the next section, the expected increased ‘Fantasizing’ is measured with a different test (see “Emotional Style”).

### 1.3. Emotional Style

The current study also investigates the link between emotional experiences and synesthesia. Previous studies have shown such association directly (emotions are specific synesthetic inducers or concurrents; Cytowic and Eagleman, 2009; Ramachandran and Brang, 2008; Schweizer et al., 2013; Ward, 2004; for a review see Dael et al., 2013). But the emotional association can also be present in an indirect manner, where the synesthetic experience is related to positive or negative emotions (e.g. because their concurrent is congruent or incongruent with the sensory stimulus; Callejas et al., 2007; Hochel et al., 2009; Perry and Henik, 2013). A neurological basis for this relationship is proposed in theories on hyperconnectivity. Ramachandran and Hubbard (2001) suggested that a mutation that causes hyperconnectivity in synesthesia would also imply increased connectivity between fusiform gyrus (and other sensory cortices) and the limbic system (especially the amygdala and nucleus accumbens). This hyperconnectivity would enhance the pleasurable or aversive associations through limbic reinforcement of concordant or discordant inputs.

Neuroimaging studies have shown functional and structural brain differences in synesthetes, as compared with non-synesthetes, in brain regions functionally related to emotion (e.g., retrosplenial cortex and insula; Nunn et al., 2002; Weiss Shah et al., 2001; Niccolai et al., 2012; Sperling et al., 2006; Specht and Laeng, 2011, Melero et al., 2013). These findings relate synesthesia to differences in experiencing emotions (*emotionality*). This does not necessarily imply increased *cognitive* ability to monitor, assess or reflect on emotions in oneself or in another person (Vorst and

Bermond, 2001). In fact, Amin et al. (2011) found, in a small group of linguistic-personality synesthetes, both increased and decreased scores on an Empathy Quotient (EQ) measurement, in grapheme-personification synesthetes as compared with controls. The current project will test the hypothesis of increased (experiencing of) emotionality in synesthetes as compared with non-synesthetes. Furthermore, the cognitive component of assessing or reflecting on emotions is also examined, but in an exploratory fashion.

One of the scales in the test used to examine Emotional Style is a ‘Fantasizing’ scale. This scale measures *Fantasizing* about virtual matters: “the degree to which someone is inclined to fantasize, imagine, day-dream, etc.”. An example of a (*positive*) item in this scale is: “Before I fall asleep, I make up all kinds of events, encounters and conversations”. The “Fantasy” factor in the IRI (Davis, 1980) that was found related to synesthesia by Banissy et al. (2013), is not exactly the same, as the IRI describes this factor as: “respondents’ tendencies to transpose themselves imaginatively into the feelings and actions of fictitious characters in books, movies, and plays”. However, there is overlap between the concepts measured in these questionnaires. In the IRI, the Fantasy scale consists of six questions; one on the frequency of daydreaming and fantasizing, two about degree of involvement in a book or movie, and three questions on identification with the main characters in a book or movie. The fantasizing scale of the BVAQ has eight questions; five on frequency of daydreaming and fantasizing, two on interest in fairytales and bizarre stories, and one question asks whether fantasizing is a waste of time. Thus, there is overlap in the type of examined behaviors. Furthermore, both questionnaires seem to ask about behaviors related to (visual) mental imagery ability.

Given these similarities, we predict increased “Fantasy” scores on the BVAQ in synesthetes, as compared with non-synesthetes. However, there are also differences between the two questionnaires. Thus, obtaining a relationship between ‘Fantasizing’ and synesthesia again in the current study, will support the notion of a more general relationship between fantasizing/daydreaming and synesthesia, rather than only a specific relationship with a particular questionnaire.

Increased (visual) mental imagery has been found related to the synesthesia trait (e.g., Barnett and Newell, 2008; Price, 2009). This has been more consistently found in imagery tests relying on self-report than in imagery test using objective measurements (Spiller and Jansari, 2008). The increased (self-reported) visual imagery experiences have been proposed to be a critical aspect of visual synesthesia (Galton, 1880; Price, 2009). Simner (2013) suggested that the trends toward high imagery might arise from a recruitment bias, where increased mental imagery leads to increased awareness of the condition and therefore increased likelihood to self-refer. In the current study, recruitment of subjects was performed by a recruitment agency, to obtain a ‘semi-representative’ sample of the Dutch population. In our study, a relationship between the factor “Fantasy” and the synesthetic trait is predicted. Obtaining this relationship in the current project would not easily be explained by self-report bias.

All predictions on personality and cognitive characteristics are tested by contrasting a diverse group of synesthetes with a group of non-synesthetes that were carefully controlled for a possible (weak) presence of synesthesia. This comparison of synesthetes versus these non-synesthetes is the basic comparison in this project, informing us about personality and cognitive characteristics related to having synesthesia (note that both are subgroups of the larger subject group and thus were recruited in identical manner). Second, we also examine if obtained effects are trait-specific or type-specific. As far as we know, this is the first study where prevalence of different types of synesthesia are explored in

a large group of a semi-representative sample (diminishing self-reference or sampling bias), and subsequently tested with personality questionnaires and cognitive tests.

## 2. Material and methods

### 2.1. Participants

The current study is part of the “ID1000” project, where 1000 subjects were tested and participated in MRI recordings. Subjects participated in two separate sessions, the first session was completed via the Internet and the second session was performed at the Spinoza Center for Neuroimaging, in the Amsterdam Brain & Cognition research center. Tests include a large battery of questionnaires; personality, cognitive, and biographical information, such as Handedness (Edinburgh handedness inventory, [Oldfield, 1971](#)) and education level. Education could be one of three levels: Education level was categorized as ‘Low’ if the lower level of high school (‘VMBO2’) is finished, or if less education was followed. Education was ‘high’ when University or College (HBO or WO) was finished or attended at the moment of testing. ‘Medium’ education are all types of training in between. Generally speaking this can be interpreted as applied training, skills training, or college training. The session with questionnaires was followed by behavioral tests, additional questionnaires, and functional and structural brain measurements. An important aspect of this study is that subjects were recruited by a recruitment agency (Motivaction BV) to be representative (gender, education level) for the Dutch population between 18 and 25 years at the moment of inclusion. Recruitment was within this age range to restrict (neuro-anatomical) variance due to age. Because of this age restriction we will refer to this group as a ‘semi-representative’ sample. The recruitment procedure allows to reduce sampling bias, that might otherwise influence obtained characteristics such as intelligence and personality. Moreover, the manner of recruitment is unrelated to interest in (or knowledge about) synesthesia. For practical reasons, not all tests in the ID1000 project were presented to all subjects. The synesthesia questionnaire was presented at a later stage in the project (after more than half of the subjects were already tested). This choice had no relationship to the topic of the questionnaire. 368 Subjects (47.8% females; age range 20 to 26 years) received an extensive questionnaire on synesthesia at the end of the testing day, in addition to successfully completing the other cognitive and neuroimaging experiments of the ID1000 project. This subgroup was not (self-) selected, the inclusion/exclusion criteria were the same for all subjects in the ID1000 project, and all subjects in the batch received this synesthesia test (thus there is no particular recruitment/selection bias for this subgroup). Part of the large set of tests was linked with the information obtained in the synesthesia tests, subjects gave separate permission for this. All subjects gave their written informed consent to participate in the study, which was approved by the local ethics committee of the University of Amsterdam. Subjects received financial compensation for their participation.

### 2.2. Determining Synesthesia

A ‘golden standard’ in diagnosing grapheme-color synesthesia is a consistency test, such as used in the Synaesthesia Battery ([Eagleman et al., 2007](#)). While the standard procedure for calculating consistency is the ‘distance’ between (concurrent) answers in repeated tests of the same (inducing) item, such procedure was not feasible in the current project for both theoretical and practical reasons. First, our study was set up to test a broad range of different types of synesthesia. Most of these synesthesia types are not

present in these consistency procedures. Furthermore, while distances between provided colors (RGB values) can easily be calculated and compared between subjects, no such procedure exists for the distances between most non-visual sensations (e.g., taste), or concepts (e.g., personalities). Consequently, while it is possible to create a single cut-off score for color-distance, and use this for all synesthesia types with color as concurrent, this cannot be translated into a similar and equally strict distance for other all concurrents. Third, we wish to compare (prevalence of) different forms of synesthesia, which makes it critical to maintain the same diagnostic procedure for all synesthesia types. One practical aspect of the testing procedure is that it needed to fit within the testing day of the larger (ID1000) project. Therefore, we designed one single procedure, used for all synesthesia types, to include or exclude subjects as synesthetes.

[Novich et al \(2011\)](#) used online testing to reach an exceptionally large group of subjects. They analyzed the forms of synesthesia reported by 19,133 participants in the Synaesthesia Battery ([Eagleman et al., 2007](#)). Analyses showed patterns of co-occurrence between certain types of synesthesia, revealing five distinct categories of synesthesia types. The large number of subjects, and their careful procedures in creating categories, makes this an excellent starting point for the current study. We also included additional questions to search broadly for other types of synesthesia (either encountered in our own lab or reported in literature).

Each of the five [Novich et al. \(2011\)](#) synesthesia types were included in our test. Subjects indicated if linguistic elements (letters or numbers), and if time elements (days, months, years), evoke color sensations. These two questions were then combined to form the category “Colored Sequences” from Novich and colleagues (which includes the well-known “Grapheme-Color” synesthesia type). A question on experiencing colors to music, musical instruments, or tones tested the “Colored Music” category. The category “Colored Sensations” also entails synesthetic colors, but there are several possible inducers. In this category many different (smaller) types are clustered together. Accordingly, 3 different questions were asked that all pertain to this category: i) Person, personality or emotion have a color, ii) Temperature, touch on the skin, pain or orgasm have a color, iii) Taste in the mouth or scent has a color. The question for the category “Spatial Sequences” asked about synesthetic shapes (a certain location in space, a 3D shape, or on a line) in response to time/sequences (year, months, numbers or letters). For the category “Non-Visual Sequelae”, concurrents are non-visual. This category consisted of 2 different questions, one on synesthetic experiences to sound (sounds have a certain smell or taste, or certain sounds give a touch/sensation on the skin) and one on synesthetic experiences to sights (certain things I see have a certain smell/taste, or certain things I see give me a sensation as if I touch something).

