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Notwithstanding a growing body of research, synaesthesia remains a phenomenon surrounded by uncertainties. The condition is believed to occur in approximately four percent of the population (Cytowic, 2018; Simner et al., 2006) and with great inter-individual variability but low intra-individuality. It is not uncommon for synaesthetes to be unaware that their experiences are not shared by others, and it is a phenomenon that can easily be misunderstood, and its different forms underrepresented (Day, 2005). This, coupled with its rarity in occurrence and variability from person to person, also presents the continuing challenge of low sample sizes in synaesthesia research.

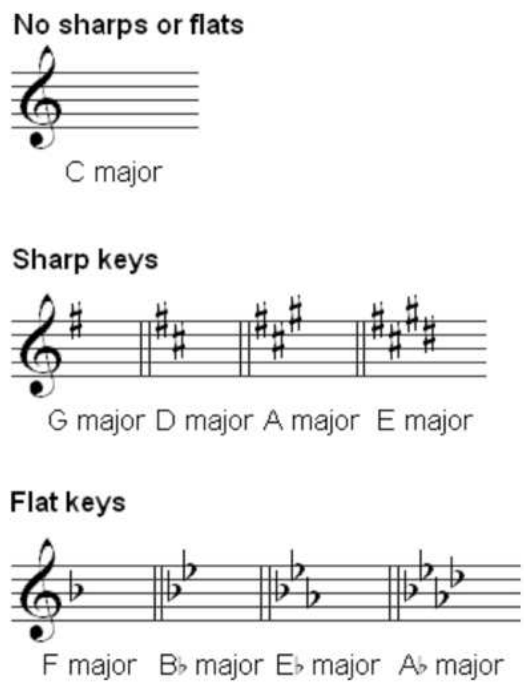
One form of synaesthesia associated with music (music-colour synaesthesia) falls under the umbrella term “chromesthesia” or “coloured hearing” (Ward, Tsakanikos & Bray, 2006). Yet scholarship interested in music-colour synaesthesia has a broad scope, encompassing not only the more frequently examined tone-colour synaesthesia but also phenomenal experiences mediated by style, timbre, and tonality (Peacock, 1995). Indeed, recent research argues that it is unlikely that a single mechanism underlies all forms of synaesthesia and rejects a “one for all” explanation for its cause (Auvray & Deroy, 2015; Simner, 2012). In this article, I focus on a single concept-driven form of music-colour synaesthesia that arises from reading written musical key signatures.

The association of colour with key signatures is not a new phenomenon (Day, 2008, p. 284). It is known to have been a cause for disagreement between the composers Scriabin and Rimsky-Korsakov: “Scriabin considered the tonality of F-sharp to be a bright saturated blue according to most sources. Rimsky-Korsakov perceived that key as an indefinite gray-green color” (Peacock, 1985, p. 495). This article provides the first empirical demonstration of music-colour synaesthesia for written key signatures and investigates its form of manifestation. Specifically, the present contribution demystifies the assumption that musical inducers are purely based on sound. Instead, it tests the hypothesis that musical *concepts* are at the heart of the synaesthetic experience, at least for this particular kind of synaesthesia associated with written key signatures (Curwen, 2018).

For the purpose of this paper the term "key signature" is used to relate to the indication of the key or tonic of the music. The tonal centre or tonic key of a melody is in the Western tonal tradition both a percept (Krumhansl, 2010) and a symbolic concept used in music theory and music notation. Reading a key signature is intrinsic to being able to read music, whilst being sensitive to the tonic key is a basic feature of tonal pitch perception irrespective of musical training (e.g., see Tillman, 2012). A musical key is denoted by a written key signature that appears immediately after the clef at the beginning of the first line of music with a set of up to seven sharp (♯) or seven flat (♭) symbols indicating the notes to be used when playing in each key. It is not necessary for the music to be sounded out for the concept of the intended key to be communicated, as shown in Figure 1.

Figure 1

Nine major key signatures written on the treble clef



Although historically described as a sensory-to-sensory phenomenon in which a sensation in one sense (an inducer) triggers a sensation in another unrelated sense (a concurrent) (Grossenbacher & Lovelace, 2001), there is evidence that in some forms of synaesthesia a non-sensory stimulus is enough to induce the condition (Chiou & Rich, 2014; van Leeuwen et al., 2015). For example, Dixon et al. (2000) demonstrated that when numerical additions such as 5 + 2 were followed by a colour patch, naming times were faster when the colour of the patch was congruent with the synaesthete's colour for the correct response; the physical presence of the inducer was not necessary (Meier, 2014). In music, the main factor in a newly described pitch class-colour synaesthesia was the name, and not the sound, of the pitch (Itoh et al., 2017, 2019); and Ward, Tsakanikos and Bray's (2006) experimental investigation of synaesthesia for written musical notes demonstrated that the synaesthetic colour of a note was determined by musical context and was neither dependent on the mode of presentation nor on a change in form of the stimuli. This notion is supported by Lima (2020) in a grounded theory study that demonstrates a strong conceptual basis for music notation-colour synaesthesia. The synaesthetes in Lima's study reported that it was "the idea or notion of a particular music-notational percept that elicits a synesthetic color for them" (p. 185). Two participants in particular recognised that "they will not have a 'final' color for a given concept unless they" [were to] "consciously recognize it as such" (p. 185). For example, a note may hold the same position on the stave in the treble clef and on the bass clef, but its meaning is different: the middle line on the treble clef is a "B" and on the bass clef a "D". Should synaesthesia be elicited at a conceptual level, the same colour will be assigned to a D whether it is shown on the middle line of a bass stave or below the bottom line of a treble stave (Curwen, 2020). In Ward, Tsakanikos and Bray's (2006) study, musical notes were printed in either congruent or incongruent colours with the participants' synaesthetic colours in words or on the stave (either in bass or treble clef). In a reverse Stroop design (Stroop, 1935), Ward and colleagues required synaesthetes to ignore the veridical colour and name their synaesthetic colour for the musical note. Significant interference was observed with longer reaction times for naming notes in incongruent colours. The authors suggest that the results show that interference occurred when the identity of the note was required to be processed (i.e., when suppressing its veridical colour).

Yet exactly how deeply the inducer needs to be processed remains uncertain. Smilek et al. (2001) concluded that although the meaning and concept needs to be activated to produce synaesthesia, conscious identification is not necessary: access to the meaning was enough, but there was no need for identification. In contrast, Mattingley et al. (2001) found that implicit processing (i.e., without conscious identification of the inducer) was not sufficient to produce synaesthesia. When letters and digits were presented briefly and then masked, synaesthesia could be eliminated if the stimuli were not made available for conscious report, even when there was evidence otherwise of the substantial processing of stimuli that would usually produce synaesthesia. Further studies (see Rich and Mattingley, 2003; Mattingley et al., 2006; Sagiv et al., 2006) have supported Mattingley and colleagues' (2001) results. Notably, these studies investigated only one form of synaesthesia: grapheme-colour synaesthesia. As mentioned earlier, recent research suggests that an explanation of a single operating mechanism for synaesthesia may be inadequate (Simner, 2012) and that it may be incorrect to assume that there is a unity between all types of synaesthesia. This brings into question not only the extent to which conscious report is required but also whether such findings may be extended to other forms of synaesthesia.

Can the concept of a written key signature be sufficient to induce a synaesthetic experience? The present study provides the first empirical demonstration of synaesthesia for reading written key signatures in five experiments. Similar paradigms to that of Ward, Tsakanikos and Bray's (2006) reverse Stroop design in their experiment "Stroop Interference for Naming Synaesthetic Colors", and Banno et al.'s (2017) experiment "Colour matching task" are employed to test the following hypotheses:

1. *The existence of a synaesthetic association with written key signatures.* Longer reaction times will be observed when naming synaesthetic colours if presented with incongruent pairings between colour and key signature, indicating the presence of synaesthesia for written key signatures.
2. *Synaesthetic association persists irrespective of presentation modality and form of key signatures.* A change in the form of the stimuli from a key signature written in words to that of a key signature written on the stave (either in the treble or the bass clef) should not result in a change of synaesthetic colour.

The main objective of the study was to demonstrate that synaesthesia for written key signatures is a genuine form of synaesthesia and that it is linked to conceptual rather than to purely perceptual processing of the inducing stimulus**.** Consistency over time (Baron-Cohen et al., 1987) has been established as the primary measure when identifying synaesthesia. However, if employed as the only means of validation, a consistency test may lead to some forms of synaesthesia being overlooked. For example, the presence of some inconsistency and variation over time has been observed, particularly in children (Cytowic, 2002; Eagleman et al., 2007; Rogers, 1987), and it has been suggested that consistency might be better regarded as an "associated characteristic" rather than as an all-defining one (Ward & Mattingley, 2006, p. 130). Taking this into consideration, Experiment 1 employed two diagnostic measures for consistency, and Experiments 2 and 5 tested the presence of interference for incongruent pairings of colour and key signature. Experiment 2 also presented key signatures in three separate modes – words, treble clef and bass clef – to test whether a change in form altered the concept of the key signature resulting in an absence of, or a change to, the synaesthetic colour. Experiment 3 was supplementary to Experiment 2 and investigated whether the processing of key signatures was generally quicker when presented in words rather than in musical notation. Experiment 4 was a pre-test to Experiment 5 and tested the priming effect of achromatic key signatures.

