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Coloured Letters and Numbers (CLaN): A reliable factor-analysis based synaesthesia questionnaire

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A B S T R A C T

Synaesthesia is a heterogeneous phenomenon, even when considering one particular sub-type. The purpose of this study was to design a reliable and valid questionnaire for grapheme-colour synaesthesia that captures this heterogeneity. By the means of a large sample of 628 synaesthetes and a factor analysis, we created the Coloured Letters and Numbers (CLaN) questionnaire with 16 items loading on 4 different factors (i.e., localisation, automaticity/attention, deliberate use, and longitudinal changes). These factors were externally validated with tests which are widely used in the field of synaesthesia research. The questionnaire showed good test–retest reliability and construct validity (i.e., internally and externally). Our findings are discussed in the light of current theories and new ideas in synaesthesia research. More generally, the questionnaire is a useful tool which can be widely used in synaesthesia research to reveal the influence of individual differences on various performance measures and will be useful in generating new hypotheses.

1. Introduction

Synaesthesia can be described as extraordinary perceptual experiences associated with normal sensory or cognitive process. For instance, in grapheme-colour synaesthesia a letter printed in black triggers a highly specific and consistent colour experience. So far, many different forms of synaesthesia have been identified in scientific work, including spatial associations with days and months (time–space synaesthesia; Simner, Mayo, & Spiller, 2009; Smilek, Callejas, Dixon, & Merikle, 2007), tactile experiences elicited from observing touch (mirror-touch synaesthesia; Banissy & Ward, 2007; but see Rothen & Meier, 2013), and even colours evoked by swimming styles (swimming-style colour synaesthesia; Nikolić, Jürgens, Rothen, Meier, & Mroczko, 2011; Rothen, Nikolić, et al., 2013). Not only do many different forms exist, but also the heterogeneity within a particular form is large. For instance, synaesthetic experiences may be perceived in the mind's eye (often referred to as associator synaesthetes) or as if projected onto the synaesthesia inducing stimulus (often referred to as projector synaesthetes) (Dixon, Smilek, & Merikle, 2004; Ward, Li, Salih, & Sagiv, 2007). Yet, by means of conventional statistical analyses (e.g., factor analysis) no psychometrically sound questionnaire exists to assess how different aspects of the heterogeneity of synaesthetic experiences influence performance in various tasks and its underlying neural activation. It is our aim to provide the field of synaesthesia research with such an instrument using standard statistical techniques.

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Questionnaires (and/or interviews) in synaesthesia research have been generally applied for three reasons. Firstly, to assess that the reported experiences are indeed likely to be synaesthesia rather than some other phenomena (e.g. for diagnostic purposes). For instance, questions relating to synaesthesia as a life-long trait, that is consistent and automatic have been used for this purpose (Baron-Cohen, Harrison, Goldstein, & Wyke, 1993; Rothen & Meier, 2010a; Simner, Harrold, Creed, Monro, & Foulkes, 2009; Simner et al., 2006). Secondly, questionnaires have also been applied to reveal the relationship between synaesthesia and other phenomenological experiences or associated personality traits. For instance, to assess the link between synaesthesia and eidetic imagery (Glicksohn, Steinbach, & Elimalach-Malmilyan, 1999) or visual imagery (Barnett & Newell, 2008), to estimate the prevalence of synaesthesia in meditators (Walsh, 2005) or fine art students (Domino, 1989). Moreover and most important in the context of this article, questionnaires have been applied to capture (and quantify) individual differences of the synaesthetic phenomenology.

Questionnaires concerned with individual differences in grapheme-colour synaesthesia almost exclusively focus on the associator–projector type distinction (Rouw & Scholte, 2007; Skelton, Ludwig, & Mohr, 2009). Phenomenological differences between associator and projector type synaesthetes, identified by using the PA questionnaire, are associated with functional and structural differences in the brain (Rouw & Scholte, 2007, 2010; Van Leeuwen, den Ouden, & Hagoort, 2011) and, as such, this measure has some external validity. However, test–retest reliability and factor structure of the questionnaire have never been reported. The analyses performed using the questionnaire assume a single factor structure (along the projector–associator dimension), but this has not been established using techniques such as factor analysis and others have argued that further fractionations are possible (Ward et al., 2007). An illustrated projector–associator questionnaire (i.e., Illustrated Synaesthesia Questionnaire – ISEQ) has been created and shown to produce reliable test–retest results on the basis of a rather small sample of 12 grapheme-colour synaesthetes (Skelton et al., 2009).

The projector–associator distinction has also been linked to various behavioural differences linked to the processing of graphemes and/or colours (e.g., Dixon et al., 2004; Gebuis, Nijboer, & van der Smagt, 2009; Hubbard, Arman, Ramachandran, & Boynton, 2005; Ward et al., 2007). In a synaesthetic version of the Stroop-test, participants must name the real colour of a grapheme and ignore their synaesthesia or, alternatively, name their synaesthetic colour and ignore the real colour (Dixon et al., 2004; Ward et al., 2007). Performance on these tasks has been found to relate to the projector–associator distinction (measured by self-report rather than questionnaire scales). Projector synaesthetes were found to exhibit *stronger* Stroop interference (i.e., RT difference between incongruent and congruent trials) when the veridical colour of the synaesthetic inducers on the screen had to be named in comparison to when the colour of the synaesthetic experiences had to be named. In contrast, associator synaesthetes were found to exhibit *weaker* Stroop interference when the veridical colour of the synaesthetic inducers on the screen had to be named in comparison to when the colour of the synaesthetic experiences had to be named (Dixon et al., 2004). Furthermore, it was found that projector synaesthetes were generally faster in synaesthetic colour naming as compared to veridical colour naming and associator synaesthetes were generally slower in synaesthetic colour naming as compared to veridical colour naming (Dixon et al., 2004; Ward et al., 2007). To date Stroop-type tasks are probably the most often applied tasks in synaesthesia research and very often used to validate genuine synaesthetic experiences (Banissy & Ward, 2007; Nikolić et al., 2011). However, it is important to note that 'synaesthetic' Stroop effects may also be found in non-synaesthetes who have been trained to have similar associations (Meier & Rothen, 2009; Rothen, Nikolić, et al., 2013; Rothen, Wantz, & Meier, 2011). In the present study, we link performance on this task with particular phenomenology and, hence, show that Stroop-type interference is linked to synaesthetic experiences rather than the presence of grapheme-colour associations per se (such as those that may be learned).

