Consciousness and Cognition 31 (2015) 73–85

Contents lists available at ScienceDirect

Consciousness and Cognition

journal homepage: www.elsevier.com/locate/concog

Beyond visual imagery: How modality-specific is enhanced mental imagery in synesthesia?

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ARTICLE INFO

Article history:
Received 14 June 2013
Available online 15 November 2014

Keywords:
Synesthesia
Mental imagery
Visual imagery
Auditory imagery
Gustatory imagery
Tactile imagery
Olfactory imagery

ABSTRACT

Synesthesia based in visual modalities has been associated with reports of vivid visual imagery. We extend this finding to consider whether other forms of synesthesia are also associated with enhanced imagery, and whether this enhancement reflects the modality of synesthesia. We used self-report imagery measures across multiple sensory modalities, comparing synesthetes' responses (with a variety of forms of synesthesia) to those of non-synesthete matched controls. Synesthetes reported higher levels of visual, auditory, gustatory, olfactory and tactile imagery and a greater level of imagery use. Furthermore, their reported enhanced imagery is restricted to the modalities involved in the individual's synesthesia. There was also a relationship between the number of forms of synesthesia an individual has, and the reported vividness of their imagery, highlighting the need for future research to consider the impact of multiple forms of synesthesia. We also recommend the use of behavioral measures to validate these self-report findings.

1. Introduction

Individuals with synesthesia ('synesthetes') have anomalous perceptual experiences: sensory stimulation in one modality induces additional atypical experiences within the same or different modality. Sound-color synesthetes, for example, experience colors in addition to sound when hearing auditory stimuli (Ward, Huckstep, & Tsakanikos, 2006). Synesthesia can also be induced by cognitive concepts, with one common form being grapheme-color synesthesia, in which color perceptions are induced by reading, hearing or thinking about letters, numbers and words (Ward, Li, Salih, & Sagiv, 2007). Other documented examples include word-taste synesthesia (taste experiences from words), sound-taste synesthesia (taste experiences from non-linguistic sounds), auditory–visual synesthesia (experiencing visual geometric shapes from sound) and so on (e.g., Beeli, Esslen, & Jancke, 2005; Chiou, Stelter, & Rich, 2013; Ramachandran & Hubbard, 2001; Smilek, Callejas, Dixon, & Merikle, 2007; Ward & Simner, 2003; Ward et al., 2006). In the majority of cases synesthesia is developmental, and has been present for as long as the synesthete can remember, though in a minority of cases synesthesia can be acquired after sensory loss (e.g. Steven & Blakemore, 2004) or neurological damage (e.g. Fornazzari, Fischer, Ringer, & Schweizer, 2012). Importantly, these additional synesthetic experiences occur without effort and are generally consistent over time (but see Simner, 2012).

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http://dx.doi.org/10.1016/j.concog.2014.10.010
1053-8100/

Over the past ten to fifteen years, our understanding of synesthesia has grown considerably (Hubbard, Brang, & Ramachandran, 2011) and there now exists a large body of research showing a range of neural and behavioral traits associated with the condition. For example, there are differences between the brains of synesthetes and non-synesthetes, with synesthetes having greater structural connectivity in several different regions (Jancke, Beelie, Eulig, & Hanggi, 2009; Rouw & Scholte, 2007, 2010; Zamm, Schlaug, Eagleman, & Loui, 2013; for review see Rouw, Scholte, & Colizoli, 2011). There are also reported differences between synesthetes and non-synesthetes in the early sensory processing of visually presented stimuli (Barnett et al., 2008). Yet more research has started to explore the impact that synesthesia has on an individual's cognitive and perceptual abilities, with some data suggesting that synesthetes may show enhanced abilities in certain aspects of memory (for a review see Rothen, Meier, & Ward, 2012) and sensory perception (Banissy, Walsh, & Ward, 2009). In the current study we ask whether synesthesia is also accompanied by enhanced abilities in mental imagery.

Clearly, the key difference between synesthetes and non-synesthetes is that synesthetes have quasi-perceptual experiences in the absence of the usual external stimulation (e.g. they experience colors in the absence of visual stimulation). The *quality* of these experiences differs from synesthete to synesthete, with some describing their synesthetic experience (termed the "concurrent") as vivid and tangible and others describing them as simply a 'feeling of knowing' (Dixon, Smilek, & Merikle, 2004; Hubbard, Arman, Ramachandren, & Boynton, 2005; Ward et al., 2007). Even so, descriptions of synesthetic percepts often seem similar to descriptions of mental images, and while there are some differences between synesthetic concurrents and mental images per se (e.g., synesthetic concurrents are typically reported to arise in a very involuntary manner, while at least some types of mental images are more effortful in character) we might nonetheless investigate the mental imagery abilities of synesthetes as compared to those of non-synesthetes. Specifically, since mental imagery can be thought of as "seeing in the mind's eye in the absence of appropriate immediate sensory input" (Kosslyn, Thompson, Kim, & Alpert, 1995, p. 1335), and since this description could also be applied to at least some synesthetic experiences, one might ask whether synesthetes' mental imagery abilities are different to those of non-synesthetes (see also Simner, 2013).

A small number of studies have started to explore the question of mental imagery in synesthesia. Barnett and Newell (2008) focused on self-reported vividness of visual imagery, comparing a group of synesthetes to a group of non-synesthete matched controls. Strength of visual imagery was reported using the Vividness of Visual Imagery Questionnaire (VVIQ, Marks, 1973), a self-report measure which asks respondents to generate a series of visual images of various scenes, and to rate how clear and vivid particular elements of these scenes are in the 'mind's eye'. The results showed that as a group, synesthetes reported significantly more vivid visual imagery than the control group. Following on from this, Price (2009) looked at the self-reported imagery of *sequence-space synesthetes*. These individuals experience sequenced units such as letters, numbers and months in particular spatial arrays, for example, envisaging months in an ellipse shape surrounding the torso (Sagiv, Simner, Collins, Butterworth, & Ward, 2006). Using a different measure to the VVIQ, the Object-Spatial Imagery Questionnaire (OSIQ, Blajenkova, Kozhevnikov, & Motes, 2006), Price too found that sequence-space synesthetes reported stronger visual imagery than a control group (the same result was later found by Rizza & Price, 2012). Furthermore, Price found that compared to non-synesthetes, synesthetes reported using imagery more frequently on an everyday basis.