In addition, we asked about synesthesia types that we either encountered in our own lab or that have been reported in synesthesia literature. One additional question asked about personality as synesthetic concurrent ([Simner and Holenstein, 2007](#); [Smilek et al., 2007](#); [Amin, Olu-Lafe, Claessen, Sobczak-Edmans, Ward, Williams, & Sagiv, 2011](#)); do letters, numbers, days, months or other concepts have a personality? [Simner et al., \(2011\)](#) labeled this type ‘sequence-personality synesthesia’. Another question was if sensations, concepts, or words evoke a physical act or gesture, as we have heard reports of words evoking gestures. One question probed lexical-gustatory synesthesia ([Ward, and Simner, 2003](#); [Simner and Ward, 2006](#); [Colzoli et al., 2013](#)), where linguistic elements (words) give a particular taste in the mouth. The final question was a very broad and open question, to probe any type of (possible) synesthesia not yet mentioned (or even not yet discovered). A list of many possible experiences was given as

examples, to help interpret this question. The test ended with the 'hearing-motion' movie of moving dots (Saenz and Koch, 2008), with the question: Do you hear anything while watching this? Subjects indicated their answer on a 5 -point-scale, ranging from 1) hearing nothing at all to 5) hearing it very clearly. If subjects indicate they do -or might- hear something (answer 3–5), a description of the sound is asked. These subjects are also asked to provide examples of other hearing-motion experiences they might have had.

### 2.2.1. Classified as synesthetes

As explained above, a single procedure was devised so that each type in this project could be tested with identical criteria. Therefore, the following procedure was devised. First, for each type of synesthesia, a short description was followed by the question "does this apply to you?" ("is dit op u van toepassing?"). Subjects answered on a 5-point Likert Scale, ranging from 1 (does not apply to me at all) to 5 (completely applies to me). Furthermore, if the answer was 3 or higher, subjects were asked to provide five examples of experiences they have had of this particular synesthesia type. Next, the provided examples were classified into one of 5 categories: The first is 'incomplete answer' which means there was really not enough information to grade the example as good or bad (e.g. 'red' rather than 'my A is red'). The second is 'too few examples' (less than 5). If five full examples were given, they could be 'bad examples', 'good examples', or 'very good examples'. The strength of the examples were rated based on a set of strict criteria.

The first criterion is specificity of the described concurrent (e.g., subjects who indicate to see color with time elements, but gave as example 'everything!', 'seasons' or 'strictly chronological' were not included in the spatial-sequence synesthesia type). We also excluded subjects if the sensations could not be properly named (e.g., 'big closet' or 'depictions' for number form, or naming five musical instruments, each followed by 'non-specific colors'). Also excluded were examples that might be common associations or memories rather than synesthesia (e.g., 'if someone makes the sound of a cow, I imagine I am in the countryside'. Or 'money=concern'/'crowd of people=safety'). Similarly, we excluded common sensations that are not currently regarded synesthesia (e.g., 'screeching sound of a blackboard gives me a tingling sensation on my skin, particularly my back'). The next exclusion criterion was concurrents that are analogous to the inducer (e.g., if all five letters have a color that starts with that letter; w=white, r=red). Such analogous examples were also rejected if they were cross-modality (e.g., 'seeing a jug of peanut butter makes me taste peanut butter', 'sound of pouring coffee makes me smell coffee').

The classification of individual reports was based on this set of pre-defined rules, and performed by a rater. The classification rules were created based on the definition of synesthesia as described in synesthesia literature (see Colizoli et al., 2014). The rater was chosen because from those involved in the study, only this person had knowledge and experience (in terms of meeting and talking with synesthetes, and designing tests of synesthesia) that would aid in applying the rules. The rules were created at the start of the project. While we feel that within the current possibilities this was the strongest procedure for this study, we acknowledge that current choices on in- or exclusion are necessarily somewhat arbitrary in nature. For example, stricter criteria will always lead to less synesthetes included in the study. This has already been shown with varying consistency thresholds (see also "Discussion"). Furthermore, the critical (defining) characteristics of synesthesia are still much debated (e.g., Simner et al., 2012, Cohen Kadosh and Terhune, 2012; Eagleman, 2012). Please note that the classifications were made before merging the subject information with all other results, so that categorization in subject categories was made

without knowledge on how this would influence all other results and analyses.

Each type of synesthesia was assessed per subject, independently of all the other types, and the strength of examples in one question did not affect the assessment of the examples presented in another question. Therefore, assessment of one type of synesthesia did not affect assessment of another type.

### 2.2.2. Not Categorized

All subjects that were not included as 'synesthetes', but also excluded from the non-synesthete group (see below), ended in a third category, 'non-categorized'. Subjects providing bad examples were not categorized as 'non-synesthete' but were in the 'not-categorized' group.

### 2.2.3. Classified as Non-Synesthetes

The 'non-synesthete' group was defined based on more questions than the 'synesthete' group, in order to have a stringent procedure in excluding all possible (weak) forms of synesthesia. Subjects in the 'non-synesthete' group indicated on all questions that they did not recognize that type of synesthesia (including movement-sound). Furthermore, earlier in the testing session of the project, two questions were included that were simple 'yes-no' questions, probing grapheme-color synesthesia and number-form synesthesia. These questions were used as additional check, excluding anyone who (might) recognize these sensations. Another additional question at the beginning of the testing session asked very broadly about any other type of situation where a sensation evokes another sensation, and asked the subjects to describe such situation if they might recognize it. If subjects indicated to have sensations that might possibly refer to synesthesia, or synesthesia-like experiences, they were also excluded from the 'non-synesthete' group.

## 2.3. Intelligence Test

To measure intelligence we used the Dutch adaption (Amthauer, Brocke, Liepmann, Beauducel & Vorst, 2014, Hogrefe, Amsterdam, <http://www.hogrefe.nl/tests-vragenlijsten/producten-singele/ist-intelligentie-structuur-test.html>) of the Intelligence Structure Test 'IST-2000R', Amthauer, Brocke, Liepmann & Beauducel, 1999), an intelligence test battery based on the structural model of intelligence. The IST uses a 3 × 3 design, as three cognitive domains (Reasoning, Knowledge, and Memory) are each tested with three types of items (Verbal, Numerical and Figural). Originally, the IST 2000-R and the Dutch adaption measured the knowledge and reasoning domains with three subtests, and the memory domain with one subtest. In the ID1000 project we have used items supplied by the IST publishers, to expand measuring the memory domain with two additional subtests (extending the original IST with 55 items). These items will be added to the next published version of the Dutch IST. All items presented in the IST are in black-and-white.

'Reasoning' (180 items) includes sentence completion, verbal analogies and similarities (verbal material); numerical calculations, number series and numerical signs (numerical material); embedded figure task, cube rotation and matrix completion (figural material). Each of these nine tests consisted of 20 items. The 'Knowledge' domain (84 items) comprises knowledge on art-literature, geography-history, mathematics, science, and daily life. The items refer to, for instance, names (verbal), years in which events occurred (numerical) and the layout of famous buildings (figural). Each of these nine test consisted of 9 to 10 items. In the current project, additional hypotheses were tested in the 'Memory' domain. Namely, do the specific synesthetic inducer-concurrent relations enhance memory specifically for that type of material?

We will therefore explain this material in more detail. The memory domain consisted of 88 items. The sub scale for verbal memory consisted of three different tests. In the first test, subjects needed to learn a list of words (for instance 'golf'), followed by answering questions about these words (e.g. 'the word that started with a 'g' was a: a) sport b) nutrition c) city d) occupation e) building). Also included was a verbal short term memory test (lists of words that needed to be repeated of increasing length), and a test to measure verbal episodic memory by first reading a story and then having to answer questions about a story the subjects were presented with. The sub scale for numeric memory consisted of three different tests. In the first test a list of numbers was presented, followed by questions about this list (e.g., 'how many numbers were lower than 10'). In the second test subjects were presented with lists of numbers of increasing length that needed to be repeated. In the third test subjects were presented with a story in which numbers played a central role. The sub scale for figural memory consisted of three different tests. In the first test subjects were presented with pairings of non-sense figures, after which subjects indicated which figure was paired with which other figure. These figures were artificial shapes without any particular association or meaning (thus unlikely to evoke synesthesia). In the second sub test subjects were presented with sequences of the above shapes shortly. Next they had to identify which row, of four alternatives, contained the correct figure sequence. In the third test subjects were presented a 'painting' that consisted of many smaller items. After this presentation disappeared subjects had to indicate, from a number of foils, which items had been present.

The IST provides sub scores (for cognitive domains and types of items) as well as a "Total Intelligence" score. In total there were 352 items and the test can last up to 3 hours.

#### 2.4. Personality Test

The NEO-PI-R (Costa and McCrae, 1985), and its shorter version, the NEO-FFI, are psychological personality inventories set up to measure the 'big five' personality traits: Extraversion, Agreeableness, Conscientiousness, Neuroticism, and Openness to experience. The five domains are described (NEO-Personality Inventory - Revised; Costa and McCrae, 1992) as follows.

- *Neuroticism*: identifies individuals who are prone to psychological distress
- *Extraversion*: quantity and intensity of energy directed outwards into the social world
- *Openness to Experience*: the active seeking and appreciation of experiences for their own sake
- *Agreeableness*: the kinds of interactions an individual prefers from compassion to tough mindedness
- *Conscientiousness*: degree of organization, persistence, control and motivation in goal directed behavior

The five factor model has a long history of discussions and scrutinization. Research persistently shows that the five factors account well for individual differences (e.g., Tupes and Christal, 1961; Borgatta, 1964; Norman, 1963), although some researchers have reservations about the specifications being too imprecise or too limited to encompass the domain of personality (e.g., Hogan, 1986; Briggs, 1989). Still, the 'big five' is currently the most extensively used model for personality, and it has repeatedly shown its usefulness across age, culture, different measurement instruments, and over time (within the same individual) (e.g., McCrae and Costa, 1987; Noller et al., 1987). It also has shown its applicability (e.g. in job performance, Barrick and Mount, 1991). In this project we used the short form of the NEO-PI-R, the NEO Five-Factor Inventory (NEO-FFI; Costa and McCrae, 1992). The NEO-FFI

has found support for its reliability, validity and usefulness in a variety of contexts and cultures (e.g., McCrae & Costa, 2004; Robbins, et al. 2001; Zillig, Hemenover, and Dienstbier, 2002), although concerns about its reliability have also been expressed (Caruso, 2000; Hull, et al. 2010).

