FACE PROCESSSING IN ADULTS WITH SYNAESTHESIA

THE EFFECT OF SPATIAL FREQUENCY AND ORIENTATION ON CONFIGURAL FACE DISCRIMINATIONS IN ADULTS WITH SYNAESTHESIA

BY

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Abstract

The structural and functional differences observed in the brains of adults with synaesthesia is thought to arise, at least in part, from less-than-normal neural pruning of the exuberant connections present within and among sensory cortical areas in infancy (reviewed in Maurer, Gibson, & Spector, 2013). This hypothesis is supported by previous work that has demonstrated that synaesthetes are superior at processing foreign speech sounds and inverted faces (Maurer et al., in prep). The present study investigated a link between spatial frequency and face processing in adults with synaesthesia by testing synaesthetes and non-synaesthetes on their ability to discriminate upright and inverted faces filtered at high and low spatial frequencies. As predicted, synaesthetes (n=20) were significantly more accurate than non-synaesthetes (n=20) at discriminating among inverted full spectrum faces (p=0.0235), with no differences in upright faces, replicating previous findings that support the hypothesis that synaesthetes undergo less perceptual attunement (Ghloum et al., 2013). Unexpectedly, synaesthetes were faster at responding across all face conditions. Faster reaction times with no sacrifice to accuracy suggest that synaesthetes may be processing faces more efficiently. In addition, no significant differences in accuracy were observed for high and low filtered faces at any orientation between synaesthetes and non-synaesthetes. Future studies could further explore the basis of synaesthete's face processing advantages by using eye movements and a narrow-band noise-masking paradigm.

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Introduction

Synaesthesia is a neurological condition where a stimulus in one modality elicits an atypical perception in either the same or different modality. In sound-colour synaesthesia, a specific sound such as C-sharp is perceived with a specific color such as a pearly blue. Another example is grapheme-colour synaesthesia, where letters or numbers printed in black ink are experienced as coloured (e.g., A is red, B is blue). Colour is not always implicated in synaesthesia, as individuals with spatial sequence synaesthesia can perceive a sequence (e.g., days of the week, months of the year) in a three-dimensional mental map (Simner, 2011). Furthermore, there are two types of synaesthetes: projectors and associators (Dixon, Smilek, & Merikle, 2004). Synaesthetic precepts in projectors are experienced as if projected onto the environment whereas associators are commonly described as experiencing their precepts within the mind's eye.

There are over 80 different types of synaesthesia identified to date (Day, 2016). The two most common types are grapheme-colour synaesthesia and spatial sequence synaesthesia (Cytowic & Eagleman, 2009). Estimates on the prevalence of synaesthesia are difficult to obtain, as many synaesthetes are either unaware of their condition or keep their condition secret for fear of being scrutinized (Rich, Bradshaw, & Mattingley, 2005). However, through methods of random sampling, the prevalence for all kinds of synaesthesia in the general population is estimated to be between 5-10% (Simner, Mulvenna, & Sagiv, 2006).

For the majority of the 20th century, synaesthesia was regarded more as an over-learned memory association than a perceptually authentic condition (Howells, 1944). However, in recent years behavioural and neuroimaging evidence gives strong support for the perceptual authenticity of synaesthesia, providing hallmarks for identifying the condition.

One of the hallmarks of synaesthesia is that synaesthetic percepts are consistent over time. For example, when examining reported coloured associations of words, letters, or phrases, 92.3% of answers on retest from coloured-hearing synaesthetes were identical to the original test taken a year earlier. In comparison, non-synaesthetes tested a week after from the original test only had 37.6% of answers identical to the first test (Baron-Cohen, Harrison, Goldstein, & Wyke, 1993). Even when non-synaesthetes were told to remember their choices, synaesthetes out-performed controls in matching sounds to the perceived colour when re-tested one-month later (Asher, Aitken, Farooqi, Kurmani, & Baron-Cohen, 2005). Although these studies support the perceptual authenticity of synaesthesia, methods used to measure consistency vary across experiments. Thus, a large-scale standardized method to assess consistency in synaesthesia is needed.