Besides the projector–associator distinction, other sources of individual differences exist in grapheme-colour synaesthesia which may also provide valuable information to cognitive scientists, but were only very rarely considered (e.g., Barnett et al., 2008; Rich, Bradshaw, & Mattingley, 2005). For instance, some synaesthetes report vivid synaesthetic experiences whereas others perceive them rather faded. Also synaesthetes differ in the way they use their synaesthetic experiences in everyday life (e.g., as mnemonics). Moreover, whilst synaesthesia is normally defined as being automatic, several of our participants report that, for them, they need to think about the colour before it appears. It is unclear whether this maps onto the projector–associator distinction or is orthogonal to it. Therefore, it is important to assess other sources of individual differences in order to correctly classify a synaesthete and when we try to link performance in a specific task with individual differences in grapheme-colour synaesthesia.

2. Questionnaire

2.1. Method

2.1.1. Participants

We recruited 628 self-referred grapheme-colour synaesthetes – via the synaesthesia research websites of the University of Sussex and the University of Bern, and via different internet platforms relevant to synaesthesia – to complete an online questionnaire and to do an internet based test of consistency to assess the genuineness of their synaesthesia (Eagleman, Kagan, Nelson, Sagaram, & Sarma, 2007). In total 249 participants completed both the internet based test of consistency and the questionnaire. The remaining 379 participants completed the questionnaire, but not the test of consistency. Of the initial 628 participants, 405 participants completed the English version of the questionnaire and 223 participants completed the German version of the questionnaire (cf., Section 2.1.2). Fifty-three participants of the 628 participants completed the questionnaire a second time on another occasion (enabling us to measure test–retest reliability). Hence, the questionnaire has been completed a total of 681 times. This test does not ask for demographic details.

2.1.2. Materials

The original questionnaire consisted of 30 items (Appendix A). All items were related to grapheme-colour synaesthesia. Each item was rated on 5-point Likert-scale (1 strongly disagree, 2 moderately disagree, 3 neither agree nor disagree, 4 moderately agree, 5 strongly agree). We created an English version (Appendix A) and a German version (Supplementary material) of the questionnaire in order to be able to access more participants. The questionnaire consisted of two internet pages. On the first page, there were 21 items specifically related to synaesthetic experiences for letters and numbers. For the purpose of these questions, participants were asked to think about their phenomenology with respect to some illustrative examples of letters (Aa Bb Cc Dd Ee Ff Gg) and numbers (0 1 2 3 4 5 6 7 8 9). The last 9 items were presented on the subsequent internet page and referred to grapheme-colour experiences in general (e.g. outside of the current testing scenario). The specific items were related to the following aspects of synaesthetic experiences: the location of the colour experiences (conceptually related to the projector–associator distinction); the extent to which the colours appear automatically or require effort/attention; the extent to which the participants use their associations in daily life; the extent to which the associations have changed in intensity over time (longitudinal changes) or can be changed at will (intensity/flexibility); and, finally, the extent to which colours also trigger thoughts about graphemes (bidirectionality). Note that the questionnaire is only concerned with aspects of the synaesthetic experience but not with aspects of the synaesthetic inducer.

As test of consistency, we used the standardised grapheme-colour consistency test, which is accessible via the internet (www.synesthete.org). That is, the material consisted of letters from A to Z and numbers from 0 to 9 as synaesthetic inducers and possible synaesthetic colour concurrents in HSV space (Eagleman et al., 2007).

2.1.3. Procedure

After clicking on the link to the questionnaire on one of our recruitment pages on the internet, participants were presented with an introductory screen which informed about the nature of the questionnaire. By continuing, participants were presented with a data protection statement on the subsequent page. Thereafter, participants were presented with 21 items followed by nine additional items as specified in Section 2.1.2. Note, it was not possible to go back to the first set of items again, after proceeding to the second set. Next, participants were asked to indicate their first name, last name, and e-mail address which would allow us to contact them and associate the data from the questionnaire with the data of the consistency test. Once participants submitted their responses to the items, they were presented with a thank you and goodbye screen providing further contact details of our research group for any questions and comments they may have wanted to submit.

Next, those participants who had not yet completed the test of consistency before (e.g., as part of another project), were invited by email to do the test by following a link. During the assessment of grapheme-colour consistency, participants were presented with the graphemes A–Z and 0–9 in random order three times each. Participants had to pick one colour represented in HSV (Hue, Saturation, and Value) colour space for each grapheme according to the elicited synaesthetic colour experience. There was also a no-colour option for the cases where the presented grapheme did not elicit a synaesthetic colour experience.

2.1.4. Analysis

We conducted a factor analysis on the data of the questionnaire. We were particularly interested in items that load highly on one factor but not on others. The data were analysed in SPSS 19 (Statistical Package for the Social Sciences, version 19) as follows. Given the design of the questionnaire we performed a maximum likelihood factor analysis with a fixed number of five factors (i.e., corresponding to localisation, automaticity/attention, deliberate use, longitudinal changes, and intensity/flexibility) and varimax rotation. Note that the varimax rotation was justified by the fact that the unrotated factors were not significantly correlated with each other. The factor analysis was not conducted with a fixed number of six factors because the aspect of bidirectionality was only covered by two items and hence, cannot result in a meaningful factor based on its own items. Therefore, the items related to bidirectional aspects of synaesthesia were not taken into consideration for the factor analysis.

Colours selected in the test of consistency were saved as representations in RGB (Red, Green, Blue) colour space. To calculate consistency of syneasthetic colour experiences, we adapted the method of Rothen, Seth, et al. (2013). That is, we converted RGB values into CIELUV values. First, we linearised RGB values by applying inverted gamma functions (gamma compression), and converted these linear RGBs into tristimulus values (XYZ; Brainard, Pelli, & Robson, 2002). Based on these XYZ values, we calculated CIELUV (Hunt & Pointer, 2011, p. 55). We used standard RGB (sRGB; Stokes, Anderson, & Chandrasekar, 1996) to obtain monitor specifications as these are most representative of a range of random monitors. Next, we calculated Euclidean distances in CIELUV space between the two instances of each inducer on an individual basis. For each subject the grand mean of these Euclidean distances was calculated as a representative value for overall consistency. Hence, a lower value implies greater consistency. A cut-off value of 135 has been suggested as resulting in maximal sensitivity (i.e., true positives) and specificity (i.e., true negatives), but can be adjusted depending on whether someone is concerned with sensitivity or specificity (Rothen, Seth, et al., 2013). Because this method is based on a perceptual colour model, it provides a more accurate measure for synaesthetic consistency as compared to synaesthetic consistency based on non-perceptual colour spaces, such as for example RGB and HSV colour spaces (Rothen, Seth, et al., 2013).

The alpha level was set to .05 for all statistical analyses and *t*-tests were two-tailed. Exceptions are indicated at the specific location.

2.2. Results

Average consistency was 63 (*SD* = 31) for the 249 participants who completed the grapheme-colour consistency test. Participants whose consistency value differed by more than 3 *SD* from the average consistency were regarded as outliers (*N* = 2) and excluded from the sample. The consistency values of the remaining 247 participants ranged from 7 to 156 with five participants exceeding the previously described optimal cut-off value of 135. If not further specified, the following analyses are based on this sample.