The NEO-FFI contains 60 items (12 items for each trait). Each item consists of a statement, rated on a 5-point Likert scale ranging from 'strongly disagree' to 'strongly agree'. In this project, we presented the 2007 version (Hoekstra et al., 2007). The test took about 15 minutes to administer.

#### 2.5. Emotional Style

The Bermond-Vorst Alexithymia Questionnaire (BVAQ, Vorst, and Bermond, 2001) was included to measure personality constructs related to emotional experiences as well as ability in identifying and describing emotions. Alexithymia (Sifneos, 1972) is most prominently known as an inability to identify and describe emotions in the self, but is in fact a multi-facet-construct composed of five distinct (yet logically related) salient features (Müller et al., 2004). The Bermond-Vorst Alexithymia Questionnaire (BVAQ, Vorst and Bermond, 2001) is designed to measure these five dimensions of alexithymia. Each dimension is measured by eight items with four positively and four negatively formulated items in reference to the underlying trait. The 40-item self-report comprises two parallel versions of 20 items each. The subject rates each item on a five-point Likert scale, ranging from 1 (strongly agree) to 5 (strongly disagree), with half of the items positively keyed and half negatively keyed. To make the results easier to interpret we reversed end results such that high scores indicate ability (rather than disability) in that particular trait. The Bermond-Vorst Alexithymia Questionnaire (BVAQ) measures the following five traits (from Vorst and Bermond, 2001).

\* *Emotionalizing* (Emotionalizing): the degree to which someone is emotionally aroused by emotion inducing events. An example of a (*negative*) item in this scale is: "When something totally unexpected happens, I remain calm and unmoved".

\* *Fantasizing* about virtual matters (Fantasizing): the degree to which someone is inclined to fantasize, imagine, day-dream, etc. An example of a (*positive*) item in this scale is: "Before I fall asleep, I make up all kinds of events, encounters and conversations".

\* *Identifying* the nature of one's own emotions (Identifying): the degree to which one is able to define one's arousal states. An example of a (*positive*) item is: "When I am distressed, I know whether I am afraid or sad or angry".

\* *Analyzing* one's own emotional states (Analyzing): the degree to which one seeks out explanations of one's own emotional reactions. An example of a (*negative*) item is: "I hardly ever go into my emotions". The scale consists, in the version currently used, out of two scales. One is related to one's own emotions and the other related to the emotions of others.

\* *Verbalizing* one's own emotional states (Verbalizing): the degree to which one is able or inclined to describe or communicate about one's emotional reactions. An example of a (*negative*) item is: "I find it difficult to verbally express my feelings".

Based on the previous findings in synesthesia literature, showing synesthesia to arise from or evoking emotions, as well as relate synesthesia to openness to experience/mind-wandering/visual mental imagery/ fantasizing, two hypotheses were formulated. We expect increased scores in synesthetes, as compared with non-synesthetes, in Emotionalizing. We also predict increased scores in synesthetes, as compared with non-synesthetes, in Fantasizing. There are no expectations on a relationship between synesthesia and the cognitive ability to Identify, Analyze or Verbalize emotions, and these relationships were examined in an exploratory analysis.

Literature shows that 'Alexithymia' is perhaps better not approached as one distinct homogenous phenomenon. In particular, it has been suggested (Bermond, 1997) that Type I alexithymia is characterized by absence of emotional experience, while Type II Alexithymia is characterized by a cognitive (emotional cognition) deficit with sparing of the emotional experience. Furthermore, these different types may be related to different neural mechanisms. A review by Larsen et al., (2003) showed that specifically the cognitive aspects of alexithymia have been found associated with deficits in interhemispheric transfer. In contrast, an absence of the emotional experience, with consequently also no cognitions accompanying the emotion, have been found associated with right unilateral cortical (specifically, orbitofrontal cortex and anterior cingulate cortex) lesions. Thus, it is relevant to formulate specific hypotheses for the emotional and cognitive components of this questionnaire. In the current study, an effect in emotional experiences but not necessarily in emotional cognition or emotional reflective processes is expected. Therefore, an analysis is added to test the proposed relationship of synesthesia with the (second-order) Type I component (Emotionalizing and Fantasizing). In contrast, no particular relationship between synesthesia is expected with the second-order Type II component (Identifying, Analyzing and Verbalizing).

### 2.6. One Trait of (Weaker vs Stronger) Synesthesia? Intercorrelations between test scores

In this section we examine if we can find evidence for 1 trait, general synesthesia, as opposed to specific effects related to specific types of synesthesia. This is done by exploring the relationships between the obtained scores in the different sections (on prevalence, intelligence, personality and emotionality).

### 2.7. Statistical Analyses

All statistical tests were checked on (violated) assumptions, and appropriate measures were taken if necessary. For example, for all analyses, the variables were either normally distributed, the used tests were robust to violation of the normality assumption, or an alternative (e.g. non-parametric) test was used. For brevity, the procedures are not reported for each test individually, but are listed below.

The t-tests used to compare two subject groups (synesthetes versus non-synesthetes; or grapheme-color synesthetes versus non-synesthetes), were always independent-samples t-tests. If Levene's test for equality of variance shows unequal variances in the groups, an adapted t-test is always reported (as can be viewed by the adapted degrees of freedom, thus diverging from  $df = 194$  for synesthetes versus non-synesthetes). T-tests and One-way ANOVAs are considered robust for violation of the normality assumption. Still, in case of violation of the assumption of normal distribution of the dependent variable (as tested with Shapiro-Wilk), we always re-ran the analysis with a Mann-Whitney U test (instead of t-test) or with a Kruskal-Wallis test (instead of the one-way ANOVA). There are no cases where this led to a different (significance) conclusion. In one case, the non-parametric results showed a significant effect instead of a trend, in this one case the non-parametric results are reported in the manuscript (see "Intelligence Domain").

Repeated measures GLM (ANOVA) were used to inspect interactions, such as the interaction between subject group (synesthetes versus non-synesthetes) and stimulus type in the intelligence test (verbal, figural, numerical). If violations of sphericity were obtained (as indicted by Mauchly's test of sphericity), but the conclusion was an absence of an effect, no further steps were taken (as this violation makes the test too liberal, corrections would

not alter the conclusion). More specifically, both the 3\*2 interaction between stimulus material and subject group, and the 3\*2 interaction between intelligence domain and subject group, on intelligence scores was not significant, thus are reported despite violation of sphericity.

For all correlation analyses, non-parametric (Spearman) correlations were used (variables in these analyses violated the normality assumption). All statistical analyses were performed with IBM SPSS Statistics for Macintosh, Version 20.0.

## 3. Results

### 3.1. Prevalence of different Types of Synesthesia

In total 368 subjects were tested with the synesthesia questionnaires. Of these, 89 subjects (47 females) were categorized as having one or several types of synesthesia, 107 subjects (53 females) fell in the 'non-synesthete' category, leaving 172 subjects uncategorized. These results show a prevalence of 24.18%, which is a sharp increase as compared to the prevalence commonly cited in synesthesia literature.

Education level could be one of three levels: Education level was categorized as 'Low' if the lower level of high school (VMBO2) is finished, or if less education was followed. Education was 'high' with University or College (HBO or WO) finished or currently attending. 'Medium' education are all types of training in between. Generally speaking this can be interpreted as applied training, skills training, or college training. As expected, no differences were obtained when comparing the synesthetes and non-synesthetes on general characteristics and demographics (see Table 1) such as education level ( $t(194) = 1.57, p = .12, d = 0.23$ ) handedness as examined with the Edinburgh handedness inventory (Oldfield, 1971) ( $t(172) = 1.12, p = .26, d = 0.17$ ), or even length in centimeters (all subjects  $M = 177$  cm,  $SD = 10$ ; synesthetes  $M = 176$  cm  $SD = 9$ ; non-synesthetes  $M = 177$  cm  $SD = 9$ ). Although the groups were similar in age (all subjects  $M = 22.7$  yrs.,  $SD = 1.7$ ; synesthetes  $M = 22.3$  yrs.,  $SD = 1.7$ ; non-synesthetes  $M = 22.8$   $SD = 1.8$ ), and all subjects were in the age range from 20 to 26 years, the non-synesthetes groups had more individuals, with mainly more individuals in the non-synesthete group with age 24 and 25 years. Therefore the non-synesthete group had slightly increased age as compared with the non-synesthetes ( $t(194) = 2.10, p = .04, d = 0.30$ ). Finally, we found that the male-to-female ratio was similar in the synesthete and non-synesthete group ( $t < 1$ ), thus not showing a relationship between sex and presence or absence of synesthesia.

The number of synesthetes per synesthesia type is presented in Table 2. Not included in this table are concept-gesture synesthesia and linguistic-taste synesthesia, as these were not found in the current subject group. The category 'movement-sound' was also removed from analysis. While many subjects indicated hearing

**Table 1**

General demographic characteristics of synesthetes, non-synesthetes, and the overall group.

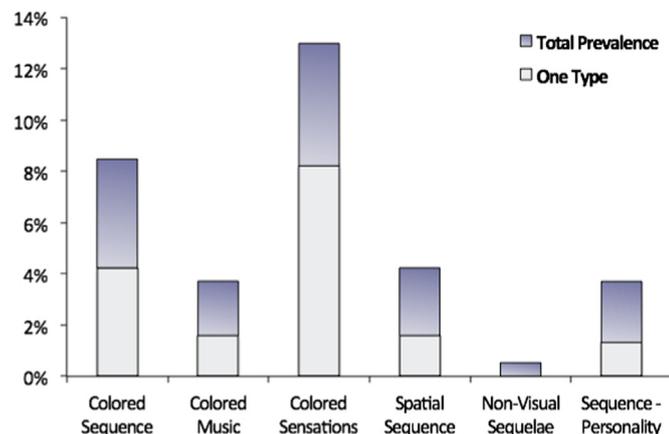
		Synesthete	Non-Synesthete	All subjects
N		89	107	368
Education	High	48.3 %	37.4%	41.3%
	Medium	40.4%	46.7%	46.2%
	Low	11.2%	15.9%	12.5%
Sex	Male	47.2%	50.5%	52.2%
	Female	52.8%	49.5%	47.8%
Handedness	Left	15.7%	10.3%	10.8%
	Right	84.3%	89.7%	89.1%

**Table 2**  
The number of (all) synesthetes with a particular type of synesthesia, followed by the number of synesthetes with *only* this particular type of synesthesia, out of 368 examined subjects. The last 4 columns are the mean scores (and standard deviations) for the four tests/subtests that showed differences for synesthetes and non-synesthetes, presented per type of synesthesia (showing the mean scores of synesthetes with only one type of synesthesia).