Experiment 1: Verification of Synaesthesia for Reading Key Signatures

The aim of Experiment 1 was to verify the existence of synaesthesia for reading key signatures in a group of self-reporting synaesthetes by employing two measures of consistency as diagnostic criteria: vector distance in RGB choices and Euclidean distances in CIELUV colour space. Only keys with up to four sharps or four flats were selected to ensure that subitizing was possible (Kaufman et al., 1949).[1] Judgement for groups of items between one to four has been shown to be rapid (Saltzman & Garner, 1948), accurate (Jevons, 1871), and confident (Taves, 1941). Additionally, numbers of items beyond four have been demonstrated to increase response times by an extra 250 – 50ms per additional item (Trick & Pylyshyn, 1994). As participants were required to respond as quickly as they could in Experiments 2 to 5, keeping stimuli to a maximum of four flats or sharps controlled the time attributed to reading the key signature.

Method

Participants

Participants were recruited in two separate calls via social media – the first for synaesthetes and the second for controls – from the University of Sheffield, the Royal Northern College of Music, and the author's own contacts (see Table 1 for full Participant details). Ethical approval was obtained from the research ethics committee at the University of Sheffield. All respondents were required to complete an online Google form questionnaire to determine their level of musical ability and to identify any types of synaesthesia present.

[1] Subitizing is the process of immediately knowing the number of items presented visually without the need for estimation or counting.

Self-reporting synaesthetes who experienced colours for key signatures were asked to specify whether they needed to sound out the key or not. Based on this initial assessment, the experimenter then arranged to meet with each participant in person to document the colours they associated with each key. All participants were provided with information about the study and were able to provide consent via a radial button on the Google form.

Synaesthetes. Of the 12 self-reporting synaesthetes, only nine met the criteria for synaesthesia when reading written key signatures without needing to sound out the key (Participant numbers 1-9). Of those nine, only six had synaesthetic responses to all the nine major keys tested: of the other three, one had responses to eight keys, one to six keys, and one to five keys. All were classed as associators,[2] and all could fluently read key signatures written in both bass and treble clefs. Two possessed absolute pitch (Participants 6 and 7). Possession of absolute pitch was not independently verified but identified by self-report. All participants were able to indicate whether they possessed absolute pitch by responding "Yes", "No", or "Don't know" on the Google form. All participants had obtained a high musical standard (i.e., at least Grade 8 or equivalent of the Associated Board of the Royal Schools of Music), and so it was considered reasonable to assume that they were familiar with the condition and whether it was present or not.

Controls. Two of the 11 controls (Participant numbers 19 and 20) were identified as possessing strong grapheme-colour synaesthesia for letters. Both admitted to using letter names rather than key signatures to select their colours and were highly consistent in their selection. It was not possible to determine how this would influence their performance in respect of key signatures, so their results were not included. None of the controls reported possessing absolute pitch.

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[2] Synaesthetes are classed as associators or projectors according to their experience of the concurrent. Associators typically describe their experience as being in the mind's eye (Dixon et al., 2004; Dixon & Smilek, 2005) or as knowing the colour (Ward et al., 2007), while projectors claim to see colours projected outside the body into external space (Smilek et al., 2001).

Table 1

Participant Profiles

Participant ID	Syn/ Con	Age Range	Sex	Musical Training	AP	Fluency Key Sigs	Music-C Syn	Type	Other Forms
1	S	25-44	Male	> 15yrs	No	Yes	MKC/MT/T	A	D/M, SS
2	S	45-64	Male	> 15yrs	No	Yes	MKC/MT/T	A	GC, D/M, SS
3	S	25-44	Female	> 15yrs	No	Yes	MKC/MT/T	A	GC, D/M
4	S	15-24	Male	10-15 yrs	No	Yes	MKC/MT/CS/T	A	LG
5	S	15-24	Female	> 15yrs	No	Yes	MKC/MT/CS/T	A	None
6	S	45-64	Female	> 15yrs	Yes	Yes	MKC/MT/CS/T	A	None
7	S	25-44	Male	> 15yrs	Yes	Yes	MKC/MT/CS/T	A	None
8	S	15-24	Female	6-10 yrs	No	Yes	MKC/MT/CS/T	A	GC, D/M, AT, MT
9	S	15-24	Female	10-15 yrs	No	Yes	MKC/MT/CS/T	A	None
10	C	45-64	Female	6-10 yrs	No	No	None	N/A	None
11	C	25-44	Female	10-15 yrs	No	Yes	None	N/A	None
12	C	65+	Female	> 15yrs	No	Yes	None	N/A	None
13	C	15-24	Female	> 15yrs	Don't Know	Yes	None	N/A	None
14	C	25-44	Male	> 15yrs	No	Yes	None	N/A	None
15	C	25-44	Male	6-10 yrs	No	Yes	None	N/A	None
16	C	25-44	Female	> 15yrs	No	Yes	None	N/A	None
17	C	25-44	Female	> 15yrs	No	Yes	None	N/A	None
18	C	45-64	Male	> 15yrs	No	No	None	N/A	None
19	C	45-64	Female	6-10 yrs	No	Yes	None	N/A	GC
20	C	15-24	Female	> 15yrs	No	Yes	CS/T	N/A	GC

Note. Syn = synaesthete, Con = control, AP = absolute pitch, Fluency Key Sigs = ability to read key signature fluently, Music-C Syn = music-colour synaesthesia, MKC = concept of key signatures, MT = musical tones, T = timbre, CS = compositional style, A = associator, GC = grapheme-colour synaesthesia, D/M = days/months, SS = spatial sequence, AT = auditory-tactile, MT = mirror touch, LG = lexical-gustatory.

Materials

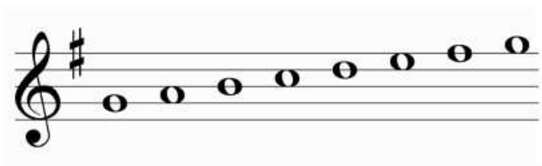
The materials used were the key signatures for nine major keys written on the treble clef: C major, G major, D major, A major, E major, F major, Bb major, Eb major and Ab major, as shown in Figure 1 (above).

Procedure

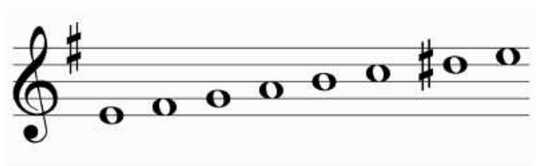
Synaesthetes were required to select as closely as possible their synaesthetic colour for the nine major keys without sounding out, or playing, the keys. Controls were asked to select the colours they felt made the best match for each key. Only major keys were used to avoid any ambiguity when reading from the stave. This is because pairs of major and minor keys are associated with the same key signature. In these instances when playing in the harmonic minor key it is required to also sharpen the seventh pitch. This is not indicated in the key signature, but instead on the stave. For example, a scale in G major on the treble clef will use the same key signature as its relative minor (E minor) but will also require a D♯ as shown in Figure 2. As it is not clear from the key signature alone whether the key should be major or minor, only major keys were used.

Figure 2

Example of associated keys G Major and E Minor denoted on the stave of the treble clef



G Major



E Minor

Colours were selected using www.w3schools.com developer website (*w3schools*, n.d.) and the standard "Colour Picker" Apple Mackintosh HD application. Participants were required to move a cross-hair cursor over a colour wheel and to adjust a vertical slider to control luminance on an Apple MacBook Air monitor. Previous studies have demonstrated in grapheme-colour synaesthesia that synaesthetes show more consistent answers than controls when both groups are retested at a later date (Baron-Cohen, et al., 1993; Dixon et al., 2000; Mattingley et al., 2001). To further verify the presence of synaesthesia for key signatures beyond self-report, the colour selection exercise was therefore repeated in a surprise retest one month later (though it was not possible to meet with Synaesthetes No. 1, 2 and 7 until five, eight and four months later respectively, nor to meet with Controls No. 12 and 13 until three months later). It was expected that synaesthetes would have a very precise selection of colours and would demonstrate a higher internal consistency for the colours selected at test and retest in comparison to controls.

Analysis

The colours selected were precisely identified in terms of RGB (red, green, blue) space and later transformed to representations in CIELUV space, as recommended by Rothen et al. (2013) where L stands for luminance, and U and V represent chromaticity values of colour images (Rahimzadeganasl & Sertel, 2017).[3] The website www.Colorhexa.com (*ColorHexa*, n.d.) was used to make the transformations. The main criticism of the use of RGB values is that it is device-specific. The digital representations for RGB may be the same across different devices, but they do not account for any difference between monitor outputs. This means that colours produced on one machine may not be quite the same as those on another. Although the use of standard RGB (sRGB) across devices has attempted to counter

[3] Reasons for adopting representations in CIELUV space over RGB values are explained by Hamilton-Fletcher (2015).

this, the distance measured within sRGB space between two colours does not relate to the perceptual distance of a human observer. Colour spaces generated by the International Commission on Illumination (CIE) account for the specific phosphor intensities of sRGB channels and can produce a large variety of colours taking into account the cone-response characteristics of human observers. Although converting sRGB values to CIE colours does not solve the problem of colour transformations between devices, it can help towards mitigating the problem (Hamilton-Fletcher, 2015, p. 33) by enabling distances between colour spaces to be measured more accurately as would be judged by human observers (Hunt & Pointer, 2011).