In order to assess consistency on a larger scale, an online battery was developed by Dr. David Eagleman at the Massachusetts Institute of Technology in Cambridge, Massachusetts (Eagleman, Kagan, Nelson, Sagaram, & Sarma, 2007). To date, 19,133 participants have been tested, 12, 127 of whom are reported to have some form of synaesthesia (Novich, Cheng, & Eagleman, 2011). In this test, available free online (http://www.synesthete.org), participants are able to select, from a list of all synaesthesia types (over 80 types), which types they think they have. Based on their selection, a consistency test appropriate for that type of synaesthesia is administered. In one test, grapheme-colour synaesthetes are asked to specify their colour association for each grapheme. The letters (A-Z) and the numbers (0-9) are presented randomly three times. For each grapheme, participants select a colour using the RGB scale. A Consistency score from the online synaesthesia battery is then calculated using the geometric distance between the RGB values of the chosen graphemes. A score less than 1 indicates the consistency expected from synaesthetes. However, an alternative and preferred method considered to be more specific and sensitive, converts the RGB values in CIELUV coordinates (Rothen, Seth, Witzel, & Ward, 2013). Euclidean distances using CIELUV colour space is thought to provide a more accurate estimation of colour perception than the city block distances used in RGB colour space (Rothen et al., 2013). Thus, using the information obtained from the online battery, consistency is then analyzed based on the new criteria set by Rothen and colleagues.

Synaesthetic percepts are also susceptible to stroop-like interference, providing further behavioural evidence for the perceptual authenticity of synaesthesia. In the classic stroop task, coloured words (such as red) are printed in a colour consistent (red ink) or inconsistent (blue ink) with the meaning of the word itself (Stroop, 1935). Participants are instructed to ignore the word and name the coloured ink. Considering that reading is a more automatic process than naming colours, it is difficult to ignore reading a coloured word when trying to identify the colour of the word. Thus, the consequences of stroop interference are seen as decreases in accuracy and increases in reaction times for correctly naming the colour of the word instead of the word itself. Similar stroop effects have been observed in synaesthetes when the colour of the presented stimulus is incongruent with their synaesthetic percepts compared to when the coloured stimulus is congruent (Mattingley, Rich, Yelland, & Bradshaw, 2001; Dixon, Smilek, Cudahy, & Merikle, 2000; Ward, Huckstep, & Tsakanikos, 2006).

In addition to behavioural evidence, neuroimaging has provided support for the perceptual authenticity of synaesthesia. Using fMRI, the activation of the grapheme area in grapheme-colour synaesthetes was no different than the activation in non-synaesthetes when shown achromatic digits. However, synaesthetes showed increased activation of colour areas V4/V8 compared to non-synaesthetes (Hubbard & Ramachandran, 2005). Similar findings have been demonstrated in coloured-hearing synaesthetes showing increased activation in colour areas V4/V8 to spoken words (Nunn, Gregory, & Brammer, 2002). The observable differences in activation provide clear evidence for the perceptual reality of synaesthesia.

There are two main theories on the development of synaesthesia: the disinhibited feedback model and the cross-activation model. The disinhibited feedback model postulates that there is less-than-normal development of inhibition from higher cortical areas to lower cortical areas (Grossenbacher & Lovelace, 2001). This may lead to extra firing between two normally inhibited areas of the brain. The cross-activation model postulates that during development, there is less-than-normal pruning of excess connections (Ramachandran and Hubbard, 2001). Infants are born with an abundance of connections that are pruned in an experience-dependent fashion. When this pruning is less than normal, it may lead to the excess connections observed in the brains of adults with synaesthesia, forming connections between two normally segregated areas (Hubbard, Brang, & Ramachandran, 2011)