Table 1 presents the results of the factor analysis. The Kaiser–Meyer Olkin measure of sampling adequacy suggested that our sample was factorable (KMO = .733). Factor loadings smaller than .4 were suppressed in the output and excluded, resulting in a factor-solution of 5 factors with a total of 17 items. However, only one item with a factor loading greater than .4 loaded on the last factor. Since it is not feasible for a single item to build a factor on its own, the item/factor was excluded. The mean score on the remaining 16 items of the questionnaire was 47.17 (*SD* = 9.146) and the value of Cronbach's alpha was .755. The mean values of each item and factor and Cronbach's alpha for each of the factors are included in Table 1. Based on the result of this analysis, the reduced version of the questionnaire consists of 16 items loading on 4 different factors.

Following this finding, we tested whether those 16 items of the final CLaN (that loaded on the first 4 factors in the previous analysis, see Appendix B) lead to the same factor structure for the English and the German version, respectively. That is, we repeated the analysis including the specified 16 items seeking a 4 factor solution. The analysis was conducted twice, once for data from the English version and once for the data from the German version. Factor loadings smaller than .3 were suppressed in the output. We obtained similar results for both analyses (Table 2). Next, we repeated this procedure with all 628 self-referred synaesthetes (irrespective of synaesthetic consistency) in order to test for the generalisation of the factor structure. Again, we obtained similar results for both versions of the questionnaire (Supplementary Table 1).

Finally, we assessed test–retest reliability of the final 16 items of the CLaN for those 53 participants who completed the questionnaire twice. The average time between the two occasions of questionnaire completion was 119.45 days (*SE* = 17.21). Fig. 1 presents the descriptive results and correlations between test and retest for the final 16 items of the CLaN which have been identified to lead to a reliable 4 factor solution. All correlations were significant at the .01 level, but one which was significant at the .05 level, indicating generally good test–retest reliability.

2.3. Discussion

Towards our aim to create a reliable questionnaire which covers different sources of individual differences in synaesthesia, we were able to identify 4 factors in a sample of verified synaesthetes. These 4 factors consisted of a total of 16 items which showed good internal consistency. Moreover, the internal consistency for each factor separately was good.

Table 1
Rotated factor matrix of factor loadings for the 28 initial questionnaire items.

	factor						
item	1	2	3	4	5	mean (SD)	N
04) see synaesthetic colours on computer screen	0.810					2.42 (1.356)	247
16) colour seems where letter/number is printed	0.738					2.43 (1.292)	247
21) can point to the location of the colours	0.573					2.39 (1.365)	247
06) colours in several locations at the same time	0.548				0.497	2.29 (1.289)	247
08) when looking at a page colours appear before words	0.502					2.44 (1.277)	247
13) do not see colours	-0.451					3.36 (1.463)	247
07) only colours when thinking of letters as having colours		-0.712				4.00 (1.184)	247
17) colours appear automatically without effort		0.682				4.28 (0.913)	247
03) colours without attending to them		0.629				3.68 (1.243)	247
05) feels like having to go an fetch colours		-0.581				3.99 (1.133)	247
25) use colours to remember sequences			0.813			3.55 (1.360)	247
27) use colours to remember dates and plan appointments			0.798			3.45 (1.354)	247
26) deliberately try to use colours in everyday life			0.700			3.12 (1.232)	247
24) colours did not change intensity				-0.921		2.05 (1.141)	247
30) colours were stronger in the past				0.623		1.74 (0.935)	247
28) colours were weaker in the past				0.459		2.00 (1.084)	247
12) can alter the location of the colours					0.406	1.87 (1.058)	247
Eigenvalues	4.807	2.716	2.083	1.756	1.521		
Percentage of total variance	9.648	8.929	7.239	6.090	4.241		
Number of items	6	4	3	3	1		
Mean item score and SD in parenthesis	15.32 (5.558)	15.94 (3.441)	10.11 (3.435)	5.79 (2.502)			
Cronbach's alpha	.780	.763	.839	.697			

Note: The percentage of cumulative total variance is 36.147. Factor loadings smaller .4 were suppressed and excluded and for the reason of simplicity of inspection the respective items with lower factor loadings are not shown. Mean scores and Cronbach's alpha of items with negative factor loadings are based on reversed scales. Item numbers correspond to items in Appendix A.

Using these 16 items, we were able to replicate the 4 factors when assessing the data of the English and the German version of the questionnaire separately. This was also the case when we assessed the two versions including all participants who filled in the online questionnaire irrespective of the verification of their synaesthesia via a test of consistency. However, we acknowledge that order of the different factors was different for the English version of the questionnaire when including all participants. Moreover, we also acknowledge that the items of factor 4 changed the direction of their factor loadings between the different analyses. However, we would like to point out that it was always the same items that were opposed to each other. That is, if item A loaded negatively on the factor and item B positively in one analysis, they were always opposed to each other in that when A loaded positively on the factor in another analysis B would then load negatively on that factor in for the same analysis. Nevertheless, in all of the three analyses the same items grouped together to factors indicating a relatively stable factor structure of the questionnaire especially for the first three factors. Furthermore, we were able to show that the 16 items (of the 4 factors) generally exhibit very good test–retest reliability. With respect internal consistency and test–retest reliability, our results indicate that we succeeded in creating a valid instrument to measure individual differences in the experience synaesthesia.

Table 2
Rotated factor matrix of factor loadings for the 16 final items of the CLaN.