Type	Total no. synesthetes (N=89)	No. with only 1 type (N=62)	Intelligence (N=62)	Openness (N=62)	Emotionality (N=62)	Fantasizing (N=62)
Colored Sequences	32	16	194 (49)	42 (5.8)	26 (3.5)	28 (5)
Colored Music	14	6	215 (55)	43 (6.3)	23 (4.6)	28 (2.9)
Colored Sensations	49	29	207 (37)	43 (6.5)	27 (3.9)	29 (6.3)
Spatial Sequences	16	6	216 (39)	39 (8.9)	26 (4.2)	25 (9.2)
Non-Visual Sequelae	2	0				
Sequence Personality	14	5	212 (38)	40 (5.5)	27 (2.3)	27 (5.5)
<b>Non-Synesthetes</b>			<b>194 (43)</b>	<b>38 (6)</b>	<b>25 (5)</b>	<b>24(7)</b>

something while watching the movie, and almost all could give a description of what they heard (81 subjects), it was very difficult to assess those descriptions. Based on the standard criteria this proved difficult (e.g. is 'boom-boom' a specific enough description of the sound, and is 'the sound of breathing in and out' an analogue description or not?). Moreover, when asked for other examples, almost all of these subjects found it hard to think of such instances, often indicating that they had never thought about this before, and found it hard to remember if they have had similar instances. Unfortunately, it is unclear if this is a difficulty in *re-calling* other examples, or if there *were* no instances of similar synesthetic experiences. Thus, neither assessment of descriptions (either during movie, or recalling other instances) worked properly. As the procedure could not be used to in- or exclude subjects as movement-sound synesthetes, this synesthesia type was removed from further analyses. Note that subjects reporting any additional experience in response to the movie were not included in the 'non-synesthete' control group.

Fig. 1 shows the prevalence (percentage of the total subject group) for each type of synesthesia. As some synesthetes have more than one type of synesthesia, the light bars indicate the percentage with only that particular type of synesthesia. The largest group of synesthetes are the 'colored sensations' type. While this might seem somewhat unexpected, but can at least partly be explained by the fact that this category represents the answers on three questions, each probing for different experiences (ranging from person, to touch, to a taste) that might evoke particular colors. As expected, color-sequence (including grapheme-color but also time element-color) synesthesia also is a common type of synesthesia, followed by spatial sequences and colored music. Personality with sequences is quite common as well (as previously reported, [Simner et al., 2011](#); [Amin et al., 2011](#)), with 14 subjects



**Fig. 1.** Synesthesia prevalence (in percentage of total subject group), per synesthesia type. Colors indicate total prevalence (dark bar) and subjects with only this type of synesthesia (light bars).

giving specific and idiosyncratic descriptions of the personalities. In accordance with the setup in our project of creating types of synesthesia based on experiences that tend to cluster together ([Novich et al., 2011](#)), the majority of synesthetes fell in only one type ( $N = 62$ ). A minority of synesthetes were categorized in two ( $N = 18$ ), three ( $N = 7$ ), or four ( $N = 2$ ) types of synesthesia.

### 3.2. Increased Intelligence in Synesthetes

The synesthetes had higher ( $M = 207.39$ ,  $SD = 40.55$ ) 'total intelligence' score as compared to the non-synesthetes ( $M = 194.19$ ,  $SD = 42.53$ ). This difference is significant ( $t(1,194) = 2.21$ ,  $p = 0.028$ ,  $d = 0.32$ ). Note that this is a difference in mean score, in general the synesthetes have increased intelligence as compared with carefully selected non-synesthetes. The non-synesthetes had followed the exact same recruitment and screening procedure as the synesthetes, thus no (self-report) selection biases can explain this finding. The increased score is a significant but small effect rather than synesthetes scoring outside of normal range. The increase does not imply that all synesthetes score higher than all non-synesthetes; synesthetes' scores range from 90 to 290, and the scores from non-synesthetes range from 78 to 270. Interestingly, the 'non-categorized' subjects behaved as 'in between' group in terms of intelligence ( $N = 172$ ,  $M = 198.17$ ,  $SD = 40.36$ , range 87–270).

#### 3.2.1. Synesthesia Type

Is the overall effect of increased intelligence in fact driven by a particular type of synesthesia? Or is the tendency for increased intelligence related to the general 'trait' of synesthesia? In this analysis, the different types of synesthesia were compared and contrasted. The relatively large subset of synesthetes with only one type of synesthesia was used to examine if intelligence differed between synesthesia types (note that sound-taste category had 2 subjects, both with a second type of synesthesia, which means that there are only 5 categories in this analysis). An one-way ANOVA showed that synesthesia types did not differ from each other on the total intelligence score ( $F(4,57) < 1$ ). A clear comparison between all the synesthesia subtypes, or strong conclusions about specific subtypes, can not be made because some of the subtypes contain only a few subjects. The results do however show that the increased intelligence is not driven by one particular subtype but an overall effect. As can be seen in [Table 2](#), for each synesthesia type the mean intelligence score is similar or higher as compared with the mean intelligence in the non-synesthete group.

Interestingly, the Colored-Sequence type synesthesia was the only subtype where the mean score did in fact not differ from that of non-synesthetes. To test what we would have obtained if this was a traditional 'grapheme-color' synesthesia study, we examined a subset of all synesthetes that specifically report colors

concurrents with numbers or letters as inducers. These were 17 subjects, of which six had only grapheme-color synesthesia, and eleven had grapheme-color synesthesia as well as another sub-type of synesthesia. These synesthetes, which would have been included in the traditional ‘grapheme-color’ synesthesia studies, did show a significant advantage as compared with the group of non-synesthetes ( $t(1,122) = 2.10, p = .038, d = 0.38$ ).

Overall, these results show that the increased intelligence score is not specifically dependent on, or driven by, a particular synesthesia type.

### 3.2.2. Intelligence Domain

Which processes underlie the increased scores on intelligence in synesthesia? In this section, we examine if the obtained increased intelligence scores in synesthetes is a broad and general effect, or if the increased total intelligence score is based in domain or stimulus-type specific effects. First, we test if synesthetes have a specific advantage with a particular stimulus type or in a particular domain of the intelligence test. Next, we examine if increased scores seem related to the use of synesthesia during the test: specific advantages when the stimulus material matches the person’s synesthetic inducer or concurrent.

We first explored if there were differences between synesthetes and non-synesthetes depending on the particular stimulus materials used (the intelligence test was performed with verbal, numerical or figural items). A repeated measures GLM revealed that the overall interaction between stimulus material (verbal, numerical or figural) and subject group (synesthete versus non-synesthete) was not significant ( $F(2,193) = 1.4, p = .25, \eta_p^2 = .01$ ). Thus increased intelligence in synesthetes was a general effect, rather than depend on a particular type of stimulus material.

We next found that the increased total intelligence score was overall, rather than driven by one particular domain. Synesthetes scored higher than non-synesthetes in each domain (Mean and *SD* in synesthetes versus non-synesthetes in Reasoning was 110(26) versus 102(26); in Knowledge 41(11) versus 38(10); and in Memory 56(9) versus 54(11)). A repeated measures GLM revealed that the interaction between domain type (Reasoning, Knowledge, Memory) and subject group (synesthetes versus non-synesthetes) was not significant ( $F(2, 193) = 2.18, p = .12, \eta_p^2 = 0.02$ ).

In exploratory analyses we examined the difference between synesthetes and non-synesthetes for each domain separately. The effect was still significant for general reasoning ( $t(1, 194) = 2.19, p = .03, d = 0.31$ ), and a trend was obtained for knowledge  $t(1,194) = 1.95, p = .05, d = 0.28$ , but it did not reach significance for memory ( $t(1,192) = 1.40, p = .16, d = 0.20$ ). The Kolmogorov-Smirnov test showed that the normality assumption was violated for reasoning  $D(196) = 0.076, p = .007$  and memory  $D(196) = 0.087, p = .001$ . In this particular case, as some results obtained were on the edge of significance, we also report the non-parametric (Mann-Whitney) test. It showed increased general reasoning score in synesthetes (median = 112) as compared with non-synesthetes (median = 106)  $U = 552.0, p = 0.009, r = 0.23$ ; increased knowledge score in synesthetes (median = 41) as compared with non-synesthetes (median = 38)  $U = 538.0, p = 0.007, r = 0.24$ ; but no significant difference for memory score in synesthetes (median = 55) as compared with non-synesthetes (median = 55),  $U = 807.0, p = 0.46, r = 0.07$ . Thus, in both tests, even without multiple comparison correction, no differences between synesthetes and non-synesthetes were obtained in the ‘memory’ domain.

While the effects are small, these results indicate that the overall effect of increased intelligence scores is not driven by increased memory scores. If anything, the general (abstract) reasoning domain showed the clearest advantage for synesthetes. Together, these findings indicate that increased intelligence is

obtained in synesthetes as compared with non-synesthetes, and that this advantage is not bound to particular advantages related to domain-specific effects.

*Memory substest.* Past research has shown both general memory advantages and specific cognitive advantages related to synesthesia type. In the current project, a general intelligence test with a memory component was presented, rather than a memory test specifically tailored to measure the effects of synesthesia. So far, it seems a general increase in intelligence score was obtained, rather than memory domain- and synesthesia type specific advantages. In our test, a general memory advantage was not obtained in synesthetes versus non-synesthetes. We next test whether specific memory advantages (specific memory advantage corresponding to the particular type of synesthesia) were present. We thus tested specific relationships between item-material and synesthesia-type in the memory tests. Our first test examined if memory on figural material was better in synesthetes with color concurrents (Ward et al., 2013). All synesthetes with colored concurrents in their (only) synesthesia type were combined in one group (thus synesthetes with only colored-sequence, only colored-music, or only colored-sensations,  $N = 51$ ). This synesthetes were compared, in an independent-samples t-test, to the non-synesthete group ( $N = 107$ ). Yet, this ‘color-concurrent’ synesthete group did still not show improved figural memory performance as compared with the non-synesthetes ( $t(1,132) = 0.9, p = .37, d = 0.16$ ). Similarly, we combined in one group all synesthesia types with numbers and/or letters as inducers ( $N = 27$ , colored-sequence, spatial-sequence, and sequence-personality), which might enhance numerical and/or verbal memory (Radvansky et al., 2011). Again, no effect of synesthesia as compared with the non-synesthetes was obtained in either numerical or verbal memory ( $t(1,132) < 1$ ). These results suggests that the increased intelligence score is not driven by particular memory advantages related to particular synesthesia types.