Neuroimaging has demonstrated neuroanatomical differences in the brains of synaesthetes compared to non-synaesthetes, which support both the cross-activation model and the disinhibited feedback model. For example, when looking at grey matter differences in the temporo-occipital lobe and parietal cortex, there was an overall increase in cortical thickness and volume in the fusiform and intraparietal cortices compared to non-synaesthetes (Weiss & Fink, 2009). Specifically, there was increased density of grey matter in the right fusiform gyrus (colour and visual word area) and the intraparietal sulcus (multisensory binding of colour and shape). In addition, grapheme-colour synaesthetes were found to have bilateral increases in cortical thickness, surface area and volume in the fusiform gyrus (Jäncke, Beeli, Eulig, & Hänggi, 2009).

Differences in white matter volume and integrity are also observed in synaesthetes. Diffuse Tensor Imaging (DTI) in grapheme-colour synaesthetes has shown evidence of increased volume of white matter tracts in the right fusiform gyrus (colour and visual word area), in the left parietal cortex (multisensory binding of colour and shape) and the superior frontal lobe (Rouw and Scholte 2007). The left intraparietal cortex (IPC) has been hypothesized to induce synaesthesia through disinhibited feedback, which serves to couple areas involved in synaesthetic perception (Weiss, Zilles, & Fink, 2005). DTI has also demonstrated increased white matter integrity in the inferior fronto-occipital fasciculus (IFOF), which connects to the frontal lobe via the temporal and occipital lobes, in synaesthetes compared to non-synaesthetes (Zamm, Schlaug, Eagleman, & Loui, 2013).

Furthermore, a structural connectivity analysis has demonstrated increased structural connectivity in the brains of grapheme-colour synaesthetes compared to non-synaesthetes (Rouw & Scholte, 2007). Specifically, increased connectivity was observed between the parietal cortex and colour area V4. Similar connections from the parietal cortex also exist in the brains of synaesthetes with auditory-color synaesthesia (Neufeld et al., 2012a). In addition, a functional connectivity analysis in the same group of auditory-colour synaesthetes revealed significantly more functional connectivity between the IPC, and the primary auditory and visual cortices (Neufeld et al., 2012b). In combination with the activation in colour area V4/V8 in grapheme-colour synaesthetes when looking at a grapheme (Hubbard & Ramachandran, 2005), and sound-colour synaesthetes in response to a spoken word (Nunn et al., 2002), neuroanatomical differences in cortical thickness, surface area and volume, white matter density and integrity, as well as structural and functional connectivity in the brains of synaesthetes compared to non-synaesthetes support both the disinhibited model and the cross activation model of synaesthesia.

A possible cause for the neuroanatomical differences in the brains of synaesthetes compared to non-synaesthetes may be related to excess connections available during infancy. Infants are born with an abundance of connections, as neurons, dendrites and synapses are overproduced prenatally and early during infancy. As the infant develops, these excess connections undergo synaptic pruning in an experience-dependent manner. The most rapid pruning of synapses occurs in preschool children and continues as the child develops into an adult (reviewed in Maurer, Gibson & Spector, 2012).

A consequence of the abundance of connections during early infancy could be related to the lack of sensory specialization. For example, within the first three years, event-related potentials can be recorded in the visual cortex in response to heard speech (Neville, 1995). In addition, evoked responses recorded in the somatosensory cortex are larger when tactile stimulation of the wrist is concurrently presented with white noise compared to when it is present alone. Crucially, this increased response is absent in adults (Wolff, Matsumiya, Abroms, Velzer, & Lombroso, 1997). Further evidence comes from 2-month-old infants and adults looking at faces compared to a Christmas tree. Two-month-old infants show increased activity in the right inferior gyrus and the left auditory cortex in response to faces compared to a Christmas tree. However, adults who looked at the same stimuli did not show a response in the left auditory cortex (Tzourio-Mazoyer,et al., 2002).