English	factor					
item	1	2	3	4	mean (SD)	N
04) see synaesthetic colours on computer screen	0.795				2.41 (1.354)	157
06) colours in several locations at the same time	0.460				2.27 (1.346)	157
08) when looking at a page colours appear before words	0.401	0.433			2.37 (1.287)	157
13) do not see colours	-0.424				3.20 (1.495)	157
16) colour seems where letter/number is printed	0.730				2.45 (1.407)	157
21) can point to the location of the colours	0.547				2.36 (1.437)	157
03) colours without attending to them		0.658			3.66 (1.238)	157
05) feels like having to go an fetch colours		-0.541			3.84 (1.212)	157
07) only colours when thinking of letters as having colours		-0.761			3.90 (1.290)	157
17) colours appear automatically without effort		0.595			4.25 (0.953)	157
25) use colours to remember sequences			0.834		3.54 (1.394)	157
26) deliberately try to use colours in everyday life			0.705		3.15 (1.236)	157
27) use colours to remember dates and plan appointments			0.799		3.40 (1.395)	157
24) colours did not change intensity				-0.990	1.97 (1.146)	157
28) colours were weaker in the past				0.535	1.68 (0.961)	157
30) colours were stronger in the past				0.574	1.94 (1.119)	157
Eigenvalues	4.127	2.087	1.805	1.658		
Percentage of total variance	13.548	12.808	12.102	10.748		
Number of items	6	4	3	3		
Mean item score and SD in parenthesis	15.06 (5.624)	15.66 (3.560)	10.10 (3.504)	5.59 (2.585)		
Cronbach's alpha	.761	.747	.838	.717		
German	factor					
item	1	2	3	4	mean (SD)	N
04) see synaesthetic colours on computer screen	0.896				2.43 (1.366)	90
06) colours in several locations at the same time	0.628				2.33 (1.190)	90
08) when looking at a page colours appear before words	0.654	0.325			2.57 (1.255)	90
13) do not see colours	-0.496				3.63 (1.369)	90
16) colour seems where letter/number is printed	0.645				2.38 (1.066)	90
21) can point to the location of the colours	0.557				2.44 (1.237)	90
03) colours without attending to them		0.662			3.70 (1.258)	90
05) feels like having to go an fetch colours		-0.689			4.26 (0.931)	90
07) only colours when thinking of letters as having colours		-0.731			4.16 (0.959)	90
17) colours appear automatically without effort		0.725			4.31 (0.843)	90
25) use colours to remember sequences			0.765		3.56 (1.308)	90
26) deliberately try to use colours in everyday life			0.696		3.06 (1.230)	90
27) use colours to remember dates and plan appointments			0.843		3.53 (1.283)	90
24) colours did not change intensity				0.981	2.20 (1.124)	90
28) colours were weaker in the past				-0.349	1.86 (0.881)	90
30) colours were stronger in the past		-0.349		-0.601	2.10 (1.017)	90
Eigenvalues	4.386	2.541	2.016	1.339		
Percentage of total variance	17.440	14.745	12.233	10.048		
Number of items	6	4	3	3		
Mean item score and SD in parenthesis	15.79 (5.441)	16.42 (3.183)	10.14 (3.330)	6.16 (2.322)		
Cronbach's alpha	.819	.797	.842	.645		

Note: The percentage of cumulative total variance is 49.207 for the English version and 54.466 for the German version of the questionnaire. Factor loading smaller than .3 were suppressed. In the interest of comparability across the different factor analyses in this article, number of items, mean item score, and Cronbach's alpha are always based on the greyshaded items of the respective factor (even though item 8 in the English version of the questionnaire has a greater factor loading on factor two than one). Also in the interest of comparability, mean item score and Cronbach's alpha for factor 4 in the German version of the questionnaire were calculated by reversing the scale of item 24 instead of items 28 and 30. Item numbers correspond to items in Appendix A.

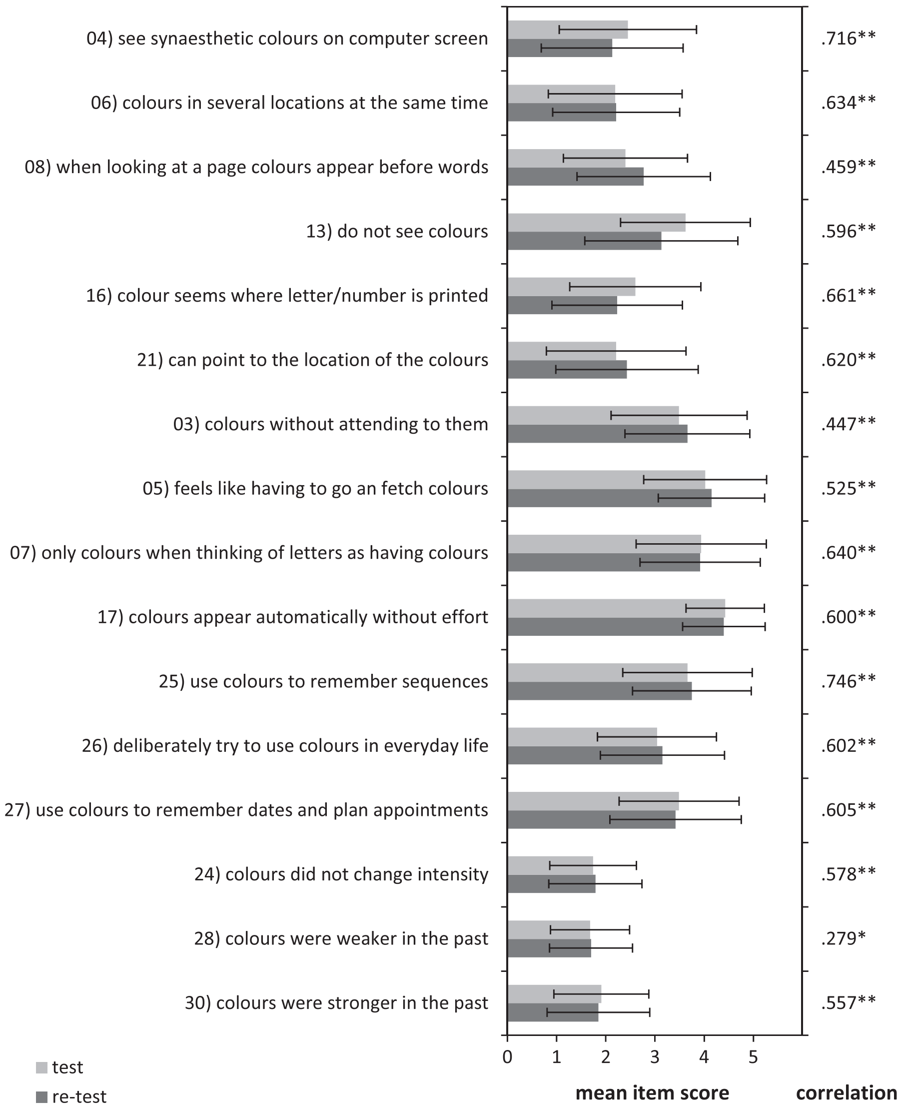

Fig. 1. Mean ($N = 53$), SD, and test–retest correlation for the 16 final items of the CLaN. Mean scores of items 13, 5, 7, 24 were calculated by reversing their scale to account for their negative factor loadings and comparability with other descriptive measures in this article. ** significant at the .01 level and * significant at the .05 level. Item numbers correspond to items in Appendix A.

Before we assess the external validity of the 4 factors, it is important to interpret the 4 factors. Factor 1 is based on items related to the *localisation* of the synaesthetic experience and bears resemblance to the projector–associator dimension. Factor 2 is based on items related to aspects of *automaticity and attention* of the synaesthetic experience. Higher scores on this factor indicate that the synaesthetic experiences tend to be elicited with greater automaticity and require less attention. Factor 3 is based on items related to the *deliberate use* of synaesthetic experiences in everyday life. Higher scores on this indicate a tendency to stronger usage of synaesthetic experiences in everyday life. Factor 4 is based on items related to *longitudinal change* of synaesthetic experiences. Higher scores on this factor indicate that the synaesthetic colours changed intensity over time and were either weaker or stronger in the past.