Vector Distance in RGB choices and Euclidean distances in CIELUV colour space. The consistency of colours between one test and the second can be measured quantitatively by calculating separate vector distances in RGB and in CIELUV colour space choices using the following equation (Rothen et al., 2013; Ward et al., 2006) to produce a score for each participant (illustrated here with RGB dimensions):

$$d = \sum \sqrt{(R_1 - R_2)^2 + (G_1 - G_2)^2 + (B_1 - B_2)^2}$$

For example, if at the time of the first test the colour selected was R = 188, G = 248, B = 107, and at the second test it was R = 122, G = 255, B = 87, this would result in an absolute value of 69. The difference between mean RGB scores in the synaesthete and control groups was analysed with an independent groups *t*-test.

As colour selection is not necessarily identical, a cut-off value for synaesthesia for written key signatures was also calculated. Rothen and colleagues (2013) employed a cut-off of 135 for grapheme synaesthetes based on the sum of combinations of comparisons from their three tests per participant from CIELUV vector distance scores (i.e., trial 1 and trial 2, trial 2 and trial 3, trial 3 and trial 1). The authors noted that different synaesthetic inducers may require different cut-off values, as controls may have varying levels of consistency depending on the type of inducer. Yet similar principles were expected to apply to all other types of synaesthesia involving colour. Rothen's exact calculation could not be performed in the current study, as only one comparison was made here (i.e., between trial 1 and trial 2). Instead, the mean value of 52 was calculated from the total CIELUV vector distance scores for all the controls and synaesthetes and used as a cut-off point for synaesthesia associated with key signatures.

Linear Regression. Next, a simple linear regression was performed to compare and evaluate how well the CIELUV values in the first test predicted the CIELUV values in the retest. The dependent variable was the CIELUV values for the nine major key signatures obtained in the second test, and the CIELUV values in the first test served as the independent random variable – a similar method to that employed by Itoh et al. (2017). The software package SPSS Statistics V25 was used to carry out the analysis of the data collected.

Results and discussion

RGB Vector distance analysis and Euclidean distance in CIELUV colour space analysis

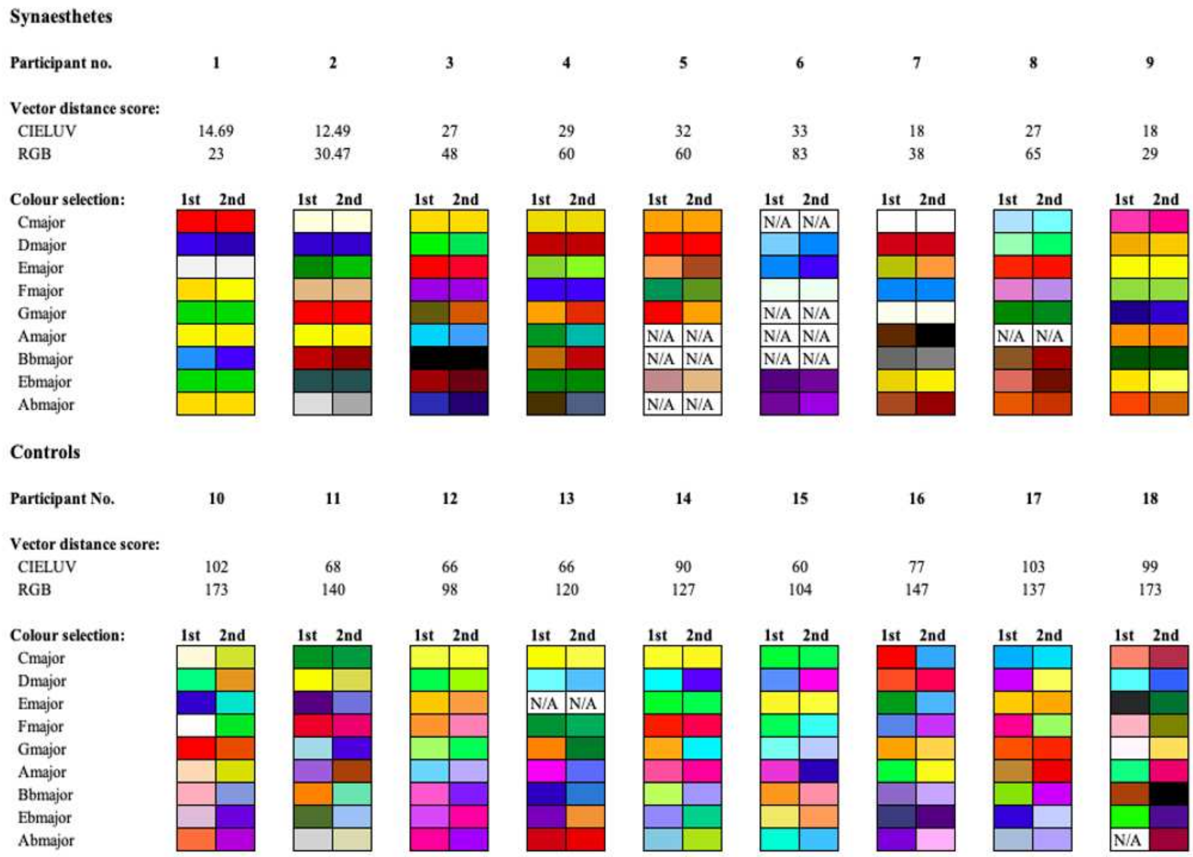
The independent groups *t*-test showed a statistically significant difference between the synaesthete and control groups on the mean RGB vector distance scores: $t(16) = -7.83$, $p < .001$. The effect size for this analysis ($d = 3.69$) was found to exceed Cohen's (1988) convention for a large effect ($d = .80$). Synaesthete scores were significantly lower than controls, indicating a much smaller vector difference between colour selections at test and retest and a higher level of consistency in synaesthetes than controls.

The calculated CIELUV cut-off score for the presence of synaesthesia of 52 was shown to be a reasonable assumption, as the nine participants classified as synaesthetes all had an average score below 34 using this method, whilst the nine controls scored in a range of 60 to 103 (see Figure 3).

However, it must be noted that while controls' scores fell into the higher range, not all the selections showed a lack of consistency across the two test conditions (e.g., Participant 12), and both synaesthetes and controls appeared to demonstrate a higher consistency for some keys (e.g., C major) than others (e.g., Bb major and Ab major). This highlights one of the shortcomings of using a consistency test as the primary measure in synaesthesia. Some controls are able to demonstrate a higher-than-chance level of consistency by choosing "red" again at retest, while synaesthetes may be searching for the precise texture, hue, colour (or mixture of colours) that they selected at the first test from a very limited pallet.

Figure 3

Comparison of Synaesthetes' and Controls' Colour Selections for Nine Major Keys.



Note. RGB vector distance and Euclidean distance in CIELUV colour space scores are given for each participant as well as choice of colour. See the online article for the colour version of this figure.

Linear regressions analysis

The results of the linear regression analysis of the CIELUV data points are summarised in Table 2. Statistically significant models were revealed in both the synaesthete and control groups, indicating that the results are unlikely to have arisen by chance. The correlations between the colour selections in the first test and those in the second test are also shown to be statistically significant in both the synaesthete and the control groups. The data displayed in the graphs at Figure 4 support this, illustrating that the colours selected by the control group are not entirely random and that a certain level of consistency exists: first-colour choices are a significant predictor of second-colour choices in both groups.

This finding is less surprising considering that previous research has drawn attention to the similarities that exist between synaesthetic pairings and some common cross-modal associations in the general population from colour, music, emotion, pitch-height and pitch-size (Gallace & Spence, 2006; Isbilen & Krumhansl, 2016; Marks, 1987, 2004; Mondloch & Maurer, 2004; Palmer et al., 2013, 2016 Walker et al., 2010; Ward, Tsakanikos & Bray, 2006). Yet the graphs in Figure 2 also highlight the different level of variability in selection between the two groups. The low R^2 values in all three control colour dimensions reflect the far less precise colour selection of non-synaesthetes, while in the synaesthete group narrower prediction intervals provide evidence for their typically specific and precise choices. At least 67.1% of the variance in second-colour choices can be predicted by variances in first-colour in the synaesthete group, whilst the highest percentage is only 24.6% in the control group. The regression coefficient (*B*) would be 1 if the results of two tests were identical and zero if random. The coefficient approaches 1 in the synaesthete group in all dimensions but falls below .5 in the control group. Notwithstanding the significant correlations in both groups, these results support the expectation that synaesthetes would demonstrate very precise selection of colours and a much higher internal consistency for the colours selected at test and retest than controls.