The pruning of abundant connections during early infancy is experience-dependent, as sensory areas of adults who lack normal visual or auditory inputs remain unspecialized. For example, adults blind from an early age show activation of the visual cortex during Braille readings and during discriminations of vibro-tactile gratings. Unsurprisingly, Transcranial Magnetic Stimulation (TMS) applied to visual cortex disrupts the ability to read Braille in blind adults. Furthermore, the visual cortex in adults born congenitally blind responds to auditory stimuli, whereas the auditory cortex in congenitally deaf adults responds to visual and tactile stimuli (reviewed in Spector & Maurer, 2009).

Infants are born with an abundance of connections within and between sensory areas. These excess connections are pruned in an experience-dependent manner leading to the specialization of sensory areas. However, the sensory cortices in blind and deaf adults who lack typical experience remain multisensory. Since synaesthesia is not a visual deficit (Cytowic, 2002), less-than-normal pruning during development may lead to the excess connections observed in the brains of synaesthetes.

Additional evidence suggesting that infants' perceptual systems become specialized as they age comes from a phenomenon known as perceptual attunement. Perceptual attunement is an experience-dependent process that describes infants' increasing skill at differentiating stimuli in native categories and the simultaneous decline of a more general ability to discriminate stimuli from non-native categories. Perceptual attunement is believed to result from synaptic pruning that begins during the first year after birth.

The development of face perception during infancy is an example of how experience with faces early in life influences the development of the own-race and own-species bias. In a visual-preference task, Caucasian newborn and 3-month-old infants were exposed to pairs of faces that were either identical in race or different in race. The overall mean percentage of looking time for own-race faces was compared to other-race faces. Caucasian newborn infants looked equally long at both faces regardless of race. However, 3-month-old Caucasian infants looked significantly longer at own-race faces compared other-race faces (Kelly et al., 2005). The lack of preference for own-race vs. other-race faces in newborn infants and the preference for own-race faces in 3-month-old infants suggests that the infants' perceptual system for faces starts to become tuned to their environment by three months of age.

Additional evidence is also observed in the own-species bias. For example, 6- and 9-month-old infants were tested on their ability to discriminate monkey faces. Each infant was first familiarized with a monkey face for 20 seconds, and then presented with 5-second test trials. Each test trial contained a familiar face and a novel face (Pascalis, de Haan, & Nelson, 2002). An increase in looking time towards the novel face indicates the ability to discriminate the monkey faces. Six-month-old infants looked longer at the novel face, in contrast to 9-month-old infants, who showed no differences in looking time between the familiar and the novel face. Adults tested under similar experimental conditions showed no evidence of being able to discriminate monkey faces. Combined with 3-month-old infants' preference for own-race faces, the difficulty of 9-month-old infants and adults in performing monkey face discriminations suggests that face perception is broadly tuned at birth only to become tuned within the first year of life.

Perceptual attunement has also been demonstrated using phonetic discrimination, visual language discrimination, intersensory speech discrimination, cross-species intersensory face and voice matching, cross-race and cross-species facial discrimination, cross-species voice discrimination, and musical rhythm perception (reviewed in Maurer & Werker, 2014).

Typical pruning of excess connections during infancy occurs in an experience-dependent fashion. When sensory input is abnormal, the visual and auditory cortices in blind and deaf adults, respectively, remain unspecialized compared to normal adults. This lack of specialization is normally observed during infancy structurally (over expression of dendritic spines declining with age), functionally (cross activation during sensory stimulation), and perceptually (specialization for native categories i.e., perceptual attunement). Given the neuroanatomical differences in the brains of synaesthetes compared to non-synaesthetes, the excess connections observed during adulthood may be the consequence of less-than-normal pruning during developing. Furthermore, the behavioural consequences of less-than-normal pruning during development may manifest through perceptual attunement, where specialization toward native information occurs in an experience-dependent fashion. Therefore, it is possible that adults with synaesthesia may undergo less perceptual attunement during development, which would manifest as either the lack of the specialization toward native categories and/or differences in discrimination among non-native categories.