3. External validity

Next, we assessed the external validity of the final 4 factors of the CLaN. Our first goal was to identify factors that are related to synaesthetic consistency and the bandwidth of synaesthetic inducer (i.e., number of items [letters/numbers] which induce synaesthetic experiences). Our second goal was to identify factors correlated with two variants of the synaesthetic Stroop test. The latter goal was based on the fact that synaesthetic Stroop tests are probably the most often applied tests in the field of synaesthesia research. The materials and procedure for the Stroop tests were adopted from a previous study (Ward et al., 2007; see also, Dixon et al., 2004).

3.1. Methods

3.1.1. Participants

We used the data of those 247 participants who completed both the test of consistency, the questionnaire, and who were not regarded as outliers. In addition, a subset of 18 participants completed two versions of a Stroop test in the laboratory; mean age = 36 years (*SD* = 11), 6 male and 12 female, all fluent English speakers.

3.1.2. Materials

We described the stimuli for the test of consistency already in Section 2 of this article. The stimuli for the Stroop test consisted of 8 different graphemes (letters and digits) and the corresponding synaesthetic colours which varied between individual synaesthetes. The colours were selected on the basis of each individual's data in the test of consistency. All graphemes existed in their congruent version (i.e., coloured in the corresponding synaesthetic colour) and in different incongruent versions (i.e., reassigned colours that corresponded to one of the other graphemes).

3.1.3. Procedure

We described the procedure for the test of consistency already in Section 2 of this article. During the synaesthetic Stroop test, participants were presented with 64 trials. For half of the trials, the grapheme was presented in a colour congruent with their synaesthetic experience and for the other half of the trials the grapheme was presented in a colour incongruent with the synaesthetic experience. The order of stimulus presentation was randomized. Each trial started with a fixation cross presented at the centre of the screen for 1000 ms followed by the grapheme. All stimuli were presented against a grey background. The stimuli remained on the screen until the participant made a response into a microphone. There were two different versions of the Stroop test which differed in the task demands as follows. Participants were required to name either their synaesthetic colour and ignore the veridical colour, or to name the veridical colour and ignore their synaesthetic colour. Each participant did both versions of the Stroop test. The order of the different versions of the Stroop test was counterbalanced across participants.

3.2. Analysis and results

We first consider the sample of those 247 participants who completed the questionnaire and the test of consistency. In order to identify factors that are related to synaesthetic consistency and the bandwidth of the synaesthetic inducer, we correlated each of the four factor scores with the synaesthetic consistency value (i.e., distance in CIELUV colour space) and the number of synaesthetic inducers. The average consistency value was 61 (*SD* = 25) and average number of synaesthetic inducers graphemes was 30 (*SD* = 9). Notably, because consistency is expressed as distance in colour space lower values denote greater consistency. We identified a significant negative correlation between synaesthetic consistency and the factor *deliberate use* ($r = -.146$, $p < .05$). That is, participants with higher scores on the deliberate use factor tend to show greater synaesthetic consistency. Synaesthetic bandwidth was correlated with the factors *deliberate use* ($r = .250$, $p < .001$), *localisation* ($r = .230$, $p < .001$), and *automaticity/attention* ($r = .203$, $p < .01$). That is, higher scores on these factors were linked with greater sets of synaesthetic inducers. No other factor was significantly correlated with synaesthetic consistency and/or bandwidth, respectively.

For the Stroop test (i.e., subsample $N = 18$), incorrect response trials and trials in which the microphone was inappropriately triggered (e.g., because the microphone was accidentally triggered or the response was not detected) were excluded from the reaction time analysis. The mean reaction times and error rates of the Stroop task are depicted in Fig. 2. We conducted a two-factorial Analysis of Variance (ANOVA) with the within subject factors *task version* (veridical vs. synaesthetic) and *congruency* (congruent vs. incongruent) to assess synaesthetic Stroop effects in both versions of the task. The ANOVA revealed a main effect *congruency* $F(1,17) = 29.897$, $p < .001$. There were no other significant effects or interactions, all Fs < 1.156, all ps > .297.

We explored whether Stroop interference (i.e., incongruent minus congruent) is related to any of the four factors of the CLaN for both versions of the Stroop test separately. For the task of naming synaesthetic colours (and ignoring real colours) there was a significant negative correlation between synaesthetic colour naming Stroop interference and the factor *automaticity/attention* ($r = -.551$, $p < .05$). This is shown in Fig. 3. Thus, those synaesthetes who claim that the experience is less automatic show more interference from the incongruent veridical colour. There were no other significant correlations.

Considering next the absolute naming times in the two tests (i.e. collapsing across congruency), the factor *localisation* was significantly correlated with absolute naming times of veridical ($r = -.529$, $p < .05$) and synaesthetic colours ($r = -.701$, $p < .01$). That is, a tendency to see colours located on the text is associated with shorter RTs for both, naming synaesthetic colours and real colours. This is shown in Fig. 4. The factor of *deliberate use* was related to a relative difference in colour naming times across the two tasks ($r = -.469$, $p < .05$). That is, those participants who claim to use their synaesthesia less in everyday life are relatively slower (relative to naming the veridical colours of graphemes) at naming the synaesthetic colours of graphemes. This is shown in Fig. 5. There were no other significant correlations.

Although not entirely independent, we were able to confirm the previous finding of a significant correlation between the factor *deliberate use* of synaesthetic experiences and synaesthetic consistency in CIELUV colour space in this subsample ($r = -.601$, $p < .01$, Fig. 6).

3.3. Discussion

The assessment of the external validity of the CLaN was based on two samples, one including all participants who filled in the questionnaire and passed the test of consistency and the other on a subsample which additionally participated in a Stroop test experiment in the laboratory. The analyses based on the first sample indicated that greater synaesthetic consistency is linked to a greater tendency to use synaesthetic experiences in everyday life (e.g., to remember PIN codes, etc.) and was confirmed in the subsample of the synaesthetes who participated in the laboratory based Stroop experiment. Moreover, having a greater bandwidth in grapheme-colour synaesthesia was related to higher scores on the factors *deliberate use*, *localisation*, and *automaticity/attention* in the sample including all synaesthetes who passed the test of consistency. It is important to note that correlations are not able to indicate the direction of causation. That is, synaesthetes who show greater consistency may use their experiences more in everyday life because they have more consistent experiences and hence, the experiences are more useful. However, it may also be the other way round in that the synaesthetes who deliberately use their experiences more in everyday life are more consistent as a result of this increased use of their experiences. The same applies to the number of synaesthetic inducers and the relationship to the factors *deliberate use*, *localisation*, and *automaticity/attention*.