Figure 4

Graphs of Regression Analysis Highlighting Difference in Variability in Colour Selection between Synaesthetes and Controls

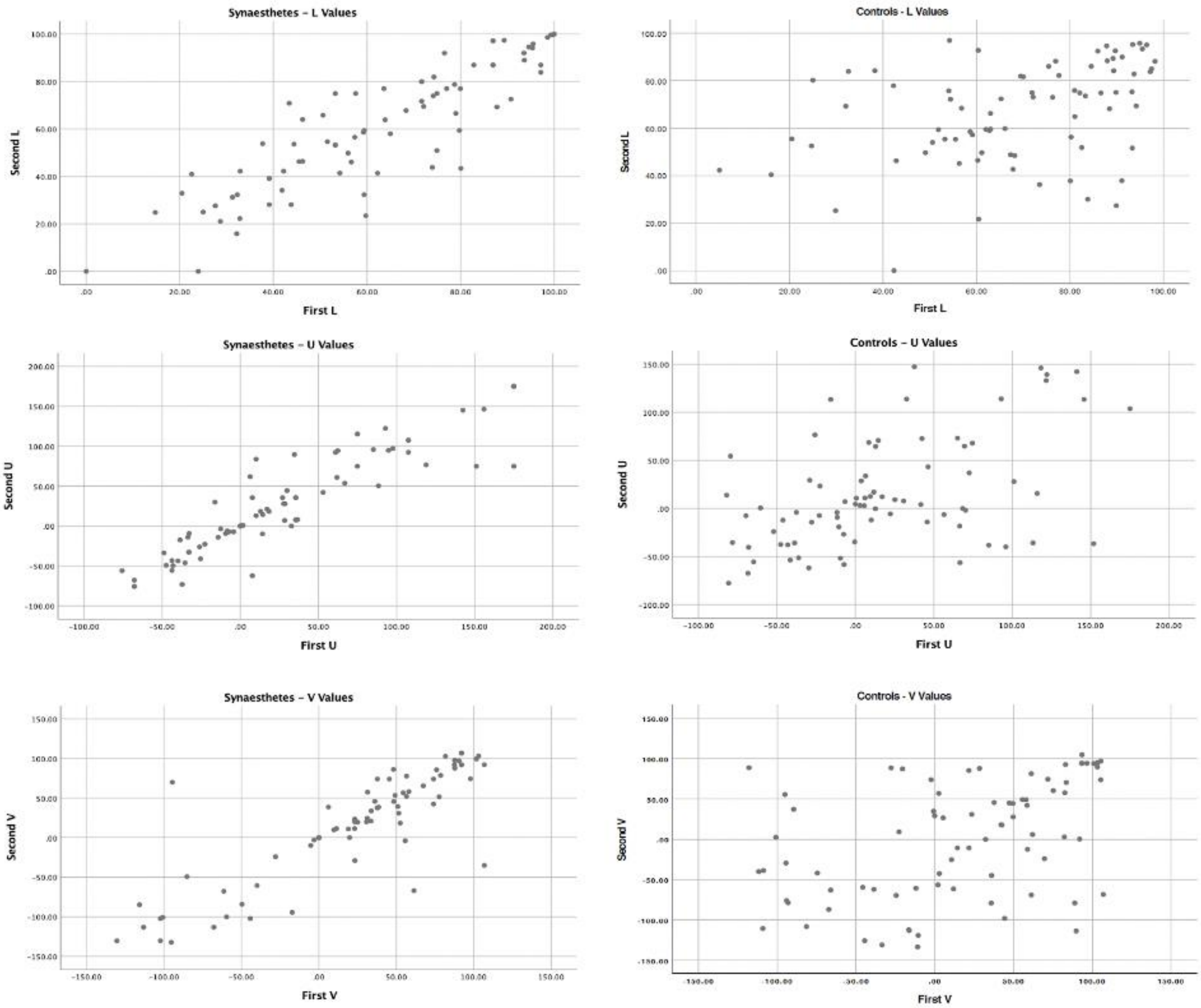


Table 2

Summary of Results of Linear Regression Analysis between First and Second CIELUV Colour Selections in Controls and Synaesthetes

	Model	**Adjusted R^2**	**Slope of Regression**
Synaesthetes			
L	F (1,78) = 232.78, p < .001	74.60%	B = .90, t = 15.26, p < .001
U	F (1,78) = 366.30, p < .001	82.20%	B = .89, t = 19.14, p < .001
V	F (1,78) = 162.02, p < .001	67.10%	B = .90, t = 12.73, p < .001
Controls			
L	F (1,76) = 14.50, p < .001	14.90%	B = .38, t = 3.81, p < .001
U	F (1,76) = 26.06, p < .001	24.60%	B = .46, t = 5.11, p < .001
V	F (1,76) = 17.89, p < .001	18.00%	B = .48, t = 4.23, p < .001

Note. The analysis is along the three colour axes (L, U and V) between the first- and second-colour selections.

Experiment 2: Stroop Interference for the Naming of Synaesthetic Colours of Written Key signatures

The aim of Experiment 2 was to demonstrate the presence of interference when naming synaesthetic colours for incongruent pairings of colour and key signature beyond self-report, and to test whether synaesthetic responses exist irrespective of mode of presentation (Hypothesis 1 and Hypothesis 2 respectively). As posited by Ward, Tsakanikos and Bray (2006), identifying the printed colour of a key signature may not necessarily require the identification of the key signature itself. A reverse Stroop approach was therefore adopted that required synaesthetes to name their synaesthetic colour for the key signature rather than veridical colour of the stimuli. By asking synaesthetes to ignore the colour on the screen and to name their synaesthetic colour instead, they are required to "process the identity of the note more deeply" (2006, p. 32).

A further point that strongly influences the adoption of a reverse Stroop design is the fact that all nine synaesthetes in this study were classed as associators. Dixon et al. (2004) showed that the performance of associators and projectors in Stroop tests revealed different patterns of interference. Projectors showed a significantly larger Stroop effect compared to associators and were faster at naming their synaesthetic colours than associators. These findings suggest a difference in the automaticity of synaesthetic processing between projectors and associators. Gatti and Egeth (1978) also posit that a projector's synaesthetic colour experience might simply be more difficult to ignore than that of an associator. As the synaesthetic colour is projected out into the world rather than held in the "mind's eye", its physical proximity to the veridical colour may make it harder to overlook. An associator may more easily be able to ignore their synaesthetic colour as it is held internally and spatially away from the target colour patch and name the veridical colour in a standard Stroop test with little interference.

It was expected that a longer reaction time would be observed when naming synaesthetic colours if synaesthetes were presented with incongruent pairings between colour and key signature, but that the change in the form of the stimuli from a key signature written in words to that of a key signature written on the stave (either in the treble or the bass clef) would not affect a change in synaesthetic experience (Chou & Rich, 2014).

Method

Participants

Participants comprised the nine synaesthetes (Participants 1-9) verified as synaesthete in Experiment 1.

Materials

Three sets of stimuli in the form of coloured key signatures for the nine major keys were created for each individual participant in accordance with their synaesthetic colour for each key. The first set was written in words, and the second and third set notated on the stave in the treble clef and the bass clef respectively. Again, no minor keys were used to avoid ambiguity when reading from the stave. Incongruent pairings were then created from these colours for each participant and matched with other keys so that there were nine congruent pairings and nine incongruent pairings for each set. Each pairing was presented once in random order comprising 18 trials for each set, totalling 54 trials. Examples of the type of stimuli are shown in Figure 5.

Figure 5

Example of Congruent (Middle) and Incongruent (Top and Bottom) Stimuli Written in Words or Musical Representations

Note. Participants were required to ignore the veridical colour and name their synaesthetic colour (e.g., blue). The Word and Bass Clef stimuli are printed in red (see the online article for the colour version of this figure).

Procedure

The synaesthetes were presented with coloured key signatures written either in words, on the stave in the treble clef, or in the bass clef. Each stimulus was preceded by a fixation cross for 1000ms, after which the stimuli remained on the screen for 4000ms during which time a verbal response was recorded. No auditory stimuli were used. Participants were asked to ignore the veridical colour of the stimulus and to name out loud their synaesthetic colour for each key as quickly and as accurately as they could into a microphone. Participants were presented with on-screen instructions and were allowed a short practice trial before the experiment began. The reaction time for each response per participant was measured in milliseconds and recorded in a Waveform audio format (.WAV). The test was run using the open-source software package PsychoPy3 Experiment Builder (v3.0.5).

Analysis

Synaesthetes' performances were analysed by calculating mean reaction times (RT), as illustrated in Figure 6. Each RT measurement was verified by comparing it to the recording on the corresponding .WAV file. Any discrepancies were adjusted accordingly and incorrect responses noted. To reduce the effect of outlier RTs, incorrect responses and errors in timings when the microphone was inappropriately triggered were excluded from the reaction time analysis, together with RTs of more than three standard deviations from the mean. Data was compared using a repeated measures two-way 2 x 3 ANOVA with congruency between veridical colour and synaesthetic colour (Yes, No) and mode of presentation (Treble Clef, Bass Clef, Words) as within-subjects factors. The software package SPSS Statistics V25 was used to carry out the analysis of the data collected.