### 3.3. Personality Characteristics of Synesthetes

The NEO-FFI showed differential patterns for synesthetes and non-synesthetes. Conform the hypothesis, there was a clear effect of increased ‘Openness’ in synesthetes, as compared with non-synesthetes ( $t(1,194) = 5.55, p < .001, d = 0.80$ ). In addition, we explored the other four characteristics, with Bonferroni correction for FWER at a threshold of  $p = 0.0125$ . This showed increased Neuroticism ( $t(1,194) = 3.51, p = .001, d = 0.50$ ), and decreased Conscientiousness ( $t(1,194) = -3.20, p = .002, d = 0.46$ ) in synesthetes as compared with non-synesthetes (see Table 3). Extraversion and Agreeableness did not show a relationship with synesthesia ( $t < 1$ ). Next, for each personality trait that showed differences between synesthetes and non-synesthetes, we found that the scores did not differ between the synesthesia subtypes; Openness ( $F < 1$ ), Neuroticism ( $F(4,57) = 1.50, p = .21, \eta^2 = 0.095$ ) and Conscientiousness ( $F(4,57) = 1.36, p = .26, \eta^2 = 0.087$ ). In other words, the synesthetes with only one type of synesthesia

**Table 3**

Mean score (and standard deviation) on each of the five personality traits, comparing synesthetes to non-synesthetes. The last column presents the mean score (and standard deviation) of all subjects in the total (ID1000) project.

Personality Trait	Synesthesia (89)	Non-Synesthete (107)	All Subjects (965)
Neuroticism	34.58(6)	31.51(6)	32.47(6)
Extraversion	40.96(5)	41.79(6)	41.64(6)
Agreeableness	39.58(7)	40.14(6)	40.25(6)
Conscientiousness	36.29(6)	39.04(6)	37.75(6)
Openness	43.37(6)	38.49(6)	40.87(6)

do not differ from each other on their scores on these personality traits. As the increased “Openness” was predicted to differ for synesthetes versus non-synesthetes, the mean scores per synesthesia type for Openness are presented in Table 2. This again shows that the effect was overall (slight increase of “Openness” in all synesthesia types) rather than driven by a particular type of synesthesia.

We also examined if ‘Openness’ is related to intelligence, as has been reported in literature (Ackerman and Heggestad, 1997; DeYoung, 2011). Increased Openness was found related to increased intelligence ( $r_s(196) = .23, p = .002$ ). In the non-synesthetic group, this general effect was obtained ( $r_s(107) = .20, p = .036$ ). In the synesthetic group, the effect did not reach significance ( $r_s(89) = .19, p = .08$ ). This correlation is not significant but the obtained correlation is in the same direction.

### 3.4. Synesthetes have increased Emotionality

As expected, the synesthetes, as compared with non-synesthetes, scored significantly higher on the ‘Fantasizing’ scale ( $t(1,194) = 4.83, p < .001, d = 0.69$ ). The expected increased ‘Emotionality’ in synesthetes was also obtained ( $t(1,193) = 2.77, p = .006, d = 0.40$ ; corrected for non-equal variances). The relationship between synesthesia and ‘Identifying’, ‘Analyzing’, and ‘Verbalizing (self or others)’ was examined exploratory (with Bonferroni correction). None of these tests showed any difference between synesthetes and non-synesthetes (all tests  $t < 1$ ).

The relatively large subset of synesthetes with only one type of synesthesia was used to test if the scales that differed between synesthetes and non-synesthetes (‘Fantasizing’ and ‘Emotionality’) showed differential effects for the different types of synesthesia. This one-way ANOVA showed that synesthesia types did not differ from each other on ‘Fantasizing’ ( $F(4,57) < 1$ ) or on ‘Emotionality’ ( $F(4,57) = 1.92, p = .12, \eta^2 = 0.19$ ). In Table 2, the scores per type are presented, showing that the increased scores in synesthetes on these scales is an overall effect rather than bound to a particular synesthesia type.

As explained previously, an additional analysis tested the proposed relationship of synesthesia with second-order Type I component (Emotionalizing and Fantasizing), as contrasted with (the absence of) the relationship with second-order Type II component (Identifying, Analyzing and Verbalizing). A repeated measures GLM showed that the interaction between subject group (synesthetes versus non-synesthetes) and Component (Factor I versus Factor II) was significant ( $F(1, 194) = 21.33, p < .001, \eta_p^2 = .10$ ).

### 3.5. A general ‘Synesthetic Trait’?

Results in this study are in line with the notion of a ‘general trait’ of synesthesia. If there is a general synesthetic trait, does that mean that it is possible to have ‘stronger or weaker’ synesthesia (e.g., Ramachandran and Hubbard, 2001; Martino and Marks, 2001)? An example of a ‘supersynesthete’ would be Luria’s Shereshevsky, where a stimulus in one modality produced a reaction in every other modality (Luria, 1968). The idea is that having several, different types of synesthesia, reflect stronger (‘super’) synesthetes. We measured the number of types of synesthesia for each synesthete, with the assumption that more types of synesthesia would indicate a stronger presence of the ‘trait’ synesthesia. Next, we examined if the relationships (found in the previous sections) with certain personality and cognitive characteristics, can again be obtained *within* the group of synesthetes, based on number of types (‘strength’) of synesthesia. An advantage of this measurement is that the ‘number of types’ is not related to the scores on the presented intelligence tests and questionnaires, and thus is independent from the other (synesthesia)

measurements. A disadvantage is that the range is limited; synesthetes ranged from 1 to 4 types of synesthesia (and the latter category contains only 2 synesthetes).

Spearman’s rank order correlation showed that the number of types of synesthesia correlated with “Openness”, with more types of synesthesia related to the strongest increase of Openness ( $r_s(89) = .33, p = .002$ ). Exploring correlations with the other personality characteristics showed no correlations with Neuroticism, Extraversion or Agreeableness. Interestingly, Conscientiousness showed a negative correlation, with less conscientious synesthetes having more types of synesthesia ( $r_s(89) = -.26, p = .013$ ).

Note that these analyses are *within* the group of the synesthetes only, and therefore are independent of the previous reported results, which contrasted synesthetes with non-synesthetes. With the exception of “Neuroticism”, the results in these analyses are in line with the proposal that an increase in the ‘trait’ of synesthesia (as measured in types of synesthesia) is related to stronger effects in the associated personality characteristics; increased Openness and decreased Conscientiousness.

We next analyzed intelligence scores, but found no correlation between total intelligence score and the number of types of synesthesia. Furthermore, exploratory analyses on the three domains and the three item types in the intelligence test showed no correlations. Thus, the relationship is not obtained between ‘stronger’ synesthetes and increased intelligence.

Emotional style was also examined. Both ‘Emotionality’ ( $r_s(89) = .27, p = .01$ ) and ‘Fantasizing’ ( $r_s(89) = .29, p = .005$ ) correlate with number of types of synesthesia. None of the ‘cognitive’ factors (Identifying, ‘Analyzing’, and ‘Verbalizing (self or others)’) showed correlations. Thus, the factors that differ between synesthetes and non-synesthetes also were found related to strength of synesthesia, as measured in the number of subtypes of synesthesia he or she has.

Finally, on each question about specific synesthetic experiences, recognition of this particular type of synesthesia would be indicated by synesthetes by crossing either a 3, 4 or 5 on a Likert scale. One hypothesis is that ‘stronger’ synesthetes will use higher numbers to reply to this question. For each subject we calculate their indicated ‘strength’, but only for the Likert-scale question (s) corresponding to their verified synesthesia type. For subjects with more than one type of synesthesia, the mean of all responses (indicated number) was taken. This measurement of strength of ‘recognition of the experience’ as indicated by the synesthetes on the Likert scale, did also correlate with ‘strength’ of synesthesia as reflected in the number of types of synesthesia ( $r_s(89) = .44, p < .001$ ).

Overall, these analyses are of exploratory nature, and some of the obtained correlations are weak. Still, all results are in line with a model that a general trait of synesthesia may be more weakly or more strongly expressed. Note that it is not at all obvious that variations in the number of types of synesthesia necessitates the view that synesthesia is a continuous dimension in terms of underlying gene expression (see also Ward and Simner, 2005). The results do show, however, that the obtained related personality and cognitive characteristics are associated the strongest with the ‘stronger’ cases of synesthesia.

## 4. Discussion

In this study, we examined prevalence of different types of synesthesia in a (semi-) representative sample of the Dutch population. Furthermore, personality and cognitive characteristics were compared between synesthetes and non-synesthetes. In this setup, including several different types of synesthesia, we obtained a prevalence rate of synesthesia of 24%.

This rate is strongly increased as compared with most previous studies (Johnson et al., 2013, but see Barnett et al., 2008). This may at least partially be due to less stringent selection criteria. The Eagleman et al. (2007) (color) consistency scores could not be used in the current study, as not all synesthesia subtypes had color concurrents. Furthermore, while it would have been interesting to test a subgroup of our synesthetes (the grapheme-color synesthetes), with the standardized (grapheme-color) consistency test (Eagleman et al. 2007), the setup of the current project did not allow to contact and re-test subjects after the experiment. Adding more selection criteria, e.g., based on consistency, could have resulted in a lower prevalence rate. An interesting question is whether individuals failing the consistency test (as their concurrents are more changeable) necessarily are not synesthetes at all (see Simner, 2011; Niccolai, Jenness, Stoerig & van Leeuwen, 2012). Niccolai et al. (2012) found modulations of the synesthetic experiences (including changes of the concurrent color) in 17% of their synesthetic participants. They note that ‘the exclusion of low-consistency synesthetes may result in a generalization of findings to a population that is actually more varied’. Recruiting procedures may also have influenced prevalence rate, as Mann et al. (2009) reported a prevalence of 26% for time-space in a sample of undergraduates not specifically recruited to test synesthesia. Finally, the increased prevalence rate of course also reflects the effect of including many different, rather than only a single, subtype of synesthesia. If only the ‘grapheme-color’ synesthetes (color-to-letter or color-to-numbers) had been studied, not taking into account other types of synesthesia, the prevalence rate would have been 4.6% (prevalence was 1% in Simner et al. 2006; and 2% in the control group of Rothen and Meier, 2010b). If estimates of different forms of synesthesia (not just grapheme-color) are presented, the prevalence is much higher (23% in Barnett et al., 2008; 54% in Baron-Cohen et al., 1996).