Price's study therefore supported Barnett and Newell's conclusion that enhanced visual imagery may be a common trait associated with synesthesia. However, most of the synesthetes in the Barnett and Newell study had grapheme-color synesthesia, and the synesthetes in the Price study were sequence-space synesthetes, limiting their conclusions to only forms of synesthesia with visual–spatial concurrents. Furthermore, the self-report questionnaires used by these authors are themselves limited to visual–spatial forms of imagery. However, it is possible to form mental images across all sensory modalities, for example to form images of sounds, smells, tastes or tactile experiences. In the current study we therefore widen the assessment of synesthetes' mental imagery to include different forms of synesthesia and different types of mental imagery (i.e., involving other sensory modalities).

If individuals with visual forms of synesthesia have enhanced visual imagery, this could be due to their everyday experiences of visual concurrents – a sort of practice effect – since improvements in imagery with practice have been shown elsewhere (Noll et al., 1985; Rodgers, Hall, & Buckolz, 1991). If so, we would expect the enhanced imagery to be restricted to the modalities of the synesthesia. For example, a grapheme-color synesthete may report enhanced visual imagery, but would not be expected to report enhanced taste imagery. The idea that imagery enhancement may be restricted to the modalities involved in an individual's synesthesia is supported by a recent study showing that synesthetes with visual concurrents showed enhanced visual perception but not enhanced tactile perception, and vice versa for synesthetes with tactile concurrents (Banissy et al., 2009). Of course it should also be noted that enhanced mental imagery within one modality could also be the *trigger* for synesthesia, rather than a consequence (see Price, 2013).

Alternatively, synesthetes may experience enhanced imagery across all sensory modalities and this general enhanced imagery could result from more widespread structural or functional brain differences. As argued by Rouw et al. (2011), in their review of studies exploring brain areas involved in different forms of synesthesia, a broad network of areas is involved in synesthesia, extending beyond the modality-related sensory areas to other regions (e.g., those involved in feature binding and cognitive control). Rouw et al. concluded that a general 'synesthetic constitution' is likely to have effects beyond synesthesia. This broad constitution might affect imagery more broadly, given what we know about the neurological basis of imagery. Studies looking at the neural activity of mental imagery in the general population have shown both modality-specific and modality-independent activation. For example, although creating a visual image triggers neural activity in visual areas of the brain (and auditory images in auditory areas and so on), there may also be a 'default mode network', or core

Table 1
Summary of scales used for each concurrent/inducer modality.

Concurrent or inducer modality	Scales
Visual	VVIQ, SUIS, VMIQ-I, VMIQ-E
Auditory	CAIS
Tactile	Touch imagery and Bodily Sensations subscales from Bett's Questionnaire upon Mental Imagery, VMIQ-K
Olfactory	VOIQ
Taste	Taste imagery subscale from Bett's Questionnaire upon Mental Imagery

network, involved in imagery across all modalities (Daselaar, Porat, Huijbers, & Pennartz, 2010; McNorgan, 2012). Consequently, enhanced imagery could be unrelated to the specific synesthesia modality, and instead be related to more widespread cortical differences that affect the core network of brain areas involved in mental imagery across domains.

Our current study is a large scale comparison of synesthetes' and non-synesthetes' self-reports of imagery across a range of imagery modalities. Synesthetes with synesthesia involving a variety of different sensory modalities completed a battery of questionnaires about their mental imagery experiences, along with age- and sex-matched controls. As used by previous studies on mental imagery in synesthesia, our measures included the VVIQ (Marks, 1973) to explore visual mental imagery, and the Subjective Use of Imagery Scale (SUIS, Reisberg, Pearson, & Kosslyn, 2003) to look at reports of everyday use of mental imagery. In addition, we used a self-report measure of auditory imagery (Clarity of Auditory Imagery Scale, CAIS; Willander & Baraldi, 2010) and olfactory imagery (Vividness of Olfactory Imagery Questionnaire, VOIQ; Gilbert, Voss, & Kroll, 1997). We also included the Vividness of Movement Imagery Questionnaire (VMIQ; Roberts, Callow, Hardy, Markland, & Bringer, 2008) which rates vividness of images of 'external movement' (e.g. imagining seeing yourself throw a ball), 'internal movement' (e.g. imagining what you would see when throwing a ball) and 'kinesthetic movement' (e.g. imagining what it would physically feel like to throw a ball). For imagery relating to touch, taste, and bodily sensations such as tiredness we used an adapted version of Bett's Questionnaire Upon Mental Imagery (Sheehan, 1967). Table 1 summarizes the scales used with each concurrent/inducer modality.

The main focuses of our analysis were potential group differences between synesthetes and non-synesthetes in their total scores for each of these measures, to see if group differences exist in modalities beyond visual imagery. We were particularly interested to see whether there would be differences between specific sub-groups of synesthetes for particular image modalities (e.g. whether synesthetes with concurrents or inducers in the tactile modality report more vivid tactile imagery than other synesthetes). While we might expect synesthetes to report enhanced imagery in the modality of their concurrents, as found previously by Barnett and Newell with visual synesthetes reporting enhanced visual imagery, it is not so clear whether the same will be found for the modality of the inducer.

Finally, synesthetes often report more than one form of synesthesia (Novich, Cheng, & Eagleman, 2011) meaning they experience inducers and concurrents across many different sensory modalities, as well as within the same modality. In this study we looked at the impact of having an inducer or concurrent within specific modalities (e.g., visual, tactile) but we also looked at the overall *number* of modalities affected in any given synesthete. If the vividness of an individual's mental imagery is in some way related to them experiencing synesthesia, it may also be the case that the number of modalities involved may be related to mental imagery ability. We therefore wanted to examine whether there was a relationship between the reported vividness of imagery for each individual measure and the total number of modalities of synesthesia experienced by any individual. To date, very few studies (if any) have considered the impact of having multiple forms of synesthesia, and so this was a necessary, if exploratory, analysis.