In a subsample of 18 synaesthetes who participated in a laboratory Stroop test, we replicated previous findings that synaesthetes are slower in naming real and synaesthetic colours that are incongruent with the colour of the eliciting stimulus in comparison to naming real and synaesthetic colours that are congruent with the colour of the eliciting stimulus (Dixon et al., 2004; Ward et al., 2007). Moreover, three of the four factors of the CLaN were meaningfully related to different measures of the Stroop test. That is, (1) those who use their synaesthesia less in everyday life tend to be slower at naming their synaesthetic colours (relative to veridical colours) whereas those who use their synaesthesia more show the opposite profile; (2) a tendency to see colours that have a specific location is associated with shorter RTs for both naming veridical colours and synaesthetic colours in Stroop tests; and (3) a lower tendency to experience synaesthesia automatically is linked to more interference from an incongruent veridical colour when required to name the synaesthetic colour.

4. General discussion

By the means of a factor analysis, we created a synaesthesia questionnaire (CLaN) consisting of 16 items which load on 4 different factors: (F1) is based on the *location* of the synaesthetic experience with higher scores denoting a tendency to *see* colours that are *located*, (F2) is based on aspects of *automaticity and attention* of the synaesthetic experience with higher scores indicating *greater automaticity and less attention* to the inducing stimulus for the synaesthetic experience to be elicited, (F3) is based on *deliberate use* of synaesthetic experiences in everyday life with higher scores indicating *increased usage* of synaesthetic experiences in everyday life, and (F4) is based on *longitudinal changes* of synaesthetic experiences with higher scores indicating that the synaesthetic colours *changed intensity over time*. The CLaN exists in two different languages: English and German. Our findings indicate that both versions reliably lead to the same factor structure, are internally consistent,

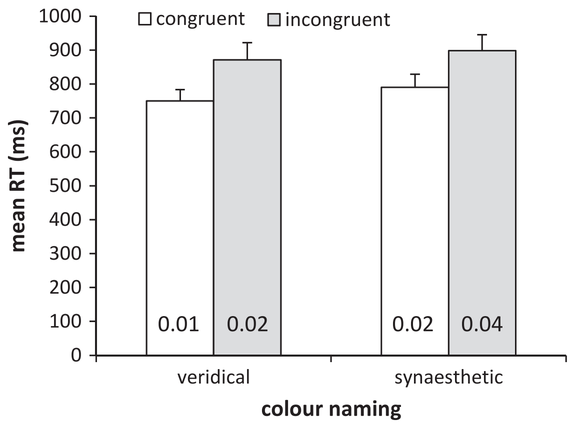

Fig. 2. Mean RTs and mean proportion of error rates of veridical and synaesthetic colour naming Stroop tests. Error bars represent standard errors of RTs.

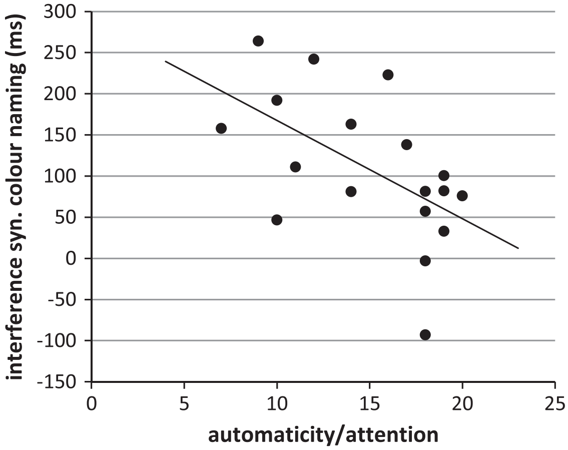

Fig. 3. A greater tendency to experience synaesthesia automatically without attention is associated with less Stroop interference in the synaesthetic colour naming task.

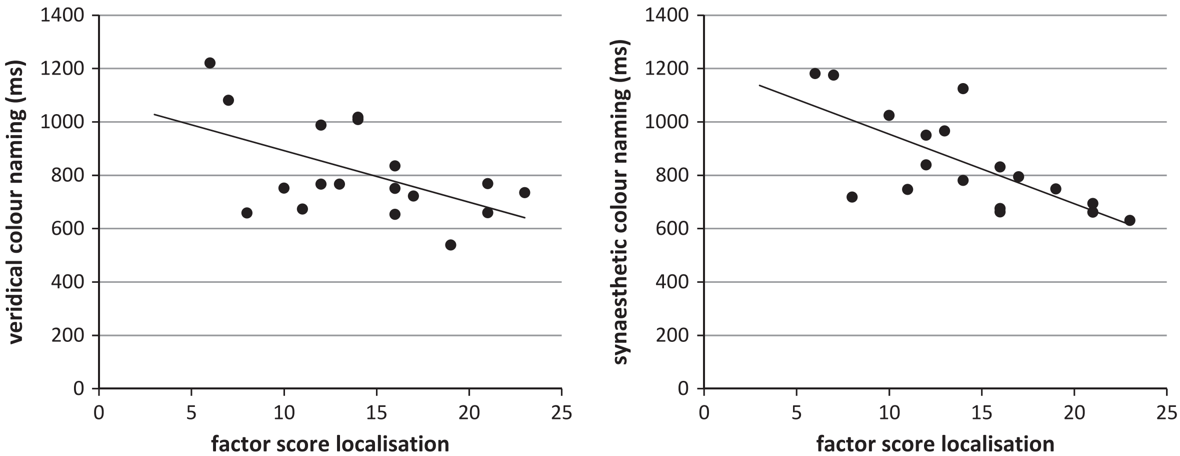

Fig. 4. A tendency to see colours that have a specific location is associated with shorter RTs for both, naming veridical colours and synaesthetic colours in Stroop tests.

and exhibit generally good test–retest reliability. Moreover, meaningful correlations between the first three factors of the CLaN and different measures of performance in synaesthesia – including measures of synaesthetic consistency, bandwidth (i.e. number of graphemic inducers that produce colour), and Stroop performance – generally suggested good external validity.

The factor that we termed *localisation* (F1) resembles the projector–associator dimension proposed by others, although it may not be identical to it (for localizer/non-localizer distinction see also, Cytowic & Eagleman, 2011). A high score on this factor would be indicative of a tendency to experience the synaesthetic colours as externally localised to the inducing grapheme itself (i.e., 'projector'). However, it is less clear what the phenomenology of a low score on this dimension would consist of (except a tendency to not see it localised on the inducer). For instance, claims to "know but not see" synaesthetic colours (Q10 Appendix A) are not significantly loaded onto this factor (as might be expected if 'associator' was at the opposite extreme of this dimension), and neither are claims to experience the colours inside the body (Q2 Appendix A) or on an inner screen (Q14 Appendix A). It is possible that these could constitute additional factors that were not revealed because too few questions were included that loaded on them. Recent neuroimaging evidence suggests that such finer cuts might exist. Specifically, those claiming to see colours on a mental screen show greater influence of the parietal lobes in synaesthesia than those claiming to project colours onto the inducers (van Leeuwen et al., 2011). The former may be associated with a slower time course, which could also explain why – in our study – those scoring higher on the localisation factor tended to be faster at naming colours on the Stroop tests.