To test this hypothesis, Ghloum, Gibson, & Maurer (2013) tested synaesthetes and non-synaesthetes on their ability to discriminate between native (upright human faces) and non-native stimuli (inverted human and chimp faces). Each stimulus set consisted of the original face (referred to as Jane) along with eight additional faces (referred to as Jane's Sisters), which were modified to change the spacing among the features (eyes were moved up/down or in/out 4mm and the mouth was moved up/down 2mm). Stimuli were identical to those used in (Mondloch, Le Grand, & Maurer, 2002;

Robbins, Nishimura, Mondloch, Lewis, & Maurer, 2010) except with the additional creation of four faces.

Participants performed a speeded simultaneous matching-to-sample task on upright human and chimp faces. The task involved matching one of the two faces at the bottom of the screen with the face at the top of the screen. A subset of participants performed the same task with inverted human faces.

Synaesthetes were better able to discriminate among chimp faces compared to non-synaesthetes, with no significant differences in accuracy when discriminating among upright human faces. These results are consistent with the hypothesis that less-than-normal pruning during development and the excess brain connectivity in adults with synaesthesia may be related to less perceptual attunement, which would manifest through the enhanced ability to discriminate non-native stimuli.

Another result demonstrated a reduced face inversion effect in synaesthetes compared to non-synaesthetes i.e., synaesthetes performed better when discriminating among inverted human faces compared to non-synaesthetes. While this result may be explained through perceptual attunement, inverted faces and the face inversion effect are not normally associated with perceptual attunement and are typically implicated in the disruption of configural face processing.

Adult face expertise is based on the processing of both the individual facial features and the relations between them. These are collectively referred to as featural and configural processing, respectively. Featural processing refers to the processing of individual facial features, whereas configural processing refers to the processing of the relations among those features.

Configural processing can be divided into 3 categories: first-order relations, second-order relations, and holistic processing. First-order relations refer to the top-down arrangement of all faces (eyes above the nose above the mouth), and are used to distinguish faces from other stimuli. Second-order relations refer to the spatial distances among features, and holistic processing refers to the binding of individual features into a global percept (Maurer, Le Grand, & Mondloch, 2002). Both second-order relations and holistic processing are used to distinguish one face from another.

One common method used to test the importance of configural information in face processing is through face inversion. Rotating a face 180° impairs overall recognition of the face and disrupts configural processing, all while preserving the facial features. In other words, when a face is inverted, the automatic face-specific processes used on upright faces are disrupted, reducing accuracy and increasing reaction times (Yin, 1969; Maurer et al., 2002). The Face Inversion Effect (FIE) describes how the effects of face inversion are larger for faces than for any other non-face object tested to date (Farah, Drain, & Tanaka, 1995; Robbins & McKone, 2007).

While it is generally agreed that inversion disrupts configural processing, there is debate concerning the role that featural information plays. One idea is that configural information is selectively disrupted when a face is inverted (Diamond & Carey, 1986). Support for this claim comes from studies that demonstrate that the FIE is larger when faces are manipulated configurally, compared to featurally (Freire et al., 2000; LeGrand et al., 2001; Maurer et al., 2002; Mondloch et al., 2002). In one example, Freire, Lee, & Symons (2000) tested upright and inverted faces using configural and featural manipulations and found a larger inversion effect for configural differences than for featural differences. This result has been replicated in other studies (LeGrand, Mondloch, Maurer, & Brent, 2001; Maurer et al., 2002; Mondloch et al., 2002)

Despite evidence that supports a preferential effect on configural processing by face inversion, other studies support the idea that featural processing is affected as well. For example, when judgments of features are made to be equally as difficult as configural modifications, the size of the inversion effect for featural modifications is identical to that for configural modifications (Yovel & Kanwisher, 2004). In fact, when featural modifications are defined by changes in shape rather than surface coloration, the inversion effect for featural changes is just as large as for configural changes (McKone & Yovel, (2009).