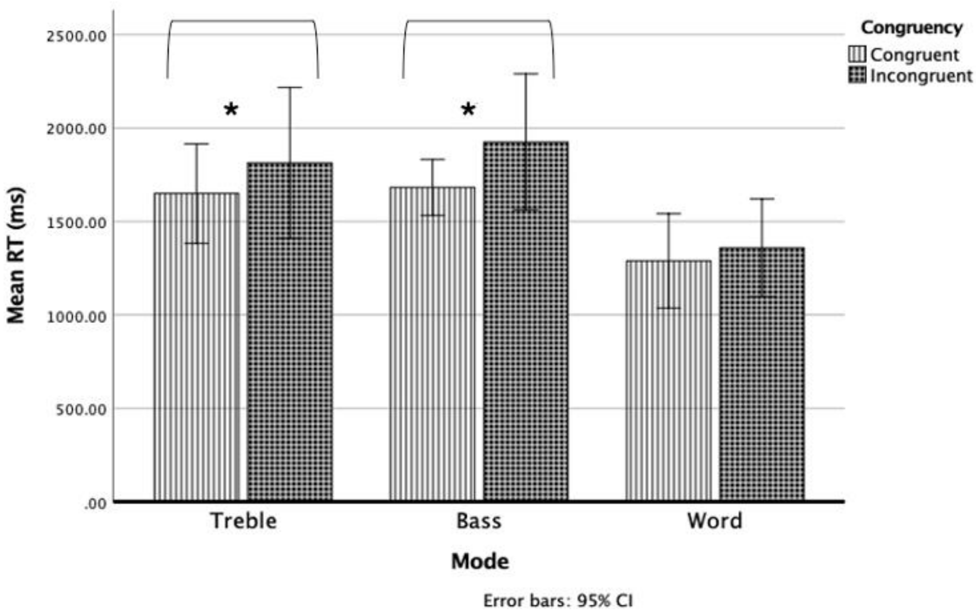
Results and Discussion

The ANOVA with congruency and mode as independent variables showed a statistically significant main effect of congruency on RTs; $F(1,8) = 6.63$, $p = .03$, $\eta^2 = .45$. A statistically significant main effect of mode was also observed on RT; $F(2,16) = 32.99$, $p = .001$, $\eta^2 = .81$. Post hoc Bonferroni tests indicated that the Word condition ($M = 1320$, $SD = 334$) had significantly ($p = .001$) faster RTs than the Treble condition ($M = 1730$, $SD = 436$) and significantly ($p = .001$) faster RTs than the Bass condition ($M = 1804$, $SD = 334$). There was no significant difference between Treble and Bass scores. No statistically significant interaction was observed between the effects of congruency and mode on reaction time; $F(2,16) = .538$, $p = .594$, $\eta^2 = .06$.

However, although overall the reaction times are faster in Word condition, the mean reaction times in the Congruent Word condition are only marginally faster than the Incongruent condition. Paired *t*-tests indicated a statistically significant difference on mean reaction times in the Treble condition, $t(61) = 2.25$, $p = .027$, and Bass condition, $t(61) = 2.042$, $p = .046$, but not in the Word condition, $t(64) = 1.13$, $p = .261$.

Figure 6

Stroop Interference in Synaesthetes when Naming Synaesthetic Colour



Note. Stroop interference is found when synaesthetes have to name their synaesthetic colour [* $p < .05$.]

As expected, synaesthetes displayed significant Stroop interference in the form of longer reaction times when they were required to name their synaesthetic colour and ignore the veridical colour of presented key signatures. Post hoc Bonferroni tests indicated that the significant main effect for mode was the result of faster naming times for the Word condition only. The presence of Stroop interference was observed across all modes of presentation, indicating that the change in the form of the stimuli from a key signature written in words to that of a key signature written on the stave (either in the treble or the bass clef) in Experiment 2 did not result in a change of synaesthetic colour, particularly as no interaction between congruency and mode was observed. However, paired *t*-tests revealed that the effect of congruence was not significant in the Word condition. The reasons for this unexpected result may be various. First, three of the nine synaesthetes also experienced grapheme-colour synaesthesia. It is possible that the colours elicited from reading the letters comprising the name of the key written in words were incongruent with the colours elicited from the concept of the key signature itself. Second, notation on the stave may provide more sensorimotor information about the concept of key rather than the written word – i.e., thoughts about production or hand shape (Curwen, 2020). Confirmation of these hypotheses would require further experimentation beyond the scope of the present study.

The presence of Stroop interference observed across all three modes of presentation when synaesthetes were asked to name their synaesthetic colour provides evidence to support the existence of synaesthesia for the concept of key signatures. It was hypothesised that there would be no interaction between congruency and mode, which was positively evidenced in the data collected. This suggests that the meaning of the stimulus was more important in eliciting a synaesthetic response than the shape or form of the stimulus itself. However, there was a significant main effect for mode. On further investigation this was revealed to be due to one mode: Word. RTs were faster for both Congruent and Incongruent words, than those of

Treble and Bass. Treble and Bass RTs for each of the conditions were very similar to each other. A possible explanation for this could be that the processing of the meaning of words may be quicker generally than that of musical notation. Ward, Tsakanikos and Bray (2006) hypothesised that "synaesthesia may take longer to appear for musical notation than for graphemes because musical notation is likely to be less familiar even to the musically trained" (p. 30). This hypothesis was tested in a separate task (Experiment 3) to compare the general processing time of musical notation with words.

Experiment 3: Processing of Musical Notation and Words

The aim of this task was to investigate whether the processing of the meaning of achromatic key signatures was generally quicker in the general population when presented in words rather than in musical notation, as suggested by the results of Experiment 2.

Method

Participants

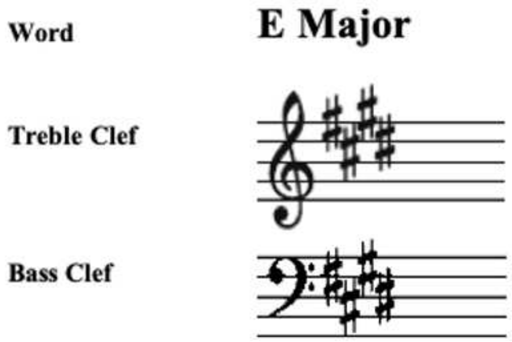
Participants comprised seven controls (Participants 11-17). Participants 10 and 18 could not be included as they were not able to read key signatures sufficiently fluently.

Materials

The same nine major key signatures were used to create three sets of monochromatic stimuli written in words, or on the stave in the treble clef or the bass clef. Examples of the type of stimuli are shown in Figure 7.

Figure 7

Example of Monochromatic Stimuli for E Major



Procedure

The processing task was in the same format as Experiment 2: participants were asked to identify out loud each key by name as quickly and as accurately as they could into a microphone, and no auditory stimuli was used. Participants were presented with on screen instructions and were allowed a short practice trial before the experiment began. Each key signature was presented twice in random order comprising 18 trials for each set, totalling 54 trials. The reaction time for each response per participant was measured in milliseconds and recorded in a Waveform audio format (.WAV), and the test was run using the open-source software package PsychoPy3 Experiment Builder (v3.0.5).

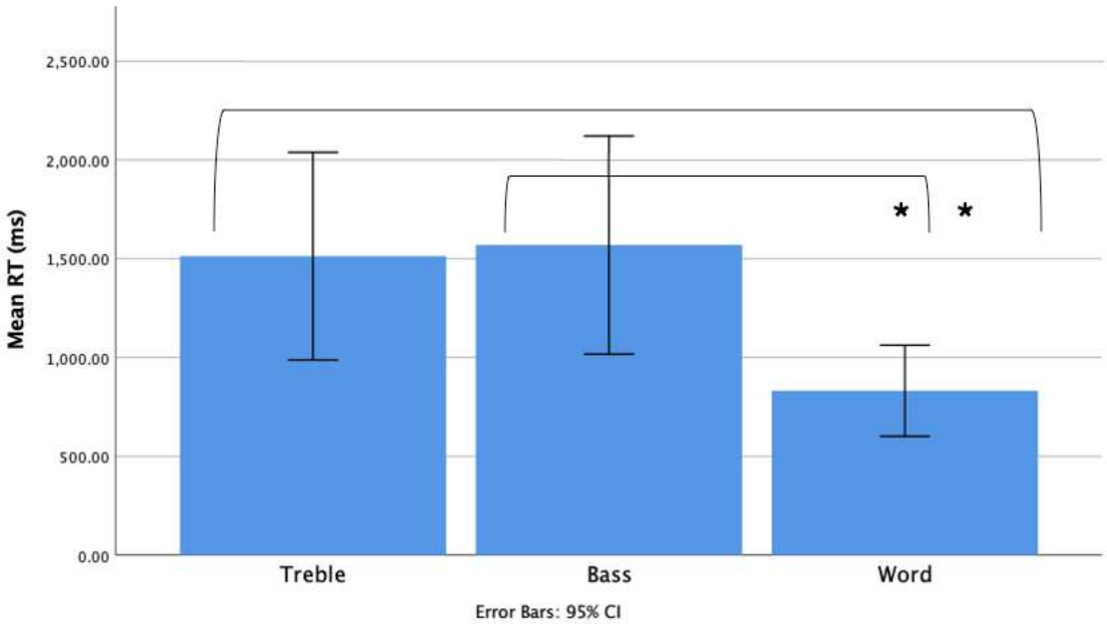
Analysis

Participants' performances were analysed by calculating the mean RTs as illustrated in Figure 8. Each RT measurement was verified by comparing it to the recording on the corresponding .WAV file. Any discrepancies were adjusted accordingly and incorrect answers recorded. As before, incorrect responses were excluded together with RTs more than three standard deviations from the mean RT to reduce the effect of outlier RTs. Data was compared using a one-way repeated measures ANOVA with mode of presentation (Treble

Clef, Bass Clef, Words) as a within-participant variable. The software package SPSS Statistics V25 was used to carry out the analysis of the data collected.