Another interesting finding of the current study was that higher scores on F2 *deliberate use* (i.e., the most stable factor) of synaesthetic experiences in everyday life (e.g., as mnemonic) were associated with greater synaesthetic consistency measures as smaller Euclidean distances in CIELUV colour space. Since correlational results do not indicate a causal relationship between two variables this effect is somewhat difficult to interpret. Three interpretations seem possible. Although they

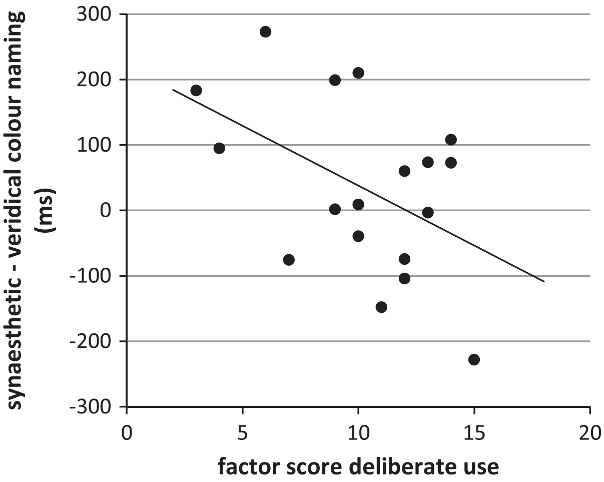

Fig. 5. A greater tendency to use synaesthetic experiences in everyday life is associated with longer RTs in veridical colour naming as compared to synaesthetic colour naming, and vice versa a smaller tendency to use synaesthetic experiences in everyday life is associated with longer RTs in synaesthetic colour naming as compared to veridical colour naming.

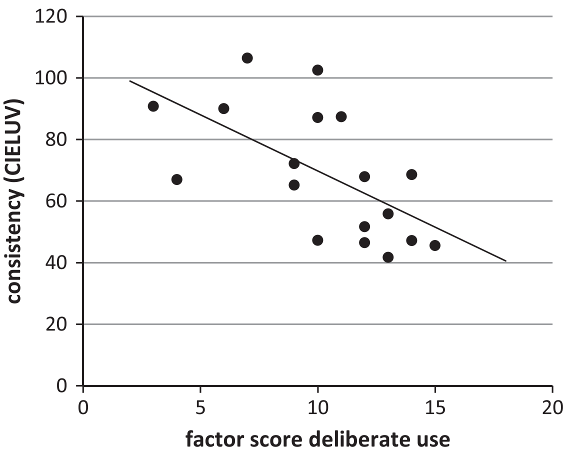

Fig. 6. Participants with higher scores on the deliberate use factor show greater synaesthetic consistency (as indicated by smaller Euclidean distances in CIELUV colour space).

are related to different aspects of synaesthesia they are not mutually exclusive. The first interpretation we will discuss is related to enhanced memory performance in synaesthesia. High consistency is crucial in order to use synaesthetic colour information as memory retrieval cues. Hence, greater consistency in synaesthetic experiences would lead to better memory or, at least, to more reliable possibilities to use synaesthetic experiences as a memory aid in everyday life. Related to the notion that synaesthesia may indeed enhance memory performance (e.g., Pritchard, Rothen, Coolbear, & Ward, 2013; Rothen & Meier, 2010b; for a review see, Rothen, Meier, & Ward, 2012; see also, Meier & Rothen, in press), it is important to mention that the most recent theory has linked enhanced memory with enhanced perception in synaesthesia and not with a benefit from additional memory cues (Rothen et al., 2012).

A second possibility to interpret the correlation between *deliberate use* of synaesthetic experiences in everyday life and synaesthetic consistency is related to the development of synaesthesia. Synaesthetic consistency may simply evolve from deliberate use of synaesthesia. That is the repeated use of colour associations in response to graphemes will consolidate the specific associations entirely in the sense of neurons that fire together wire together (Hebb, 1949). In line with this notion it is no surprise that there is a higher prevalence of grapheme-colour synaesthetes in fine-art students, since specific characteristics of artistic techniques may support the evolution of synaesthetic associations (Rothen & Meier, 2010a). Moreover, a recent study provided evidence that specific synaesthetic associations may indeed be learnt from childhood toys (Witthoft & Winawer, 2013). However, training synaesthetic associations has yet not been successful in acquiring synaesthesia (e.g., Colizoli, Murre, & Rouw, 2012; Kusnir & Thut, 2012; Meier & Rothen, 2009; Rothen, Nikolić, et al., 2013; Rothen et al., 2011).

A third possibility to interpret the correlation between *deliberate use* of synaesthetic experiences in everyday life and synaesthetic consistency is related to consciousness and cross-modal correspondences. Recently it has been hypothesised that synaesthesia may be strong and conscious form of binding which also exists in non-synaesthetes (e.g., non-random pitch-colour associations) (Rothen & Terhune, 2012), but not to a degree to be accessible by the means of conscious awareness nor to achieve the level of consistency observed in synaesthetes (Cohen Kadosh & Henik, 2007; but see Deroy & Spence, 2013). In line with this notion the degree of conscious awareness of grapheme-colour associations might be a covert moderator variable between the deliberate use of synaesthetic experiences and consistency.

Higher scores on the *automaticity/attention* factor were found to be associated with smaller Stroop interference in the synaesthetic colour naming task. This finding is not surprising and suggests that, for less automatic synaesthetic experiences, more effort is required in the production of the *synaesthetic* colour name when the real colour on the screen is incongruent. Moreover, the result is meaningful in that the *automaticity/attention* factor is associated with a task which is said to measure the automaticity of associations (e.g., Rothen, Nikolić, et al., 2013).

The *longitudinal change* factor of synaesthetic experiences was not related to any of our performance measures (i.e., consistency and Stroop). This may be understood in the light that changes in the synaesthetic experience over a prolonged period of time may be related to the age of the individual. However, since age was not asked for in our questionnaire or the other tests used (Eagleman et al., 2007), we may have missed interesting insights and it is clearly a challenge for future research to uncover the relationship between the factor *longitudinal change* of the CLaN and age and task performance. Hence, future research will need to show if this factor is externally valid or not.