In terms of different types, one synesthesia type that was common in our sample was “Colored Sensations”, which clusters all synesthetes where non-lingual inducers (e.g., personality, temperature, pain, taste) have color concurrents. Another common type was “Colored Sequence” synesthesia, where letters, numbers or time elements evoke colors. Next in prevalence were Colored Music, Spatial Sequences, and Sequence-Personality (letters, numbers, days, months or other concepts have a personality). Only two synesthetes in our sample also experienced “Non-Visual Sequelae” (concurrents are non-visual; in this case sound-to-taste). We did not find lexical-gustatory synesthetes in our sample, even though the questions probing this type of synesthesia were quite broadly formulated.

Of course, there are still other types of synesthesia that were not included in our current study, in particular synesthesia types related to having a particular expertise (Nikolić et al., 2011; Carroll and Greenberg, 1961; Loui et al., 2012). Thus, while successful in including many different types in our synesthesia sample, we acknowledge that the selection was not exhaustive. Furthermore, the category ‘movement-sound’ could not properly be assessed in our current analyses. In future research, new diagnostic measurements might need to be developed to properly incorporate this synesthesia type as well. In fact, there is ongoing discussion about the correct way of ‘defining’ synesthesia (Simner, 2012; Colizoli et al., 2014) and consequently the diagnosing procedures are also a topic of discussion. The current results show the relevance of diagnosing strategies that allow using the exact same procedures for very different types of synesthetic concurrents.

The great majority of our obtained synesthetes have color concurrents. Ward and Simner (2007) as well as Niccolai et al. (2012) found in their group of synesthetes a higher prevalence for color concurrent (e.g., music-color) as synesthesia types, while synesthetic experiences in other sensory modalities (taste, pain/

touch, smell, sound) were far less common. It is possible that a bias in the types of questions asked in the diagnostic procedure, skews the prevalence rate in favor of color concurrents. Perhaps there are more (possibly even yet unknown) types that involve very different types of experiences. While we included some very broad questions to probe all different types of synesthesia, it is possible that our questions were still not adequate. On the other hand, it is also possible that color is indeed the most common synesthetic concurrent. This could be due to color categories already being present in pre-linguistic infants (e.g., Bornstein et al., 1976; Franklin and Davies, 2004; Clifford et al., 2009). Possibly, the early presence of these categories makes it easier to use them in synesthesia to ‘map on’ the other, newer and more complex, categories.

The second question addressed in this project is whether synesthetes differ from non-synesthetes in their general characteristics, personality traits, or cognitive profiles. We found no difference between synesthetes and non-synesthetes in the simple and general characteristic of handedness, which replicates earlier findings (e.g., Ward and Simner, 2005; Rich et al., 2005). Furthermore, we found that the prevalence of synesthesia did not differ for males and females. Early studies reported a higher prevalence for synesthesia in females than in males (Baron-Cohen et al., 1996). However, a skewed female-male ratio has been obtained in self-referred samples (Ward and Simner, 2005; Rich et al., 2005; but see Barnett et al., 2008). In an important paper, Simner et al., (2006) proposed that if sampling does not rely on self-referral, a much higher prevalence rate of synesthesia is found than was previously assumed, and furthermore the asymmetry in the distribution of synesthesia across sexes disappears. The current study, testing everybody in a representative sample, and obtaining a higher synesthesia prevalence rate and equal male-to-female ratio in the synesthete and the non-synesthete group, supports this proposal.

Moving to higher cognitive functions, we did obtain a difference between synesthetes and non-synesthetes. Synesthetes showed a small but significant increase in intelligence scores. This increase was a general effect rather than specifically related to a particular synesthesia type. Furthermore, the effect was not bound to a particular domain of intelligence (in particular, it was not present in ‘memory’, and more strongly present in ‘general knowledge’ and ‘reasoning’). While some particular synesthesia-type advantages for particular stimulus material (e.g. better encoding and recognition of figural information in synesthetes with color concurrents) were obtained, in general the effects obtained were unrelated to such relations. Results are in line with a general increase of intelligence related to the ‘trait’ of having synesthesia. We did not obtain inducer/concurrent specific memory advantages in our intelligence test.

Similarly, in a personality test, the expected effect of increased “Openness” was obtained, as well as unexpected effects of increased “Neuroticism” and decreased “Conscientiousness”. Furthermore, a questionnaire on characteristics of emotionality showed increased experience of emotions (Emotionality) and increased ‘Fantasizing’. In contrast, three scales on the cognitive aspect of assessing emotions (Identifying, Analyzing and Verbalizing) did not show differences between synesthetes and non-synesthetes.

These findings are of interest in the light of the suggested relationship between autism spectrum disorders and synesthesia, finding increased synesthetic traits in a group of people with autism (Baron-Cohen et al., 2013). The results presented here (increased openness to experiences, increased emotionality, and no difference in self-rated skill in assessment of emotions) are not in line with characteristics of autism spectrum disorder (deficits in social communication and social interaction, restricted repetitive

patterns of behavior; see DSM V, American Psychiatric Association, 2013). Our current results therefore do not suggest increased autistic traits in the synesthetic group. This could mean that the relationship obtained is in one direction only (increased synesthesia in autism but not vice versa). Or perhaps there are overlapping characteristics between the two conditions, but these are not addressed in the current study.

In all of our findings, we found a general increase over all types of synesthesia rather than evidence for the effects being bound to a particular type of synesthesia. In an exploratory analysis, we defined 'stronger' synesthetes as having more types of synesthesia. This (exploratory) measurement of 'strength' of the trait of synesthesia, correlated positively with "Openness" and negatively with "Conscientiousness". It was also positively correlated with "Emotionality" and 'Fantasizing', and not related to the cognitive aspects of assessing emotions. While only a first step, these findings are promising in finding properties related to a general trait of synesthesia.

One possible problem in this project would be that the synesthetes had a general tendency or general response bias, which would explain both their tendency to indicate synesthesia, and their tendency to obtain deviant scores in the different measurements. We would argue, however, that this was not the case. First, the intelligence test is an ability test, it is hard to 'fake' better performance on such task based on conscious or unconscious response biases. If the synesthetes would have only used a 'trick' (e.g., based on mnemonic strategies), this would have led to more specific (synesthesia-type) effects. Such specific relationships between testing material and type-of-synesthesia were not obtained. Second, the obtained effects on the self-report questionnaires were specific enough to counter an explanation based on general response biases. For example, there was an increased tendency to report emotionality on the emotionality scales, but this tendency was not found on the cognitive scales of the same questionnaire. Similarly, there was an increased Openness in synesthetes, but other scales of this questionnaire showed decreased report (Conscientiousness) or no effects in the synesthetes (Agreeableness, Extraversion). These results suggest that the subjects did not generally increase their response in 'recognizing' any statement about their personal experiences. Instead, the general and smaller effects currently obtained, are in line with synesthesia related to general differences, e.g. in developmental pattern, in cognitive profile, and in brain function / structure. Such differences could give otherwise normal and healthy individuals a small but significant advantage such as the ones obtained in the intelligence scores.

We wish to stress that although a general relationship between synesthesia, intelligence and particular personality characteristics is obtained in the current study, this does not inform us about the directionality of these relationships, nor about the way these relationships fit in an overall model (we wish to thank an anonymous reviewer for bringing this issue to our attention). As often in psychological studies, the concepts and measurements may not be fully independent, but may be related at measurement and/or conceptual level (e.g. intelligence and openness). While our results can be interpreted to suggest that the obtained between-group differences are found *because* of synesthesia, (or another general underlying factor), this is currently unknown. Another, perhaps more elegant, way to look at these multiple interdependencies is from the perspective of an interactive developmental model. Rather than one particular characteristic 'leading' the others, such viewpoint assumes many interactions between both cognitive and biological processes. Not only the starting genotype is important, but also how the biological and behavioral characteristics influence each other during development of the individual. This developmental perspective allows flexible shaping of cognitive and

biological properties in response to experiences with, and actions in, the subject's environment. Causality explained as mutual reciprocal patterns rather than based on one general (latent) variable has been suggested not only in synesthesia research (e.g., Mitchell, 2011), but also in other fields such as intelligence research (e.g., Van Der Maas et al., 2006). According to the 'Interactive Specialization' account, during development cortical regions specialize in their response properties in interaction and competition with each other, and furthermore these response properties are partly determined by patterns of connectivity to other regions (Johnson, 2000, 2011). This account has been applied to diverse fields including face processing (e.g. Joseph et al., 2011) and developmental anomalies (Johnson et al. 2002).

In conclusion, current results show that it is worthwhile to broaden our view on synesthesia, and include the many different types of synesthesia in our models. Current results provide the satisfying suggestion that the previously obtained results with one particular type of synesthesia, will be relevant to synesthesia in general, and thus to other types of synesthesia as well. Previous genetic and family-based studies have suggested that the biological predisposition is to *having* synesthesia, not to having particular types of synesthesia (Barnett et al., 2008; Ward and Simner, 2005; Bargary and Mitchell, 2008). Putting these findings together, we propose the existence of a general trait of synesthesia. Under the influence of familial/genetic factors, and mediated by differences in brain structure and brain functioning, synesthetic individuals develop that differ not only in their sensory experiences but also in personal, cognitive and emotional characteristics.