Figure 8

Controls' Naming Times – Monochromatic Key Signatures in Different Modalities



Note. In the control group, Word naming times were significantly faster than in the Treble or the Bass condition [* $p < .05$].

Results and discussion

The repeated measures ANOVA indicated a statistically significant main effect of mode on RT; $F(2,12) = 22.6$, $p = .001$, $\eta^2 = .79$. Post hoc Bonferroni tests indicated that the Word condition ($M = 832$, $SD = 249$) had significantly ($p = .006$) faster RTs than the Treble condition ($M = 1513$, $SD = 568$) and significantly ($p = .008$) faster RTs than the Bass condition ($M = 1569$, $SD = 597$). There was no significant difference between Treble and Bass scores.

The hypothesis that the processing of the meaning of a key signature is quicker when written in words than when musically notated is supported here. A similar mean RT for each of the Treble and Bass conditions was recorded ($M = 1513$ and $M = 1569$, respectively) and these were approximately 85% slower than the mean RT for the Word condition (*M* = 832). In Experiment 2, mean RTs were slower than those in Experiment 3 in all conditions, but the mean RTs for the Treble and Bass conditions (*M* = 1730 and *M* = 1804 respectively) were only approximately 31% slower than the Word condition (*M* = 1320). Yet despite the smaller difference between the Word condition and the Treble and Bass conditions, a similar pattern was observed.

This offers a possible explanation for the unexpected significant main effect of mode in Experiment 2, independent of participants' synaesthesia. In conclusion the results of Experiments 2 and 3 provide support for Hypothesis 1 (the existence of a synaesthetic association with written key signatures). With regard to Hypothesis 2 (synaesthetic association persists irrespective of presentation modality and form of key signatures), synaesthesia was shown to persist regardless of whether the key signature was presented on the stave in the Treble Clef or Bass Clef, but not in the Word condition. Overall, evidence supports the existence of synaesthesia for reading written key signatures as a genuine form of synaesthesia likely linked to conceptual rather than to purely perceptual processing of the inducing stimulus (Dixon et al., 2000, 2005).

Experiment 4: Verification of the Existence of a Priming Effect for Achromatic Key Signatures

As mentioned previously, how deeply an inducer needs to be processed to elicit synaesthesia remains unclear (Chiou & Rich, 2014; Mattingley et al., 2001; Smilek et al., 2001). Mattingley et al. (2001) presented stimuli to synaesthetes for 500ms, 56ms or 28ms in a masked priming experiment and concluded that the inducer in grapheme-colour synaesthesia must be available for conscious report for synaesthesia to arise, whilst Smilek et al. (2001) reported implicit processing without conscious identification to be sufficient. Experiment 5 was designed to test Hypothesis 1 by assessing the interference of synaesthetic colours with veridical colours in a task-irrelevant manner by measuring the congruency effect on reaction times without the need for the explicit naming of synaesthetic colour. Participants were required to select whether an achromatic key signature target superimposed over a colour patch was the same or different to an achromatic key signature prime. The colour patch would be either congruent or incongruent with the participant's synaesthetic colour for the target key signature, though the colour of the patch would be irrelevant to the task. Experiment 4 was designed as a pre-test to verify the existence of a priming effect for achromatic key signatures in the general population. Employing a similar paradigm to Mattingley et al. (2001), primes were presented for durations of 500ms, 56ms and 28ms in separate blocks of trials prior to testing synaesthetes in Experiment 5.

Method

Participants

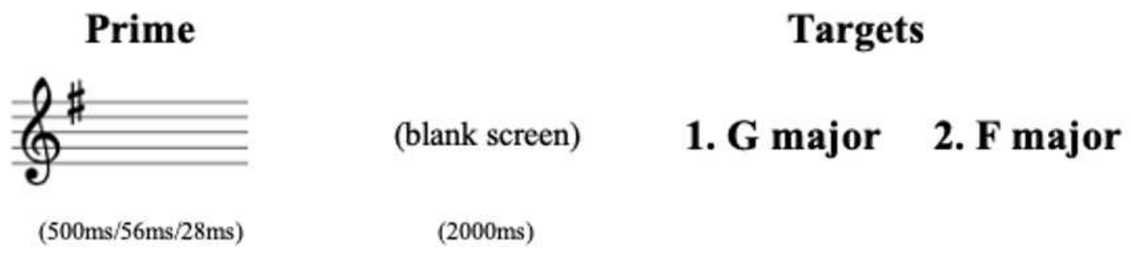
Data was collected and analysed from six synaesthetes (Participants 1, 3-6, and 8). Unfortunately, a technical malfunction meant that the data from Participants 2, 5 and 7 was not recorded.

Materials and procedure

A set of stimuli (primes) was created from nine achromatic major key signatures notated on the stave in the treble clef: C major, G major, D major, A major, E major, F major, Bb major, Eb major and Ab major. Again, no minor keys were used to avoid ambiguity when reading from the stave, and no auditory stimuli was used. Targets were in the form of written key signatures in words. Examples of achromatic stimuli and targets are shown in Figure 9.

Figure 9

Stimuli and Targets in Experiment 4



Note: The example prime is the achromatic key signature of G major notated on the treble clef. Targets are key signatures written in words (one correct and one incorrect).

The task was conducted in three separate blocks of trials. In each block a fixation cross was shown for 2000ms, followed by a prime in the form of an achromatic key signature written on the stave in treble clef. The prime was presented briefly and then followed by a blank screen for 2000ms. In the first block the prime was presented for 500ms, and then for 56ms and 28ms in blocks 2 and 3 respectively. The name of two major keys were then displayed in words, and the participant was asked to choose the correct name for the prime key signature, selecting a key press for Option 1 or Option 2 as quickly as they could. Participants were shown on-screen instructions and were allowed a short practice trial before the experiment began. The test was run using the open-source software package PsychoPy3 Experiment Builder (v3.0.5).

Analysis

Participants' performances were analysed by calculating RTs and error rates (ERs). As in Experiment 2, incorrect responses were excluded together with RTs more than three standard deviations from the mean RT, comprising 6.58% of the total data, to reduce the effect of outlier RTs. The data was analysed using a one-way repeated measures ANOVA with presentation time (500ms, 56ms, 28ms) as a within-participant variable. Owing to the repetitive nature of the extended testing across three blocks of trials, the correlation coefficients between mean RTs and ERs from combinations of the three presentation times were calculated to assess whether a speed–accuracy trade-off existed affecting response speed. The software package SPSS Statistics V25 was used to carry out the analysis of the data collected as shown in Table 3.

Table 3

Mean ERs and RTs in Experiment 4

	500ms	56ms	28ms
ER (%)	1.23	3.09	3.09
Errors (No)	2	5	5
RT (ms)	685	637	683
SD (ms)	230	160	146

Results and Discussion

No main effect on reaction time was observed due to the difference in presentation times; $F(2,10) = 607$, $p = .564$, $\eta^2 = .11$. This suggests that the prime was presented long enough in all presentation conditions to be available for identification. A speed–accuracy trade-off was not observed. ERs were very low and the mean ERs and RTs across the three presentation conditions from the 18 data points (6 participants x 3 conditions) were not significantly correlated (Spearman's rank correlation); $p(17) = .183$, $p = .468$. Additionally, ERs were not significantly correlated with the presentation time; $\rho(17) = .172$ $p = .495$. It was concluded that the presentation times of 28ms, 56ms and 500ms are appropriate to examine the effects of priming in the following Experiment 5.

Experiment 5: Interference for the Matching of Key Signatures (Synaesthetes)

The aim of Experiment 5 was to further test Hypothesis 1 by assessing the interference of synaesthetic colours with veridical colours in a task-irrelevant manner. The design was a sequential matching paradigm adapted from Banno et al.'s (2017) Experiment "Colour matching task". Banno's experiment measured the congruency effect on reaction times without the need for the explicit naming of synaesthetic colour. The advantage of this design is that, in Experiment 2, synaesthetes indicated that a simple "red" or "blue" often did not adequately describe a synaesthetic colour. This led to less confident responses from some synaesthetes. Removing the requirement to name a synaesthetic colour limited this effect.

Method

Participants

Nine synaesthetes took part as in Experiment 2, but data from only eight participants was analysed. Participant 2 had to be excluded owing to a failure to follow experimental instructions.