Overall, our findings from the Stroop task are consistent with previous studies using this task as either diagnostic marker for synaesthesia or as a paradigm to assess individual differences in synaesthesia. Regarding the diagnostic aspects of this task, we replicated previous findings that synaesthetes are slower in naming real and synaesthetic colours that are incongruent with the colour of the eliciting stimulus in comparison to naming real and synaesthetic colours that are congruent with the colour of the eliciting stimulus (e.g., Nikolić et al., 2011). Regarding the assessment of individual differences in grapheme-colour synaesthesia, two studies have to be mentioned explicitly. It was found that projector synaesthetes were generally faster in synaesthetic colour naming as compared to veridical colour naming and associator synaesthetes were generally slower in synaesthetic colour naming as compared to veridical colour naming (Dixon et al., 2004; Ward et al., 2007). Furthermore, the overall naming times were shorter for projector synaesthetes as compared to associator synaesthetes (Dixon et al., 2004; and numerically in Ward et al. (2007)). Our results are broadly consistent with these findings in that a tendency to see colours localised on the graphemes is associated with shorter naming times for both, veridical colours and synaesthetic colours in the Stroop tests.

The finding that higher scores on the *localisation* factor are associated with quicker naming times for veridical colours may be particularly interesting. Recent studies suggest generally enhanced colour processing in grapheme-colour synaesthetes (Banissy, Walsh, & Ward, 2009; Terhune, Wudarczyk, Kochuparampil, & Cohen Kadosh, in press; Yaro & Ward, 2007). Hence, it would not be surprising if higher scores on the localisation factor would be associated with better colour discrimination. In line with this, it would be interesting to see how each factor relates to individual differences in synaesthetic colours based on the frequency of inducer graphemes (Beeli, Esslen, & Jäncke, 2007; Cohen Kadosh, Henik, & Walsh, 2007; Simner & Ward, 2008; Simner et al., 2005; Smilek, Carriere, Dixon, & Merikle, 2007) or the shape of inducer graphemes (Albertazzi et al., 2013; Brang, Rouw, Ramachandran, & Coulson, 2011; Watson, Akins, & Enns, 2012).

Moreover, as already mentioned in the introduction, 'synaesthetic' Stroop effects may also be found in non-synaesthetes who trained similar associations (Meier & Rothen, 2009; Rothen, Nikolić, et al., 2013; Rothen et al., 2011). Future research will have to show how phenomenological reports for trained colour associations are related to various measures deriving from the Stroop task.

To conclude, the obtained results suggest that the CLaN has good test–retest reliability and that the subscales have good construct validity. As discussed, the CLaN provides interesting results which not only corroborate existing ideas in synaesthesia research but also provide grounds for new ideas that can be tested in future research. Moreover, although the questionnaire was developed to be used as an instrument to measure individual differences in grapheme-colour synaesthesia, it may be adapted for the use with other forms of synaesthesia which may engage similar cognitive mechanisms.

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Appendix A

Initial 30 items in the order of presentation (final 16 items highlighted).

1. I can choose to alter the intensity of the synaesthetic colour
2. I see the synaesthetic colours literally inside my body (e.g., behind my forehead)
3. I experience the synaesthetic colours even if I do not attend to them specifically (e.g., while reading a book)
4. I see the synaesthetic colours on the computer screen (or very close to it)
5. It feels like I have to go and fetch the colours, rather than the colours coming to me
6. I experience the synaesthetic colours in several locations at the same time (for instance, both on the screen and literally inside my head or some other combination)
7. I only experience the synaesthetic colours of letters/numbers if I think about them as having a colour
8. When I am looking quickly at a page of a book the synaesthetic colours appear before I am aware of what the letters/words are
9. I know exactly what colour goes with a particular letter/number
10. My synaesthetic experience of colours feels more like knowing than seeing
11. The synaesthetic colours appear weak and faded
12. I can choose to alter the location of the synaesthetic colours (e.g., by projecting them onto the wall)
13. I do not "see" colours when I look at the letters/numbers
14. I see my synaesthetic colours on an imagined screen that has no physical location that I can point to
15. The synaesthetic colours appear vivid
16. It seems that the colour is on the screen where the letter/number is printed
17. The synaesthetic colours appear automatically without any effort on my part
18. If I am asked to imagine letters or numbers as having different colours from my own (e.g., A = white, B = red, C = pink) then it is easy for me to do so
19. The colours have the same shape as the letters/numbers
20. I see the synaesthetic colours in the space outside my body (e.g., 10 inches in front of my tummy, or above my shoulder) but not on the computer screen
21. I can point to the location of the synaesthetic colours
22. When I am introduced to a new person, I think about the colour of their name
23. When I see a colour I automatically experience the letter/number
24. My synaesthetic colours did not change their intensity over the years
25. I use my synaesthetic colours deliberately for remembering sequences of numbers (e.g., PINs, telephone numbers)
26. I deliberately try to use my synaesthetic colours in my everyday life
27. I use my synaesthetic colours to remember dates and plan appointments (e.g., 28.02.2010)
28. My synaesthetic colours were weaker in the past (i.e., years ago)
29. When I see a colour I do not automatically experience the letter/number
30. My synaesthetic colours were stronger in the past (i.e., years ago)

Appendix B

Final 16 items of the CLaN

1. I experience the synaesthetic colours even if I do not attend to them specifically (e.g., while reading a book)
2. I see the synaesthetic colours on the computer screen (or very close to it)
3. It feels like I have to go and fetch the colours, rather than the colours coming to me
4. I experience the synaesthetic colours in several locations at the same time (for instance, both on the screen and literally inside my head or some other combination)
5. I only experience the synaesthetic colours of letters/numbers if I think about them as having a colour
6. When I am looking quickly at a page of a book the synaesthetic colours appear before I am aware of what the letters/words are
7. I do not "see" colours when I look at the letters/numbers
8. It seems that the colour is on the screen where the letter/number is printed
9. The synaesthetic colours appear automatically without any effort on my part
10. I can point to the location of the synaesthetic colours
11. My synaesthetic colours did not change their intensity over the years
12. I use my synaesthetic colours deliberately for remembering sequences of numbers (e.g., PINs, telephone numbers)
13. I deliberately try to use my synaesthetic colours in my everyday life
14. I use my synaesthetic colours to remember dates and plan appointments (e.g., 28.02.2010)
15. My synaesthetic colours were weaker in the past (i.e., years ago)
16. My synaesthetic colours were stronger in the past (i.e., years ago)

Note that the items were re-enumerated and hence do not have the same number as in Appendix A. Important, questions are scored on a 5-point Likert-scale from 1 to 5 (i.e., strongly disagree, moderately disagree, neither agree nor disagree, moderately agree, strongly agree). Item number 3, 5, 7, and 11 need to be reverse coded to be scored (i.e., 5–1 applies to strongly disagree, moderately disagree, neither agree nor disagree, moderately agree, strongly agree).

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.concog.2013.07.005.

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