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## References

- Ackerman, P.L., Heggestad, E.D., 1997. Intelligence, personality, and interests: evidence for overlapping traits. *Psychol. Bull.* 121 (2), 219.
- Amin, M., Olu-Lafe, O., Claessen, L.E., Sobczak-Edmans, M., Ward, J., Williams, A.L., Sagiv, N., 2011. Understanding grapheme personification: a social synaesthesia? *J. Neuropsychol.* 5 (2), 255–282.
- Ashton, M.C., Lee, K., Vernon, P.A., Jang, K.L., 2000. Fluid intelligence, crystallized intelligence, and the Openness/Intellect factor. *J. Res. Pers.* 34, 197–207.
- Banissy, M.J., Holle, H., Cassell, J., Annett, L., Tsakanikos, E., Walsh, V., Spiller, Ward, J., 2013. Personality traits in people with synaesthesia: do synaesthetes have an atypical personality profile? *Pers. Individ. Differ.* 54 (7), 828–831.
- Bargary, G., Mitchell, K.J., 2008. Synaesthesia and cortical connectivity. *Trends Neurosci.* 31 (7), 335–342.
- Barnett, K.J., Finucane, C., Asher, J.E., Bargary, G., Corvin, A.P., Newell, F.N., Mitchell, K.J., 2008. Familial patterns and the origins of individual differences in synaesthesia. *Cognition* 106 (2), 871–893.
- Barnett, K.J., Newell, F.N., 2008. Synaesthesia is associated with enhanced, self-rated visual imagery. *Conscious. Cogn.* 17 (3), 1032–1039.
- Baron-Cohen, S., Burt, L., Smith-Laittan, F., Harrison, J., Bolton, P., 1996. Synaesthesia: prevalence and familiarity. *Perception* 25, 1073–1079.
- Baron-Cohen, S., Wheelwright, S., 2004. The empathy quotient: an investigation of adults with Asperger syndrome or high functioning autism and normal sex differences. *J. Autism Dev. Disord.* 34, 163–175.
- Baron-Cohen, S., Johnson, D., Asher, J., Wheelwright, S., Fisher, S.E., Gregersen, P.K., Allison, C., 2013. Is synaesthesia more common in autism? *Mol. Autism* 4, 2–7.
- Barnett, K.J., Finucane, C., Asher, J.E., Bargary, G., Corvin, A.P., Newell, F.N., Mitchell, K.J., 2008. Familial patterns and the origins of individual differences in synaesthesia. *Cognition* 106, 871–893.
- Barrick, M.R., Mount, M.K., 1991. The big five personality dimensions and job performance: a meta-analysis. *Pers. Psychol.* 44 (1), 1–26.
- Bermond, B., 1997. Brain and alexithymia. In: Vingerhoets, A., van Bussen, F., Boelhouwers, J. (Eds.), *The (non) expression of emotion in health and disease.*

- Tilburg University Press, Tilburg, The Netherlands.
- Borgatta, E.F., 1964. The structure of personality characteristics. *Behav. Sci.* 12, 8–17.
- Bornstein, M.H., Kessen, W., Weiskopf, S., 1976. Color vision and hue categorization in young human infants. *J. Exp. Psychol.: Hum. Percept. Perform.* 2 (1), 115.
- Brang, D., Ramachandran, V.S., 2011. Survival of the synesthesia gene: why do people hear colors and taste words. *Plos. Biol.* 9 (11), e1001205.
- Briggs, S.R., 1989. The optimal level of measurement for personality constructs. In: Buss, D.M., Cantor, N. (Eds.), *Personality Psychology: Recent trends and emerging directions*. Springer-Verlag, New York.
- Callejas, A., Acosta, A., Lupiáñez, J., 2007. Green love is ugly: emotions elicited by synesthetic grapheme-color perceptions. *Brain Res.* 1127, 99–107.
- Carroll, J.B., Greenberg, J.H., 1961. Two cases of synesthesia for color and musical tonality associated with absolute pitch ability. *Percept. Mot. Ski.* 13 (1) 48–48.
- Caruso, J.C., 2000. Reliability generalization of the NEO Personality Scales. *Educ. Psychol. Meas.* 60 (2), 236–254.
- Clifford, A., Franklin, A., Davies, I.R., Holmes, A., 2009. Electrophysiological markers of categorical perception of color in 7-month old infants. *Brain Cogn.* 71 (2), 165–172.
- Cohen Kadosh, R., Terhune, D.B., 2012. Redefining synaesthesia? *Br. J. Psychol.* 103 (1), 20–23.
- Colizoli, O., Murre, J.M., Rouw, R., 2013. A taste for words and sounds: a case of lexical-gustatory and sound-gustatory synesthesia. *Front. Psychol.* 4.
- Colizoli, O., Murre, J.M., Rouw, R., 2014. Defining (trained) grapheme-color synesthesia. *Front. Hum. Neurosci.* 8.
- Costa Jr, P.T., McCrae, R.R., 1985. *The NEO Personality Inventory manual*. FL: Psychological Assessment Resources., Odessa.
- Costa, P.T., McCrae, R.R., 1992. *Revised NEO personality inventory (NEO-PI-R) and NEO five factor inventory (NEO-FFI) professional manual*. FL: Psychological Assessment Resources, Odessa.
- Cytowic, R.E., Eagleman, D.M., 2009. *Wednesday is Indigo Blue: Discovering the Brain of Synesthesia*. MIT Press, Cambridge.
- Davis, M. H. (1980). A multi-dimensional approach to individual differences in empathy. *JCAS Catalog of Selected Documents in Psychology*, 75, 989–1015.
- Dael, N., Sierro, G., Mohr, C., 2013. Affect-related synesthesias: a prospective view on their existence, expression and underlying mechanisms. *Front. Psychol.* 4.
- DeYoung, C.G., 2011. Intelligence and personality. In: Sternberg, R.J., Kaufman, S.B. (Eds.), *The Cambridge handbook of intelligence*. Cambridge University Press, New York, pp. 711–737.
- Eagleman, D.M., Kagan, A.D., Nelson, S.S., Sagaram, D., Sarma, A.K., 2007. A standardized test battery for the study of synesthesia. *J. Neurosci. methods* 159 (1), 139–145.
- Eagleman, D.M., 2012. Synaesthesia in its protean guises. *Br. J. Psychol.* 103 (1), 16–19.
- Farsides, T., Woodfield, R., 2003. Individual differences and undergraduate academic success: the roles of personality, intelligence, and application. *Pers. Individ. Differ.* 34 (7), 1225–1243.
- Franklin, A., Davies, I.R., 2004. New evidence for infant colour categories. *Br. J. Dev. Psychol.* 22 (3), 349–377.
- Galton, F., 1880. Visualised numerals. *Nature* 21, 494–495.
- Hale, J., Thompson, J.M., Morgan, H.M., Cappelletti, M., Cohen Kadosh, R., 2014. Better together? The cognitive advantages of synaesthesia for time, numbers, and space. *Cognit. Neuropsychol.* 31 (7–8), 545–564.
- Hochel, M., Milán, E.G., Martín, J.M., González, A., García, E.D., Tornay, F., Vila, J., 2009. Congruence or coherence? Emotional and physiological responses to colours in synaesthesia. *Eur. J. Cognit. Psychol.* 21 (5), 703–723.
- Hoekstra, H., Ormel, H., De Fruyt, F., 2007. *Neo PI-R Neo FFI: Big Five persoonlijkheidsvragenlijsten; Handleiding*. Hogrefe, Amsterdam.
- Hogan, R., 1986. *Manual for the Hogan Personality Inventory*. Minneapolis: Natl. Comput. Syst.
- Hull, D.M., Beaujean, A.A., Worrell, F.X., Verdisco, A.E., 2010. An item-level examination of the factorial validity of NEO Five-Factor Inventory scores. *Educ. Psychol. Meas.* 70 (6), 1021–1041.
- John, O.P., Donahue, E.M., Kentle, R.L., 1991. *The big five inventory—versions 4a and 54*. Berkeley. University of California, Berkeley (Institute of Personality and Social Research).
- Johnson, M.H., 2000. Functional brain development in infants: elements of an interactive specialization framework. *Child. Dev.* 71 (1), 75–81.
- Johnson, M.H., 2011. Interactive specialization: a domain-general framework for human functional brain development? *Dev. Cognit. Neurosci.* 1 (1), 7–21.
- Johnson, D., Allison, C., Baron-Cohen, S., 2013. *The prevalence of synesthesia*, Oxford Handbook of Synesthesia. Oxford University Press.
- Joseph, J.E., Gathers, A.D., Bhatt, R.S., 2011. Progressive and regressive developmental changes in neural substrates for face processing: testing specific predictions of the Interactive Specialization account. *Dev. Sci.* 14, 227–241.
- Kirby, J.R., Moore, P.J., Schofield, N.J., 1988. Verbal and visual learning styles. *Contemp. Educ. Psychol.* 13 (2), 169–184.
- Larsen, J.K., Brand, N., Bermond, B., Hijman, R., 2003. Cognitive and emotional characteristics of alexithymia: a review of neurobiological studies. *J. Psychosom. Res.* 54 (6), 533–541.
- Loui, P., Zamm, A., & Schlaug, G. (2012). Absolute pitch and synesthesia: two sides of the same coin? Shared and distinct neural substrates of music listening. In *ICMPC: Proceedings/edited by Catherine Stevens...[et al.]*. International Conference on Music Perception and Cognition (p. 618). NIH Public Access.
- Luria, A.R., 1968. *The Mind of a Mnemonist: A Little Book About a Vast Memory*. Harvard University Press, Cambridge, MA.
- Mann, H., Korzenko, J., Carriere, J.S., Dixon, M.J., 2009. Time–space synaesthesia—A cognitive advantage? *Conscious. Cogn.* 18 (3), 619–627.
- Martino, G., Marks, L.E., 2001. Synesthesia: strong and weak. *Curr. Dir. Psychol. Sci.* 10 (2), 61–65.
- McCrae, R.R., Costa, P.T., 1987. Validation of the five-factor model of personality across instruments and observers. *J. Pers. Soc. Psychol.* 52, 81–90.
- Meier, B., Rothen, N., 2013. Grapheme-color synaesthesia is associated with a distinct cognitive style. *Front. Psychol.* 4.
- Melero, H., Peña-Melián, Á., Ríos-Lago, M., Pajares, G., Hernandez-Tamames, J.A., Álvarez-Linera, J., 2013. Grapheme-color synesthetes show peculiarities in their emotional brain: cortical and subcortical evidence from VBM analysis of 3D-T1 and DTI data. *Exp. Brain Res.* 227 (3), 343–353.
- Mitchell, K.J., 2011. Curiouser and curiouser: genetic disorders of cortical specialization. *Curr. Opin. Genet. Dev.* 21 (3), 271–277.
- Mills, C.B., Innis, J., Westendorf, T., Owsianiecki, L., McDonald, A., 2006. Effect of a synesthete's photisms on name recall. *Cortex* 42 (2), 155–163.
- Müller, J., Bühner, M., Ellgring, H., 2004. The assessment of alexithymia: psychometric properties and validity of the Bermond-Vorst alexithymia questionnaire. *Pers. Individ. Differ.* 37 (2), 373–391.
- Nicolai, V., Jennes, J., Stoerig, P., Van Leeuwen, T.M., 2012. Modality and variability of synesthetic experience. *Am. J. Psychol.* 125 (1), 81–94.
- Nikolić, D., Jürgens, U.M., Rothen, N., Meier, B., Mroczko, A., 2011. Swimming-style synesthesia. *Cortex* 47 (7), 874–879.
- Noller, P., Law, H., Comrey, A.L., 1987. Cattell, Comrey, and Eysenck personality factors compared: more evidence for the five robust factors? *J. Pers. Soc. Psychol.* 53 (4), 775.
- Norman, W.T., 1963. Toward an adequate taxonomy of personality attributes: replicated factor structure in peer nomination personality ratings. *J. Abnorm. Soc. Psychol.* 66 (6), 574.
- Novich, S., Cheng, S., Eagleman, D.M., 2011. Is synaesthesia one condition or many? A large-scale analysis reveals subgroups. *J. Neuropsychol.* 5 (2), 353–371.
- Nunn, J.A., Gregory, L.J., Brammer, M., Williams, S.C.R., Parslow, D.M., Morgan, M.J., Gray, J.A., 2002. Functional magnetic resonance imaging of synesthesia: activation of V4/V8 by spoken words. *Nat. Neurosci.* 5 (4), 371–375.
- Oldfield, R.C., 1971. The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia* 9 (1), 97–113.
- Paulesu, E., Harrison, J., Baron-Cohen, S., Watson, J.D., Goldstein, L., Heather, J., Frith, C.D., 1995. The physiology of coloured hearing A PET activation study of colour-word synaesthesia. *Brain* 118 (3), 661–676.
- Perry, A., Henik, A., 2013. The emotional valence of a conflict: implications from synesthesia. *Front. Psychol.* 4.
- Pfeifer, G., Rothen, N., Ward, J., Chan, D., Sigala, N., 2014. Associative memory advantage in grapheme-color synesthetes compared to older, but not young adults. *Front. Psychol.* 5.
- Price, M.C., 2009. Spatial forms and mental imagery. *Cortex* 45 (10), 1229–1245.
- Pritchard, J., Rothen, N., Coolbear, D., Ward, J., 2013. Enhanced associative memory for colour (but not shape or location) in synaesthesia. *Cognition* 127 (2), 230–234.
- Radvansky, G.A., Gibson, B.S., McNERney, M., 2011. Synesthesia and memory: color congruency, von Restorff, and false memory effects. *J. Exp. Psychol.: Learn., Mem. Cogn.* 37 (1), 219.
- Ramachandran, V.S., Brang, D., 2008. Tactile-emotion synesthesia. *Neurocase* 14 (5), 390–399.
- Ramachandran, V.S., Hubbard, E.M., 2001. Synaesthesia—a window into perception, thought and language. *J. Conscious. Stud.* 8 (12), 3–34.
- Rich, A.N., Bradshaw, J.L., Mattingley, J.B., 2005. A systematic, large-scale study of synesthesia: implications for the role of early experience in lexical-colour associations. *Cognition* 98 (1), 53–84.
- Richardson, A., 1977. Verbalizer-Visualizer: a cognitive style dimension. *J. Ment. Imag.*
- Robins, R.W., Fraley, R.C., Roberts, B.W., Trzesniewski, K.H., 2001. A longitudinal study of personality change in young adulthood. *J. Pers.* 69, 617–640.
- Rothen, N., Meier, B., 2009. Do synesthetes have a general advantage in visual search and episodic memory? A case for group studies. *PLoS One* 4 (4), e5037.
- Rothen, N., Meier, B., 2010a. Grapheme–colour synaesthesia yields an ordinary rather than extraordinary memory advantage: evidence from a group study. *Memory* 18 (3), 258–264.
- Rothen, N., Meier, B., 2010b. Higher prevalence of synaesthesia in art students. *Perception* 39 (5), 718.
- Rothen, N., Meier, B., Ward, J., 2012. Enhanced memory ability: insights from synaesthesia. *Neurosci. Biobehav. Rev.* 36 (8), 1952–1963.
- Rothen, N., Scott, R.B., Meador, A.D., Coolbear, D.J., Burckhardt, V., Ward, J., 2013. Synesthetic experiences enhance unconscious learning. *Cognit. Neurosci.* 4 (3–4), 231–238.
- Saenz, M., Koch, C., 2008. The sound of change: visually-induced auditory synesthesia. *Curr. Biol.* 18 (15), R650–R651.
- Schweizer, T.A., Li, Z., Fischer, C.E., Alexander, M.P., Smith, S.D., Graham, S.J., Forzanarri, L., 2013. From the thalamus with love: a rare window into the locus of emotional synesthesia. *Neurology* 81 (5), 509–510.
- Sifneos, P.E., 1972. *Short-term psychotherapy and emotional crisis*. Harvard University Press, Cambridge.
- Simner, J., 2012. Defining synaesthesia. *Br. J. Psychol.* 103 (1), 1–15.
- Simner, J., 2013. Why are there different types of synesthete? *Front. Psychol.* 4.
- Simner, J., Holenstein, E., 2007. Ordinal linguistic personification as a variant of synesthesia. *J. Cognit. Neurosci.* 19 (4), 694–703.
- Simner, J., Gärtner, O., Taylor, M.D., 2011. Cross-modal personality attributions in synaesthetes and non-synaesthetes. *J. Neuropsychol.* 5 (2), 283–301.