Materials

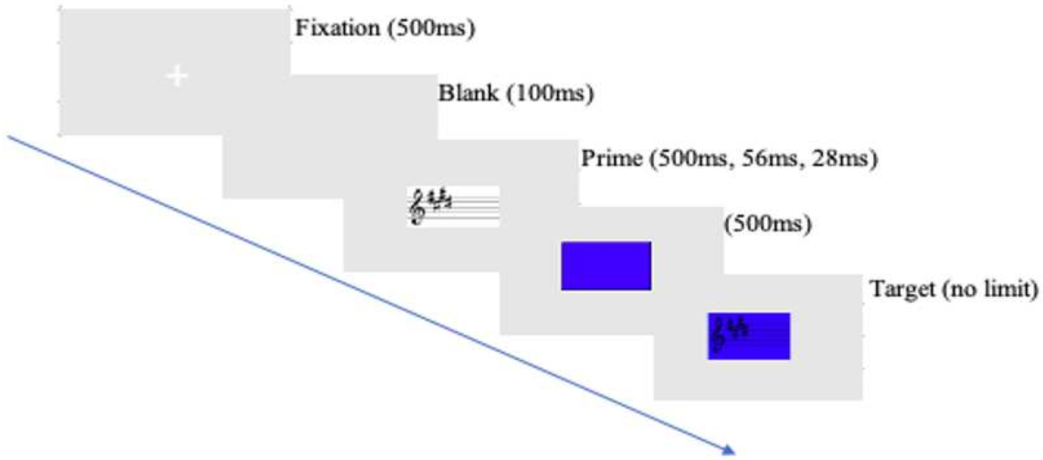
A set of stimuli was created for each synaesthete in accordance with their synaesthetic colours for each key. The stimuli comprised coloured key signatures in the treble clef only. As the aim of this experiment was to further test Hypothesis 1 by assessing the interference of synaesthetic colours with veridical colours in a task-irrelevant manner, different modes of presentation were not used, and all key signatures were presented on the treble clef. No minor keys were used to avoid ambiguity when reading from the stave. Incongruent pairings were created from the colours for each participant and matched with other keys so that there were nine congruent pairings and nine incongruent pairings per set. Half of the set of trials required a "SAME" response, and the other half required a "DIFFERENT" response. It was expected that synaesthetes would be significantly affected by veridical and synaesthetic colour congruency even though the colour was task irrelevant.

Procedure

The experiment began with a fixation point for 500ms. After a blank space for 100ms an achromatic major key signature was presented for variable durations (500ms, 56ms or 28ms) in separate blocks of trials. After this, a colour patch was presented for 500ms, followed by a target key signature superimposed over the same colour patch until a response was made. No auditory stimuli were used. Participants were asked whether the target key signature was the “SAME” or “DIFFERENT” to the first key signature, which they indicated with a key press of the left or right arrow key for “SAME” or “DIFFERENT” respectively. A schematic of the experiment is shown in Figure 10, and the types of stimuli used are shown in Figure 11. Participants were shown on-screen instructions and were allowed a short practice trial before the experiment began. Participants were presented with three blocks of 36 stimuli in random order. The test was run using the open-source software package, PsychoPy3 Experiment Builder (v3.0.5).

Figure 10

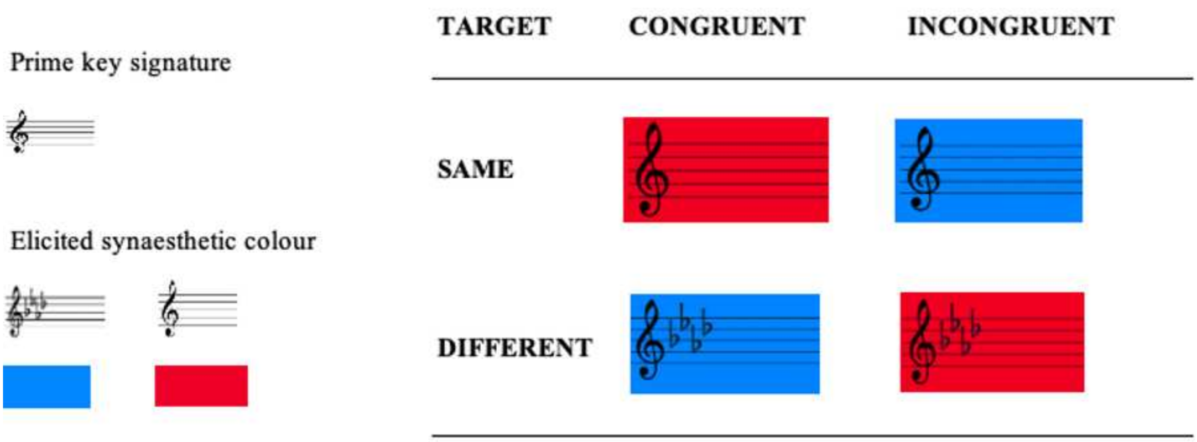
Schematic - Presentation of Prime Key Signature (500ms)



Note. Trial schematic for Experiment 5. See the online article for the colour version of this figure.

Figure 11

Sample Display for a Synaesthete who Experiences Ab Major as Blue and C Major as Red



Note. In the example, the prime is C major, and the Target can be the same in a congruent or incongruent colour, or different in a congruent or incongruent colour, to the presented target key. Four possible patterns are illustrated (2 congruence x 2 response types).

Analysis

In order to focus solely on the effect of congruency and not on the effect of whether the same or a different key was presented, only responses for “SAME” conditions were analysed. Performance was measured by analysing reaction times. Data for conditions with a “SAME” response was compared using a two-way repeated measures 2 x 3 ANOVA with congruency of colour and target key signature (Yes, No), and the presentation of the prime (500ms, 56ms, 28ms) as within-subjects factors. Incorrect responses and RTs more than three standard deviations from the mean were excluded (i.e., 7.29% of “SAME” response data). Data for conditions with a “DIFFERENT” response was not analysed because at least one of the colours, veridical or synaesthetic, would always be incongruent with one of the key signatures. To assess whether a speed–accuracy trade-off existed affecting response speed, “SAME” response ERs were calculated, together with the correlation coefficients between mean RTs and ERs from combinations of the two congruence conditions and the three presentation times. The software package SPSS Statistics V25 was used to carry out the analysis of the data collected.

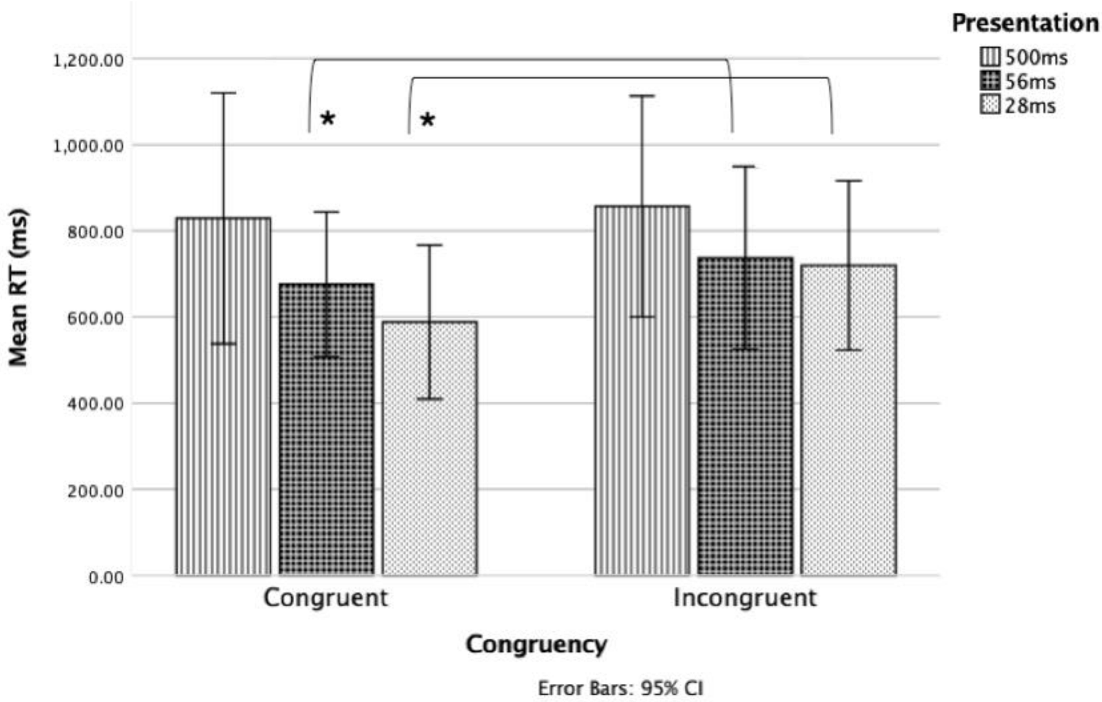
Results and discussion

The repeated measures ANOVA indicated a statistically significant main effect of congruency on RTs; $F(1,7) = 29.51$, $p = .001$, $\eta^2 = .81$ and an effect of presentation times; $F(2,14) = 7.84$, $p = .005$, $\eta^2 = .53$. Post hoc Bonferroni tests revealed that there was no significant difference between the individual presentation times. However, the mean reaction times in the Congruent 500ms condition were not significantly faster than in the Incongruent condition. Paired *t*-tests indicated a statistically significant difference on mean reactions times in the 28ms condition; $t(70) = -3.916$, $p = .001$, and 56ms condition; $t(70) = -2.549$, $p = .013$; but not in the 500ms condition; $t(70) = -.745$, $p = .459$. A statistically significant interaction was not observed between congruency and presentation on RT; $F(2,14) = 2.83$, *p*

= .093, η^2 = .29. A comparative graph of the data collected in the Incongruent and Congruent conditions is shown in Figure 12. It shows that there was a trend for RTs to be slower for the Incongruent conditions, as expected.