2. Method

2.1. Participants

Participants were 103 synesthetes (85 female, mean age = 35.2 years, range = 18–72, SD = 14.0[1]) of whom 53 (52%) were validated as genuine synesthetes using one or more of the following behavioral gold-standard measures: a consistency score of <1 and/or a Stroop test score of over 85% on the *Synesthesia Battery* (see Eagleman, Kagan, Nelson, Sagaram, & Sarma, 2007 for details), and/or a score of over 75% in a verbal consistency test (where participants verbally describe their synesthetic concurrents to a list of stimuli and are then given a surprise retest after at least 2 months). Synesthetes were recruited from online synesthesia forums, and controls were recruited from the university communities of Sussex, East London and St. Andrews. These 102 non-synesthete controls were matched group-wise for age and sex (76 female, mean age = 34.9, range = 18–68, SD = 13.3) and were screened via questionnaire to ensure they did not possess any of the following common forms of synesthesia: letter-color; number-color; pain-color; touch-color; emotion-color; personality-color; time-color; spatial forms; lexical-gustatory; ordinal linguistic personification (see Simner & Hubbard, 2013 for more details on these various forms of synesthesia). For payment, all participants were entered into a draw to win £50 in shopping vouchers, and synesthetes completing the Synesthesia

[1] Please note, three synesthetes did not provide their age.

Battery were additionally entered into a draw for an extra voucher (£25). Participants gave informed consent, and the study was approved by the University of East London ethics board.

Table 2 shows the frequency (and percentage) with which each modality serves as either an inducer or concurrent within our sample of synesthetes. This information was obtained from synesthetes' self-reports about their synesthetic experiences, and these were elicited via a questionnaire asking the participant to list any forms of synesthesia that they experienced. For the purposes of this paper we have determined the frequency of our sample with inducers/concurrents in visual, auditory, tactile, olfactory and taste modalities (to fit with the imagery scales used). It should be noted that synesthetes also reported inducers involving personalities (14%), moods (9%), orgasm (9%), pain (6%), temperatures (5%), texture (3%), and movement (1%). They also reported concurrents involving space (55%), pain (3%), words (1%), personalities (16%), gender (17%), temperature (1%), and texture (7%). These groupings were not used for the current study as they did not fit with the imagery scales used. Another important aspect to note is that synesthetes often fell into more than one grouping (i.e. a synesthete might have visual inducers, visual concurrents, and auditory concurrents, or any other combination). The total number of modalities in which any one individual experienced synesthesia, either as an inducer or concurrent, ranged from 2 up to 15, with the mean number of modalities being 5.47 (SD = 2.97). In relation to the visual modality, 59 synesthetes had both a concurrent and an inducer within the modality. However, these numbers were much smaller for the other modalities, with 2 having both an inducer and concurrent in the auditory modality, 1 with the tactile modality, 5 for the olfactory modality and 3 for the taste modality. This co-variance may be important to keep in mind when considering interpretations of the analysis presented. The number of particular forms of synesthesia (e.g. grapheme-color) has not been listed as this was not the focus of the paper, and most of the synesthetes have more than one form of synesthesia.

2.2. Materials and procedure

Participants were asked to complete six questionnaires, described in turn below. Each questionnaire was completed either in a paper format or in an electronic format, depending on the participant's preference. One synesthete did not complete the Spontaneous Use of Imagery Scale, one non-synesthete did not complete the Bodily Sensations scale, and one synesthete and one non-synesthete did not complete the Kinesthetic sub-scale of the Vividness of Movement Imagery Questionnaire.

2.2.1. Self reports of everyday use of imagery

Participants completed the Spontaneous Use of Imagery Scale (SUIS; Reisberg et al., 2003). This contains a series of statements describing the use of visual imagery in everyday activities. Participants are asked to rate the appropriateness of each statement to their own experiences, using a Likert scale of 1 (never appropriate) to 5 (always appropriate). In total there were 12 statements, such as, "*If I catch a glance of a car that is partially hidden behind bushes, I automatically 'complete it', seeing the entire car in my mind's eye*" and "*If I am looking for new furniture in a store, I always visualize what the furniture would look like in particular places in my home*".

2.2.2. Self reports of visual imagery vividness

The Vividness of Visual Imagery Questionnaire (VVIQ; Marks, 1973) was used to measure self-reports of visual imagery vividness; this questionnaire requires participants to create a series of visual mental images, and to rate how vivid certain aspects of these scenes appear to them. For example, participants visualize the outside of a shop they are familiar with, and rate the vividness of aspects such as the "*color, shape and details of the door*". There are 16 items, each rated on a scale from 1 ("No image at all, you only "know" that you are thinking of an object") to 5 ("Perfectly clear and as vivid as normal vision"). We reversed the scale for the current study in order to align its direction with the other scales being used.

2.2.3. Self reports of auditory imagery vividness

The Clarity of Auditory Imagery Scale (CAIS; Willander & Baraldi, 2010) has recently been developed to assess individual differences in clarity of auditory imagery. In this scale participants are asked to imagine 16 different sounds, such as a clock ticking, or someone sneezing. Participants are asked to rate the clarity of each auditory image, and for the purposes of this study we used a rating scale of 1 ("No sound at all, you only "know" that you are thinking of the sound") to 5 ("Perfectly

Table 2
Frequency (freq) and percentage (%) of synesthetes' reports involving particular modalities (column 1) as either inducers (columns 2–3), concurrents (columns 4–5), or neither (columns 6–7).

Modality	Inducer		Concurrent		Neither	
	Freq	%	Freq	%	Freq	%
Visual	66	64	74	72	23	22
Sound	30	29	4	4	71	69
Touch	9	9	11	11	84	82
Smell	10	10	7	7	91	88
Taste	5	5	18	18	84	82

realistic and as clear as the actual sound"). The wording has been changed from the 'not at all' to 'very clear' scale used by Willander and Baraldi, in order to have consistency in rating scales throughout this study.

2.2.4. Self reports of olfactory imagery vividness

In the Vividness of Olfactory Imagery Questionnaire (VOIQ; Gilbert et al., 1997) participants are asked to imagine a series of odorous situations, such as "the smell of a familiar car" or "someone who smokes tobacco". Participants rate the vividness of various aspects of these situations on a scale of 1 ("No odor at all, you only "know" that you are thinking of the odor") to 5 ("Perfectly realistic and as vivid as the actual odor"). In total there are 16 items to rate.

2.2.5. Self reports of tactile, taste, and bodily sensations

In order to assess individual differences in tactile imagery, taste imagery and imagery of bodily sensations, we adapted scales from Sheehan's (1967) shortened version of Betts' Questionnaire Upon Mental Imagery (the adaption involved adding additional items, and removing some items that were unclear or dated). For each of these types of imagery, participants were asked to imagine touching/feeling certain objects (e.g. sand, fur, sticky tape), tasting certain things (e.g. salt, coffee, peanut butter), or experiencing certain bodily sensations (e.g. fatigue, muscle cramp, sore throat). There were 12 items for each type of imagery, and the vividness was rated on a scale of 1 ("No touch/taste/sensation at all, you only "know" that you are thinking of the tactile sensation/taste/bodily sensation") to 5 ("Perfectly realistic and as vivid as the actual tactile sensation/taste/bodily sensation"). For a full list of the items used please see the Appendix A.