- Simner, J., Mayo, N., Spiller, M.J., 2009. A foundation for savantism? Visuo-spatial synaesthetes present with cognitive benefits. *Cortex* 45 (10), 1246–1260.
- Simner, J., Mulvenna, C., Sagiv, N., Tsakanikos, E., Witherby, S.A., Fraser, C., Scott, K., Ward, J., 2006. Synaesthesia: the prevalence of atypical cross-modal experiences. *Perception-London* 35 (8), 1024–1034.
- Simner, J., Ward, J., 2006. Synaesthesia: the taste of words on the tip of the tongue. *Nature* 444 (7118) 438–438.
- Smilek, D., Dixon, M.J., Cudahy, C., Merikle, P.M., 2002. Synesthetic color experiences influence memory. *Psychol. Sci.* 13 (6), 548–552.
- Smilek, D., Malcolmson, K.A., Carriere, J.S., Eller, M., Kwan, D., Reynolds, M., 2007. When “3” is a Jerk and “E” is a king: personifying inanimate objects in synesthesia. *J. Cognit. Neurosci.* 19 (6), 981–992.
- Specht, K., Laeng, B., 2011. An independent component analysis of fMRI data of grapheme-colour synaesthesia. *J. Neuropsychol.* 5 (2), 203–213.
- Sperling, J.M., Prvulovic, D., Linden, D.E.J., Singer, W., Stirn, A., 2006. Neuronal correlates of colour-graphemic synaesthesia: a fMRI study. *Cortex* 42 (2), 295–303.
- Spiller, M.J., Jansari, A.S., 2008. Mental imagery and synaesthesia: is synaesthesia from internally-generated stimuli possible? *Cognition* 109 (1), 143–151.
- Terhune, D.B., Wudarczyk, O.A., Kochuparampil, P., Kadosh, R.C., 2013. Enhanced dimension-specific visual working memory in grapheme-color synesthesia. *Cognition* 129 (1), 123–137.
- Tupes, E.C., Christal, R.E., 1961. Recurrent personality factors based on trait ratings (ASD-TR-61-97). Aeronautical Systems Division, Personnel Laboratory, Lackland Air Force Base, TX.
- Van Der Maas, H.L., Dolan, C.V., Grasman, R.P., Wicherts, J.M., Huizenga, H.M., Raijmakers, M.E., 2006. A dynamical model of general intelligence: the positive manifold of intelligence by mutualism. *Psychol. Rev.* 113 (4), 842.
- Vorst, H.C., Bermond, B., 2001. Validity and reliability of the Bermond-Vorst alexithymia questionnaire. *Pers. Individ. Differ.* 30 (3), 413–434.
- Ward, J., 2004. Emotionally mediated synaesthesia. *Cognit. Neuropsychol.* 21 (7), 761–772.
- Ward, J., Hovard, P., Jones, A., Rothen, N., 2013. Enhanced recognition memory in grapheme-color synaesthesia for different categories of visual stimuli. *Front. Psychol.* 4.
- Ward, J., Simner, J., 2003. Lexical-gustatory synaesthesia: linguistic and conceptual factors. *Cognition* 89 (3), 237–261.
- Ward, J., Simner, J., 2005. Is synaesthesia an X-linked dominant trait with lethality in males? *Perception-London* 34 (5), 611–624.
- Ward, J., Thompson-Lake, D., Ely, R., Kaminski, F., 2008. Synaesthesia, creativity and art: what is the link? *Br. J. Psychol.* 99, 127–141.
- Weiss, P.H., Shah, J.N., Toni, I., Zilles, K., Fink, G.R., 2001. Associating colours with people: a case of chromatic-lexical synaesthesia. *Cortex* 37, 750–753.
- Yaro, C., Ward, J., 2007. Searching for Shereshevskii: what is superior about the memory of synaesthetes? *Q. J. Exp. Psychol.* 60 (5), 681–695.
- Zamm, A., Schlaug, G., Eagleman, D.M., Loui, P., 2013. Pathways to seeing music: enhanced structural connectivity in colored-music synesthesia. *NeuroImage* 74, 359–366.
- Zillig, L.M.P., Hemenover, S.H., Dienstbier, R.A., 2002. What do we assess when we assess a Big 5 trait? A content analysis of the affective, behavioral, and cognitive processes represented in Big 5 personality inventories. *Pers. Soc. Psychol. Bull.* 28 (6), 847–858.