Figure 12

Synaesthetes - Response Data



Note. Naming times were significantly faster in the Congruent Bass and Congruent Word conditions than in the Incongruent Bass and Incongruent Word conditions [*p = .05].

Mean error rates and reaction times from 48 data points (8 synaesthetes x 6 conditions) are shown in Table 4. No speed-accuracy trade-off was observed as response speed and ER were not significantly correlated; $\rho(47) = -.251$ $p = .086$ (Spearman's rank correlation), neither was ER significantly correlated to presentation; $\rho(47) = -.250$ $p = .086$ (Spearman's rank correlation). No correlation was observed between ER and congruency; $\rho(47)$ = .-.031, $p = .832$. These results are in concurrence with those of Experiment 4. The results support the presence of Stroop interference even when the colour is task-irrelevant across all presentation times, suggesting that access to the meaning of the stimuli was accessible across all presentation times, even when the key signature was not clearly visible. However, paired *t*-tests revealed that the effect of congruence was very weak in the 500ms presentation time. This may be due to the small sample size. Nevertheless, the depth of processing required to elicit synaesthesia for key signatures remains uncertain and requires further testing.

Table 4

Mean Error Rates and Reaction Times in Experiment 5

	500ms		56ms		28ms	
	Con	Inc	Con	Inc	Con	Inc
ER (%)	0	1.56	6.25	4.69	4.69	6.25
Errors (No.)	0	1	5	4	4	5
RT (ms)	829	856	676	738	589	720
SD (ms)	348	307	201	254	214	235

Note: Con = Congruent; Inc = Incongruent

General Discussion and Conclusion

This study is the first to provide empirical evidence for the existence of a form of synaesthesia associated with reading key signatures. Notwithstanding the small sample size of synaesthetes with this type of synaesthesia, results were significant and effect sizes were large. However, there were some limitations to the study. Difficulties associated with the confirmation of genuine synaesthesia is well documented (Eagleman et al., 2007; Rothen et al., 2013) and continues to be problematic in synaesthesia research. The identification of true synaesthetes from amongst the 12 self-reporting participants was not clear-cut, and an indication of high consistency in colour selection was not an absolute means of verification

(Cohen Kadosh & Terhune, 2012; Simner, 2012). For example, two participants' results were excluded even though they returned a high consistency score. This decision was based on a very low percentage of correct responses given when naming their synaesthetic colour in Experiment 2, calling into scrutiny the automaticity of response normally present in synaesthesia.

A further complication was that some synaesthetes experienced a specific mixture of colours for certain keys. A "greeny-purple with inflections of red" was neither easy to find at first selection nor to recreate at retest. For these keys the consistency score was lower than expected, and the description given to the colour in Experiment 2 was often ambiguous and at risk of experimenter interpretation. It was also necessary to adjust the consistency scores of those synaesthetes that did not have synaesthetic colours for all nine major keys tested. Their colour associations were highly consistent and specific for certain keys, but their average consistency scores across all nine keys were lower than expected.

Two synaesthetes also reported the possession of absolute pitch (Participants 6 and 7). It cannot be absolutely certain that the "pitch" of the key was not heard in their head as a result of reading the key signatures. If so, the task of colour selection at test and retest may have been made easier and their choices not primarily conceptual. However, notwithstanding their absolute pitch, Participants 6 and 7 did not demonstrate the highest consistency scores in Experiment 1. In Experiments 2 and 5 the stimuli were presented so briefly; it might be the case that any additional processing time required to translate pitch naming to synaesthetic colour would be observed as an increase in reaction time rather than being advantageous. It is possible that this could have contributed to the lack of a significant difference between reaction times in Congruent and Incongruent conditions at 500ms in Experiment 5, but further experimentation would be required to confirm this.

The control group also presented unexpected results at retest. Although scores were lower and not as precise as in the synaesthete group, choices were not entirely random. The danger that some synaesthetes may be overlooked and that a high score may be misinterpreted as a synaesthetic association supports the argument that consistency should be better considered as an "associated characteristic" of synaesthesia rather than as a definitive measure (Ward & Mattingley, 2006).

The participation of controls in Stroop-type behavioural tests also poses problems simply because controls do not experience synaesthetic colours. This raises the question of exactly what was being tested. In Experiment 2, participants were asked to explicitly name their *synaesthetic* colour, a request that was absent in the control group. In the pilot, it was clear that although the controls' colour selection was not entirely random and that a certain level of consistency existed (as shown in Experiment 1), they were not able to reliably name the colour they had previously selected (or often any colour at all) within the 4000ms response time. This was particularly the case for controls who had to be encouraged to make any sort of colour choice for the keys in the first place. As incorrect responses and errors in timings when the microphone was inappropriately triggered were excluded from the reaction time analysis, together with RTs of more than three standard deviations from the mean, very little data was collectable. Consequently, controls were not requested to do this experiment, and a comparison with synaesthetes was not possible.

Controls were not compared to synaesthetes in Experiment 5 as controls did not make precise enough selections at Test and Retest in Experiment 1 to determine a categorical colour for each key. It might be argued that an experiment could have been run if it had been assumed that the "Congruent" condition for the controls was the colour for each key selected at first test, and the colour selected at retest was ignored. Incongruent conditions could therefore have been created with any colour at all that was not either of the colours selected at first or second test. Again this raises the question of exactly what was ~~is~~ being tested. Even if synaesthetes were presented with a period of time to become familiar with a set of colours, reaction times would most likely reflect the effects of short-term memory rather than the consistency and automaticity typically associated with synaesthesia.

Additionally, although the results of Experiment 5 suggest that the meaning of the stimuli was accessible even when the key signature was not clearly visible, Experiment 5 was not explicitly designed to investigate unconscious priming. Further experimentation would be required to confirm the depth an inducer would need to be processed in this form of synaesthesia (Mattingley et al., 2001; Smilek et al., 2001). Nevertheless, this is an interesting indication that there is no need for long exposure to the inducer for synaesthesia to arise, and that even a brief presentation may be sufficient.

Despite these limitations, the importance of this study is that it evidences synaesthetic experiences associated with music are not confined to a response on hearing an individual tone or chord (Mills et al., 2003) as much of the research to date has assumed and focussed on. Music-colour synaesthesia has a broad scope and not all types are cross-sensory (Curwen, 2018). The results challenge the traditional view that synaesthesia is fundamentally a perceptual phenomenon and support the argument that some forms of synaesthesia can arise from a conceptual stimulus (Dixon et al., 2000; Mroczko-Wąsowicz & Werning, 2012; Mroczko-Wąsowicz & Nikolić, 2014; Ward, Tsakanikos & Bray, 2006).

Empirical evidence has shown that a synaesthetic experience may be elicited without the necessity of sounding out the key, and that the concept of the key is sufficient to produce a synaesthetic response. For example, the richness of concept-driven forms of music-colour synaesthesia may be mediated by timbre, tempo or emotional meaning (Mroczko-Wąsowicz & Nikolić, 2014). The synaesthetic colours associated with a key signature provide information about the concept of the key, irrespective of its mode of presentation either as a written key signature on a musical stave or in words. Emerging from the results of Experiment 2 is the hypothesis that synaesthesia associated with music may be mediated by concept but grounded in sensorimotor action, and that notation on the stave may provide more sensorimotor information about the concept of key rather than the written word – i.e., thoughts about production or hand shape (Curwen, 2020). This presents an opportunity for future empirical research. For example, a group of non-synaesthete musicians (controls) might be given sufficient training until they could use a keyboard to silently play a selection of chords in different keys notated either on the stave (bass and treble clef) or written in words, and reliably associate a colour with each key. The group of controls would then be compared to a group of synaesthete musicians. Each group would be presented with coloured chords in different keys (notated on the stave or written in words) and asked to play them as quickly as possible. It might be expected that chords presented to synaesthetes in incongruent colours would result in slower reaction times, but not in the control group. In addition, should synaesthesia have a sensorimotor grounding, it might be expected that there would be no effect for congruency in the word condition in either group, as words may not carry the same sensorimotor information as chords notated on the stave.

In conclusion, this study supports the likelihood that separate mechanisms underlie different forms of music-colour synaesthesia, and that to gain a full understanding of the phenomenon it is important to extend investigations beyond the more commonly examined tone-colour synaesthesia.

Link to Datasets: https://doi.org/10.15131/shef.data.13140086.v4 (Curwen, 2020)

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