2.2.6. Self reports of movement imagery vividness

Participants completed the Vividness of Movement Imagery Questionnaire (VMIQ; Roberts et al., 2008). This questionnaire rates three different types of movement imagery. External visual imagery refers to the visual image that would be obtained from imagining watching yourself perform a movement from an external point of view (e.g. watching yourself running up the stairs). Internal visual imagery refers to a visual image obtained from an internal point of view, as if you were looking out through your own eyes whilst performing the movement (e.g. what you would see whilst running up the stairs). Kinesthetic imagery refers to a movement image obtained by feeling yourself perform the movement (e.g. how you would feel whilst running up the stairs). Participants were asked to imagine performing 12 different actions, and for each type of action/movement to rate the vividness of each type of movement imagery. The rating scale was 1 ("No image or feeling, you only "know" that you are thinking of the skill") to 5 ("Perfectly realistic and vivid [as normal vision or feel of movement]").

3. Results

3.1. Comparing (sub-groups of) synesthetes to controls

We calculated the total scores for each participant on each of the imagery scales. For the VVIQ, CAIS, and VOIQ scores could range from 16 to 80 and for all other scales the possible range was 12 to 60. Overall, we asked whether synesthetes report more vivid imagery in the same modality as their synesthesia, when compared to other synesthetes or non-synesthete controls. We conducted our analyses in three stages: first by considering synesthetes' concurrents, second by considering their inducers, and third considering the impact of having both a concurrent and inducer in the same modality. For all stages of analysis, when a significant effect of group was found with one of the imagery scales, we conducted planned Bonferroni pairwise comparisons. We report analyses based on the complete sample of self-reported synesthetes, but also indicate below any differences in the pattern of our results when considering only the subset of 52 synesthetes that were independently verified for synesthesia. Please see Supplementary Material for individual scatterplots for each scale.

For our first stage of analysis we split the participants into 3 groups for each imagery scale; group 1 ('CON = MODALITY') were synesthetes with a concurrent in the same modality as the scale (e.g. visual concurrent/visual scale), group 2 ('CON ≠ MODALITY') were synesthetes without a matching concurrent in that modality (e.g. NO visual concurrent/ visual scale), and group 3 ('NONSYN') were the non-synesthete controls. For our second stage of analysis we again split participants into three groups, but this time based on the modality of the inducer; group 1 ('IND = MODALITY') were synesthetes with an *inducer* in the same modality as the scale, group 2 ('IND ≠ MODALITY') were synesthetes without an inducer in that modality, and group 3 ('NONSYN') were, again, the non-synesthete controls. (We will describe our third stage of analysis further below.) Table 3 shows the means per group in each questionnaire scale.

3.1.1. Do concurrents influence imagery?

In this section we ask whether imagery is influenced by the type of concurrent (e.g., is visual imagery enhanced by having visual concurrents?). We therefore compare imagery across three groups: 'CON = MODALITY' versus 'CON ≠ MODALITY' and 'NONSYN'.

In our assessment of visual imagery, for the SUIS, a one-way ANOVA found a significant effect of participant group ($F(2,201) = 25.84$, $p < .001$, partial $\eta^2 = 0.21$). Follow-up tests showed that the synesthetes with visual concurrents reported significantly more use of visual imagery compared to synesthetes without visual concurrents ($p = .033$), and compared to controls ($p < .001$). Furthermore, synesthetes without visual concurrents reported significantly more use of visual imagery

Table 3
Means (and standard deviations in parentheses) for the everyday use of imagery (SUIS), Vividness of Visual Imagery (VVIQ), clarity of auditory imagery (CAIS), vividness of olfactory imagery (VOIQ), vividness of tactile imagery (Tactile), vividness of taste imagery (Taste), vividness of sensation imagery (Sensations), and the vividness of external movement imagery (VMIQ-E), internal movement imagery (VMIQ-I), and kinesthetic movement imagery (VMIQ-K) as a function of group used in analysis. Cells marked with an asterisk indicate that one participant of this group did not complete the relevant questionnaire.

	Visual modality				
	CON = MODALITY (N = 74)	CON ≠ MODALITY (N = 29)	IND = MODALITY (N = 66)	IND ≠ MODALITY (N = 37)	NONSYN (N = 102)
SUIS	47.1 (6.5)	42.9 (8.7)*	47.6 (6.7)*	43.1 (7.8)	39.0 (7.6)
VVIQ	61.6 (10.1)	58.6 (10.9)	62.5 (9.9)	57.6 (10.5)	55.6 (10.7)
VMIQ-I	43.7 (11.3)	44.2 (10.0)	44.0 (11.2)	43.5 (10.5)	39.9 (13.1)
VMIQ-E	36.3 (12.4)	35.6 (10.7)	37.3 (12.9)	33.9 (9.8)	36.0 (12.8)
	Auditory modality				
	CON = MODALITY (N = 4)	CON ≠ MODALITY (N = 99)	IND = MODALITY (N = 30)	IND ≠ MODALITY (N = 73)	NONSYN (N = 102)
CAIS	74.0 (4.8)	63.8 (13.8)	68.6 (14.4)	62.4 (13.0)	56.3 (15.3)
	Tactile modality				
	CON = MODALITY (N = 11)	CON ≠ MODALITY (N = 92)	IND = MODALITY (N = 9)	IND ≠ MODALITY (N = 94)	NONSYN (N = 102)
Touch Imagery	52.6 (6.7)	42.8 (12.5)	53.3 (6.2)	42.9 (12.5)	37.7 (12.7)
Bodily sensations	45.6 (10.0)	37.6 (11.3)	47.8 (9.9)	37.6 (11.2)	38.0 (10.8)*
VMIQ-K	47.8 (7.8)	41.4 (12.5)*	51.1 (14.3)	41.3 (11.7)*	37.8 (13.1)*
	Olfactory modality				
	CON = MODALITY (N = 7)	CON ≠ MODALITY (N = 96)	IND = MODALITY (N = 10)	IND ≠ MODALITY (N = 93)	NONSYN (N = 102)
VOIQ	70.1 (10.4)	51.0 (15.2)	63.3 (14.7)	51.3 (15.4)	48.3 (15.6)
	Taste modality				
	CON = MODALITY (N = 18)	CON ≠ MODALITY (N = 85)	IND = MODALITY (N = 5)	IND ≠ MODALITY (N = 98)	NONSYN (N = 102)
Taste imagery	48.9 (9.8)	39.3 (12.4)	52.6 (8.9)	40.4 (12.4)	35.3 (13.2)

than controls ($p = .043$).[2] Repeating with the VVIQ, we found a significant effect of group ($F(2,202) = 7.06$, $p = .001$, partial $\eta^2 = 0.07$). Again, synesthetes with visual concurrents reported more vivid imagery than controls ($p = .001$), but there were no other significant group differences (controls compared to synesthetes without visual concurrents $p = .502$, synesthetes with visual concurrents compared to those without, $p = .605$). Repeating with the VMIQ scores, we found the suggestion of a group effect for internal movement but this missed significance so was not explored further (VMIQ-I; $F(2,201) = 2.73$, $p = .068$, partial $\eta^2 = 0.03$), and no effect for external movement (VMIQ-E; $F(2,202) = 0.03$, $p = .968$, partial $\eta^2 < 0.001$).

In our assessment of auditory imagery, CAIS, we found a significant group effect ($F(2,202) = 8.50$, $p < .001$, partial $\eta^2 = 0.08$). Follow-up tests showed that synesthetes without auditory concurrents reported significantly higher scores on the CAIS than the non-synesthetes ($p = .001$) as did those with auditory concurrents ($p = .053$). There was no significant difference between the two synesthete groups ($p = .505$).[3]

In our assessment of tactile imagery, we found a significant effect of group ($F(2,202) = 9.31$, $p < .001$, partial $\eta^2 = 0.08$), with follow-up tests showing significantly higher imagery ratings for synesthetes with tactile concurrents versus synesthetes without ($p = .041$), and versus controls ($p = .001$). Synesthetes without tactile concurrents also had significantly higher imagery than controls ($p = .015$).[4] In our assessment of kinesthetic movement (VMIQ-K), we again found a significant group effect ($F(2,200) = 4.23$, $p = .016$, partial $\eta^2 = 0.04$).[5] The synesthetes with tactile concurrents rated their movement imagery as significantly more vivid than the remaining synesthetes ($p = .039$), with no significant difference between any of the other comparisons (comparing synesthetes with tactile concurrents to those without, $p = .342$, comparing those without tactile concurrents to controls, $p = .144$). In our assessment of bodily sensations vividness, the effect of group just missed significance and so was not explored further ($F(2,201) = 2.67$, $p = .07$, partial $\eta^2 = 0.03$).

In our assessment of olfactory imagery (VOIQ), we again found a significant group effect ($F(2,202) = 7.27$, $p = .001$, partial $\eta^2 = 0.07$).[6] The synesthetes with olfactory-based concurrents reported significantly more vivid olfactory imagery than the remaining synesthetes ($p = .003$) and controls ($p = .001$), with no significant difference between these latter ($p = .685$).

[2] When only including synesthetes who had passed the consistency test the only significant follow-up test was between the synesthetes with visual concurrents and the controls, ($p < .001$).

[3] When only including synesthetes who had passed the consistency test, the follow-up tests only showed a significant difference between those without auditory concurrents and controls ($p = .001$), likely due to the small sample size of those with auditory concurrents.

[4] When only including synesthetes who had passed the consistency test, the only significant difference was between those without tactile concurrents and controls ($p = .007$), likely because of the small number of synesthetes (3) with tactile concurrents.

[5] When only including synesthetes who had passed the consistency test, this was no longer significant, again likely due to the small number of synesthetes with tactile concurrents.

[6] This was a near-significant trend ($p = .07$) when only including synesthetes who had passed the consistency test, most likely due to the small number of synesthetes (4) with olfactory concurrents.

Finally, in our assessment of taste imagery, we again found a significant group effect ($F(2,202) = 9.52$, $p < .001$, partial $\eta^2 = 0.09$). The synesthetes with taste concurrents reported significantly more vivid taste imagery than the remaining synesthetes ($p = .011$) and controls ($p < .001$), with no significant difference between these latter ($p = .093$).[7]

3.1.2. Do inducers influence imagery?

In this section we ask whether imagery is influenced by the type of inducer (e.g., is visual imagery enhanced by having visual inducers?). We therefore compare imagery across three groups: 'IND = MODALITY' versus 'IND ≠ MODALITY' and 'NONSYN'. Our results are again presented separately for each imagery scale.

In our assessment of visual imagery, for the SUIS, a one-way ANOVA found a significant effect of participant group ($F(2,201) = 27.00$, $p < .001$, partial $\eta^2 = 0.21$). Follow-up tests showed that synesthetes with visual inducers reported significantly more use of visual imagery compared to synesthetes without visual inducers ($p = .012$), and compared to controls ($p < .001$). Furthermore, synesthetes without visual inducers reported significantly more use of visual imagery than controls ($p = .011$).[8] Repeating with the VVIQ, we found a significant effect of group ($F(2,202) = 8.98$, $p < .001$, partial $\eta^2 = 0.08$). Again, this was driven by the synesthetes with visual inducers reporting more vivid imagery than controls ($p < .001$), but with no other significant group differences (comparing synesthetes with visual inducers to those without, $p = .068$, comparing synesthetes without visual inducers to controls, $p = .928$). Repeating with the VMIQ scores, the group effect for internal movement just missed significance so was not explored further (VMIQ-I; $F(2,201) = 2.72$, $p = .068$, partial $\eta^2 = 0.03$). We also found no group effect for external movement (VMIQ-E; $F(2,202) = 0.89$, $p = .414$, partial $\eta^2 = 0.01$).

In our assessment of auditory imagery, CAIS, we found a significant group effect ($F(2,202) = 9.60$, $p < .001$, partial $\eta^2 = 0.09$). Follow-up tests showed that synesthetes both with and without auditory inducers reported significantly higher scores on the CAIS than the non-synesthetes ($p < .001$ and $p = .020$ respectively), while the difference between the two synesthete groups was not significant ($p = .143$).

In our assessment of tactile imagery, we found a significant effect of group ($F(2,202) = 9.01$, $p < .001$, partial $\eta^2 = 0.08$), with follow-up tests showing that synesthetes with tactile inducers had significantly higher ratings than controls ($p = .001$), as did synesthetes without tactile inducers ($p = .011$). The difference between synesthetes with and without tactile inducers was also significant ($p = .052$).[9] In our assessment of bodily sensation vividness, we found a significant effect of group ($F(2,201) = 3.61$, $p = .029$, partial $\eta^2 = 0.04$),[10] with the synesthetes with tactile inducers reporting significantly more vivid imagery than both controls ($p = .032$) and those synesthetes without tactile inducers ($p = .025$). The difference between synesthetes without tactile inducers and controls was not significant ($p = 1.00$). In our assessment of kinesthetic movement (VMIQ-K), we again found a significant group effect ($F(2,200) = 5.55$, $p = .004$, partial $\eta^2 = 0.05$).[11] The synesthetes with tactile inducers rated their movement imagery as significantly more vivid than the controls ($p = .008$), with no significant difference between those with and without tactile inducers ($p = .076$) and synesthetes without tactile inducers and controls ($p = .171$).

In our assessment of olfactory imagery (VOIQ), we again found a significant group effect ($F(2,202) = 4.48$, $p = .012$, partial $\eta^2 = 0.04$).[12] Synesthetes with olfactory-based inducers reported significantly more vivid olfactory imagery than controls ($p = .012$), with a close to significant difference between with those with and without olfactory inducers ($p = .057$), and no significant difference between those without olfactory-based inducers and controls ($p = .628$).

Finally, in our assessment of taste imagery, we again found a significant group effect ($F(2,202) = 7.31$, $p = .001$, partial $\eta^2 = 0.07$). Synesthetes both with and without taste inducers reported significantly more vivid taste imagery than the controls ($p = .010$ and $.015$ respectively)[13] while the difference between the two synesthete groups was not significant ($p = .114$). The findings from our analyses thus far are summarized in Table 4.

3.1.3. Is imagery stronger when inducer and concurrent are in the same modality?

For the third stage we wanted to explore the possible impact of having both an inducer and concurrent within the same modality, compared to having just an inducer or just a concurrent. In this stage we present the results for visual imagery only, due to the limited group sizes for the other modalities (see Participants section). We created 5 groups; group 1 ('BOTH = MODALITY') were synesthetes with both an inducer and concurrent in the modality of the scale (here, visual), group 2 ('CON ONLY = MODALITY') were synesthetes with only a concurrent in that modality, group 3 ('IND ONLY = MODALITY') were synesthetes with only an inducer in that modality, group 4 ('NEITHER = MODALITY') were synesthetes with neither an inducer

[7] When only including synesthetes who had passed the consistency test, only the difference between the synaesthetes with taste concurrents and the controls was significant ($p = .021$).

[8] When only including synesthetes who had passed the consistency test, the only significant difference was between the synesthetes with visual inducers and controls ($p < .001$).

[9] When only including synesthetes who had passed the consistency test, the difference between the two synaesthete groups was no longer significant, probably due to the small number (7) of synesthetes with tactile inducers.

[10] This was not significant when only including synesthetes who had passed the consistency test.

[11] This group effect was near-significant ($p = .064$) when including only synesthetes who had passed the consistency test.

[12] This was not significant when including only synesthetes who had passed the consistency test, likely because of the small number of synaesthetes (6) with olfactory inducers.

[13] When only using synesthetes who had passed the consistency test the group effect was significant ($p = .032$), but none of the follow-up tests was significant.

Table 4
Summary of results, examining group differences in the whole sample across concurrents and inducers, where 'yes' indicates a significant difference ($p < .05$), and 'trend' indicates close to significant difference ($p < .06$).

	CONCURRENT			INDUCER		
	CON = MODALITY > CON ≠ MODALITY	CON = MODALITY > NONSYN	CON ≠ MODALITY > NONSYN	IND = MODALITY > IND ≠ MODALITY	IND = MODALITY > NONSYN	IND ≠ MODALITY > NONSYN
Visual modality						
SUIS	Yes	Yes	Yes	Yes	Yes	Yes
VVIQ		Yes			Yes	
VMIQ-I						
VMIQ-E						
Auditory modality						
CAIS		Yes	Yes		Yes	Yes
Tactile modality						
Touch imagery	Yes	Yes	Yes	Yes	Yes	Yes
Bodily sensations				Yes	Yes	
VMIQ-K	Yes				Yes	
Olfactory modality						
VOIQ	Yes	Yes		Trend	Yes	
Taste modality						
Taste imagery	Yes	Yes			Yes	Yes

or concurrent in that modality, and group 5 ('NONSYN') were the non-synesthete controls. Once participants were divided into these five groups, we looked at their scores on each of our visual imagery scales in turn.

For the SUIS, a one-way ANOVA found a significant effect of participant group ($F(4,204) = 14.94$, $p < .001$, partial $\eta^2 = 0.23$). Follow-up tests showed that the synesthetes with both visual concurrents and inducers reported significantly more use of visual imagery compared to synesthetes neither visual concurrents or inducers ($p = .007$), and compared to controls ($p < .001$). Furthermore, synesthetes with visual concurrents only and synesthetes with visual inducers only reported significantly more use of visual imagery than controls ($p = .006$ and $p = .005$ respectively). Repeating with the VVIQ, we again found a significant effect of group ($F(4,204) = 5.00$, $p = .001$, partial $\eta^2 = 0.09$). This was driven by the synesthetes with both visual inducers and concurrents reporting more vivid imagery than controls ($p = .002$), whilst none of the other comparisons reached significance. With the VMIQ scores, neither the group effect for internal movement (VMIQ-I; $F(4,203) = 2.07$, $p = .086$, partial $\eta^2 = 0.04$), nor external movement (VMIQ-E; (VMIQ-I; $F(4,203) = 0.74$, $p = .567$, partial $\eta^2 = 0.02$) reached significance. Interestingly, synesthetes with visual inducers only had a higher group mean score than the other four groups for all 4 measures, although these differences did not reach significance (see Table 5).

3.2. What is the relationship between strength of imagery vividness and total number of modalities involved in synesthesia?

We found a significant positive correlation between the total number of concurrent modalities involved in an individual's synesthesia and their scores on the SUIS ($r = .257$, $p = .009$), VVIQ ($r = .320$, $p = .001$), VOIQ ($r = .258$, $p = .009$), tactile imagery scale ($r = .344$, $p < .001$), and sensation imagery scale ($r = .234$, $p = .018$). No other imagery scale scores correlated with number of concurrent modalities (all $ps > .10$) For the total number of inducer modalities involved in an individuals' synesthesia, we found a significant positive correlation with the SUIS ($r = .261$, $p = .008$), VVIQ ($r = .320$, $p = .001$), CAIS ($r = .248$, $p = .011$), VOIQ ($r = .240$, $p = .015$), tactile imagery scale ($r = .351$, $p < .001$), sensation imagery scale ($r = .231$, $p = .019$) and VMIQ-I ($r = .232$, $p = .018$). No other imagery scale scores correlated with number of inducer modalities (all $ps > .06$).

4. Discussion

Our study aimed to compare synesthetes' self-reports of imagery to those of non-synesthetes', across a wide range of imagery modalities and using a variety of synesthesia sub-types. We wanted to test whether reports of enhanced imagery

Table 5
Means (and standard deviations in parentheses) for the everyday use of imagery (SUIS), Vividness of Visual Imagery (VVIQ), the vividness of internal movement imagery (VMIQ-I), and external movement imagery (VMIQ-E) as a function of group used in analysis.

	BOTH = MODALITY ($N = 59$)	CON ONLY = MODALITY ($N = 15$)	IND ONLY = MODALITY ($N = 7$)	NEITHER = MODALITY ($N = 22$)	NONSYN ($N = 102$)
SUIS	47.4 (6.8)	46.2 (5.3)	49.7 (5.0)	41.1 (8.7)	39.0 (7.6)
VVIQ	62.1 (10.1)	59.7 (10.0)	66.3 (7.5)	56.2 (10.8)	55.6 (10.7)
VMIQ-I	43.2 (11.4)	45.3 (11.0)	50.4 (6.8)	42.2 (10.2)	39.9 (13.1)
VMIQ-E	36.7 (13.1)	34.5 (9.6)	42.0 (10.7)	33.6 (10.1)	36.0 (12.8)

were restricted to the modalities in which synesthesia is experienced as either an inducer or concurrent. We also tested whether self-rated imagery abilities were related to the number of modalities in which an individual experiences synesthesia. We will discuss our findings in relation to each of these three questions, and then explore the overall pattern of results for both the inducer and concurrent.

First, in general, synesthetes with a concurrent or inducer in a particular modality tend to report more vivid imagery within that particular modality than non-synesthetes. For example, synesthetes with a olfactory concurrent or inducer report higher olfactory imagery than controls. This was found in the visual modality (SUIS and VVIQ), auditory modality, tactile modality (tactile imagery for all tactile synesthetes, while imagery of bodily sensations and kinesthetic movement imagery was elevated for those with tactile inducers but not concurrents), olfactory modality, and taste modality. In addition, for the visual (SUIS only), auditory and tactile modalities, synesthetes *without* an inducer/concurrent in that particular modality also reported more vivid imagery than the non-synesthete controls. Overall, this pattern of results is suggestive of synesthetes, as a group, having enhanced imagery ability when compared to non-synesthetes. Previous studies have found that visual synesthetes have higher self-reported visual imagery than non-synesthete controls with the VVIQ (Barnett & Newell, 2008), and that they report a greater everyday use of visual imagery with the SUIS (following Price, 2009). This study therefore provides a useful contribution to our understanding of synesthetes' and non-synesthetes' reports of image vividness or clarity to a wide range of modalities beyond visual imagery.

Our self-reported imagery data also mirrors behavioral evidence found in other studies on synesthetes. One study (Spiller & Jansari, 2008) found that grapheme-color synesthetes were significantly faster at performing a grapheme-based visual imagery task compared with non-synesthetes. Another study (Simner, Mayo, & Spiller, 2009) found that sequence-space synesthetes showed enhanced performance on tests that make use of visuo-spatial imagery (e.g. the Visual Patterns Test, and mental rotation; see also Brang, Miller, McQuire, Ramachandran, & Coulson, 2013; Havlik & Simner, submitted for publication; but Rizza & Price, 2012). Our self-reported imagery data might also find parallels in recent studies exploring brain activity in mental imagery tasks across different sensory modalities. Olivetti Belardinelli et al. (2009) found the level of activity of sensory areas during a mental imagery task (i.e., activity resembling that associated with actual perception) was related to participants' self-reports of image vividness across many modalities. This therefore suggests that self-reports of image vividness may have some relationship with associated brain activity (see also Cui, Jeter, Yang, Montague, & Eagleman, 2007; Amedi, Malach, & Pascual-Leone, 2005) and are therefore likely to be reliable indicators of behavioral effects. Of course future studies need to compare synesthetes' performance on behavioral measures of imagery across these modalities, particularly for modalities other than visual imagery. This is especially important since one recent study, with non-synesthetes, has found a relationship between responses on imagery questionnaires such as the VVIQ, and measures of socially desirability (Allbutt, Ling, Rowley, & Shafiullah, 2011).

Further support for the idea that synesthetes might have enhanced imagery can be found from studies exploring typical synesthetic traits or personalities; these show that synesthetes have characteristics which are typically associated with enhanced imagery ability. For example, in the general population, positive schizotypy and schizophrenia have been linked to mental imagery vividness (Oertel et al., 2009; Sack, van de Ven, Etschenberg, Schatz, & Linden, 2005), and recently grapheme-color and tone-color synesthetes have been shown to have increased positive and disorganized schizotypy compared to the general population (Banissy et al., 2011). Furthermore, in the general population a relationship has been found between self-reports of image vividness and levels of fantasizing (e.g. Aleman & de Haan, 2004; van de Ven & Merckelbach, 2003; Vannucci & Mazzoni, 2009), and synesthetes have been found to report higher levels of fantasy proneness (Banissy et al., 2013).

With the current study, we were also able to explore the relationship between the modality of mental imagery and the modality in which synesthesia is experienced (as either an inducer or concurrent). Our data show that synesthetes with inducers or concurrents in certain particular modalities (e.g., taste) scored significantly higher on that imagery scale not only compared to non-synesthetes, but also compared to the remaining synesthetes. For example, synesthetes with taste as an inducer or concurrent reported more vivid taste imagery than both non-synesthetes *and* the synesthetes without taste concurrents or inducers. This pattern was found for visual synesthetes (with the SUIS), tactile synesthetes (with the touch imagery scale for all tactile synesthetes, the imagery of bodily sensations scale for those with tactile inducers but not tactile concurrents, and the imagery of kinesthetic movement imagery scale for those with tactile concurrents but not tactile inducers), olfactory synesthetes (with the VOIQ), and taste synesthetes (with the taste imagery scale).

In summary then, we found a pattern in which synesthetes report more vivid imagery according to their particular form of synesthesia, not only compared to controls but also compared to other synesthetes, and this is suggestive of a potential modality specific imagery advantage which is both general to synesthetes, and particularly enhanced for the synesthesia-related modalities. The proposal that the particular sensory modalities involved in an individual's synesthesia could have an impact on their cognitive profile has also been found with other synesthesia studies. For example, Banissy et al. (2009) found that synesthetes with color as a concurrent have enhanced color sensitivity, and synesthetes with tactile experiences as a concurrent have enhanced tactile sensitivity. Synesthetes also do better than non-synesthetes in memory recall related to their synesthesia (e.g., better recall of color information for color-experiencing synesthetes; Rothen & Meier, 2010; Yaro & Ward, 2007).

With regards to the *number* of modalities involved in an individual's synesthesia, our results suggest a weak to moderate relationship between the number of modalities and the strength of image vividness for imagery in most modalities. The total number of modalities involved as concurrents was found to be related to a synesthete's self-report of visual imagery (VVIQ and SUIS), tactile imagery, imagery of bodily sensations, and olfactory imagery. The total number of modalities involved as inducers was related to all of these in addition to clarity of auditory imagery, and vividness of movement imagery (VMIQ-I). As so little is known about the impact of having multiple forms of synesthesia, we refrain from making strong claims about the implications of such a relationship. However, it does suggest a potential avenue for future research to explore. For example, it could be that synesthetes with multiple forms of synesthesia across many sensory modalities have even greater structural neural connectivity than synesthetes with just one form. To date, studies examining the neural basis of synesthesia have mainly focused on letter- or word-color synesthesia, without reporting how many *other* forms of synesthesia these individuals may have (although see Zamm et al., 2013 for a study exploring structural connectivity with music-color synesthesia). It would therefore be useful for future studies to compare individuals with few versus many variants, in order to assess not only modality specific differences (e.g., in visual or auditory cortex for visual/auditory synesthetes) but also whether there are differences in other regions not directly implicated by the synesthetic report.

Finally, an important area the current study can comment on is the role of the modality of the inducer and the modality of the concurrent. We had predicted that synesthetes may report enhanced imagery in the modality of the concurrent, as both mental imagery and synesthetic concurrents share the experiential qualities of perceiving something without the usual external stimuli – for example, creating a visual mental image of a color might be similar in quality to experiencing a synesthetic color. Interestingly, we actually found that synesthetes, as a group, tend to report more vivid imagery than non-synesthetes, for modalities involved in *both* concurrents and inducers. Across most of the modalities we studied, we found enhanced imagery in the domain of both the inducer and the concurrent. Furthermore, when we looked at those who had both a visual inducer and a visual concurrent, we found a very similar pattern of results as when we looked at those with just a visual inducer or visual concurrent. This suggests that the modalities involved in synesthesia, as *either inducer or concurrent*, play an important role in the associated imagery abilities.

Much of the research comparing synesthetes to non-synesthetes to date has focused on advantages in processing the concurrent alone, and very little has explored whether synesthetes might have cognitive or perceptual advantages with inducer-related stimuli (although see Gebuis, Nijboer, & van der Smagt, 2009a, 2009b, who found a bi-directional priming effect between inducer and concurrent). Consequently, our results suggest that both the inducer and concurrent modality need to be considered when exploring possible differences between the perceptual and cognitive processing of synesthetes and non-synesthetes.

The spread of scores on our scales (see scatterplots in our supplementary methods) indicates that there are very few, if any, synesthetes reporting imagery that is not vivid (see also Price, 2009). If enhanced imagery is linked to the modality of the synesthesia, one possible conclusion is that enhanced imagery in synesthesia may be linked to a type of 'practice effect' in which repeated experience of synesthesia may enhance imagery abilities in the related domains. The majority of the current literature does not allow us to conclude whether improvement comes from practice, or instead, whether some a priori advantage in imagery independently leads to (or co-occurs with) synesthesia (see Price, 2013; Simner et al., 2009). However, our own results support the idea that synesthesia may be associated with an a priori imagery advantage. First we have found that enhanced visual imagery, for example, comes not just from repeated experience of visual concurrents, but also in those synaesthetes merely triggered by visual stimuli in the outside world (who presumably encounter such visual stimuli no more than the average person). Second, our novel finding of a correlation between the number of modalities involved in an individual's synesthesia and the vividness of imagery reported could be used to add weight to this argument. In other words, simply having a great deal of synaesthesia appears to enhance imagery across multiple domains. Needless to say, our suggestions here are somewhat speculative at this stage and future investigation will improve our understanding in this matter.

In summary, the current study is an important extension of previous research which suggested that synesthetes may have enhanced mental imagery. We have shown that these self-reports of vivid imagery are not restricted to visual-spatial imagery, and that they are linked to the modality of the synesthesia. The experiences of the large sample of synesthetes used in this study highlight the fact that many people experience more than one form of synesthesia, often across multiple sensory modalities. Future studies should explore the impact of these multiple forms, since research to date has often been constrained to single forms. We have started to explore the impact of modalities involved in synesthesia and conclude that the daily experience of synesthesia may heighten imagery abilities, or indeed, that the very cause of synesthesia could have widespread influences on brain development or functioning, with one possible outcome being enhanced imagery ability. Of course our study has relied on self-reports, and while there is some evidence to support the use of such measures, it is imperative that we explore synesthetes' mental imagery with behavioral measures before any strong conclusions are drawn.

Acknowledgments

We would like to thank Marc Bloomfield and Zeeshan Syed for their help with data collection. This work has been supported by a Promising Researcher Award given to MJ Spiller by the University of East London.

Appendix A

Items included in the tactile imagery scale:

1	Sand
2	Linen
3	Fur
4	The prick of a pin
5	The warmth of a tepid bath
6	Glass
7	The pages of a book or magazine
8	Clingfilm (plastic wrap, Saran wrap)
9	Silk
10	Leather
11	Sticky tape
12	Concrete

Items included in the taste imagery scale:

1	Salt
2	Granulated (white) sugar
3	Oranges
4	Strawberry jelly
5	Tomato soup
6	Coffee
7	Milk chocolate
8	Carrots
9	Apple juice
10	Honey
11	Vinegar
12	Peanut butter

Items included in the imagery of bodily sensations scale:

1	Fatigue
2	Hunger
3	A sore throat
4	Drowsiness
5	Repletion, as from a very full meal
6	A fast heartbeat, as from exercising
7	Nervousness
8	Disgust
9	Surprise
10	Muscle cramp
11	A headache
12	Fear

Appendix B. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.concog.2014.10.010.

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