To further complicate matters, the size of the inversion effect is dependent on the location of featural and configural information. The inversion effect is larger when the eyes are vertically displaced compared to when they are horizontally displaced (Goffaux & Rossoin, 2007; Crookes & Hayward; 2012). In addition, vertical displacements between the nose and mouth can also influence the size of the inversion effect (Barton et al., 2001; 2003).

To determine if configural and featural manipulations in different parts of the face disproportionally influence the size of the inversion effect, Tanaka, Martha, Bub, & Pierce (2009) tested faces that differed in the spacing between the eyes, the spacing between the nose and mouth, the size of the eyes, and the size of the mouth. Each condition was equated for discrimination difficulty. Interestingly, the size of the inversion effect was larger for manipulations in the lower region of the face compared to the upper region of the face. This suggests that featural and configural information in the eye region is relatively spared during inversion compared to the lower region of the face. Thus, the location of the information rather than the information itself may determine the differential effect of inversion.

One theory to help explain the differences during face inversion is the perceptual field hypothesis. Configural processing of upright faces requires that the diagnostic information is perceptually visible. In other words, the information needed for configural processing is within the observers' perceptual field. When a face is upright, the observers' perceptual field encompasses the information needed for configural processing. When a face is inverted, the observers' perceptual field may decrease in size, leading to a more local-based processing strategy (Rossion 2008; 2009; 2013; Xu & Tanaka, 2013).

Considering that featural and configural information is relatively conserved in the eye region of the face during inversion (Tanaka et al., 2009), it is possible that the perceptual field is narrowly focused on the eye region of the face during inversion. If this is the case, then the information contained in the nose and mouth region necessary for a holistic representation is lost during inversion. Considering this, Sekunova & Barton (2008) spatially cued participants to the upper and lower regions of the face during a face inversion paradigm. When participants were cued to the lower regions of the face, the size of the inversion effect was reduced, supporting the idea that the differential effects of face inversion is related to the observers bias toward looking at the eye region of the face, the result of years of experience, rather than the selective disruption of configural information.

In regard to synaesthetes, it is possible that the reduced face inversion effect may be related to an intrinsic bias toward looking at the lower regions of the face compared to the upper regions. Since processing of the information contained in the lower regions of the face is relatively disrupted during inversion (Tanaka et al., 2009), a natural bias in attention toward the lower regions could explain why synaesthetes perform better when looking at inverted faces compared to non-synaesthetes. However, if spatial attention is biased toward the nose and mouth region of the face, we might also expect differences between synaesthetes and non-synaesthetes in processing upright faces. Considering there were no differences between groups in processing of upright faces (Ghloum et al., 2013), an intrinsic attention bias towards lower regions of the face in synaesthetes is unlikely. However, further investigation is needed to determine if this is the case.

A more plausible explanation is related to the perceptual field hypothesis. Specifically, the reduced face inversion effect may be related to the size of the perceptual field. When a face is upright, the perceptual field encompasses all the information needed for global processing. When a face is inverted, processing of information contained outside of the perceptual field is disrupted, shifting strategies from global to more local processes (Rossion 2008; 2009; 2013; Xu & Tanaka, 2013). Since synaesthetes demonstrated a reduced face inversion effect, their perceptual fields may be larger when looking at inverted faces compared to typical adults. A larger perceptual field would indicate an ability to use global-based strategies when looking at inverted faces compared to typical adults where these strategies are disrupted. Alternatively, synaesthetes may be biased toward using local based strategies, leading to an improved performance when those strategies are used (inverted faces),

While further investigation is needed to determine the exact cause of the reduced face inversion effect, it is clear that there may be differences in how synaesthetes process faces compared to non-synaesthetes. Thus, further investigation into the face processing literature may reveal subtle differences between synaesthetes and non-synaesthetes in the way they process faces.

One method to study the underlying mechanisms behind face processing is to manipulate spatial frequency information. Spatial frequency is one of the basic building blocks of vision (Patel, Maurer, & Lewis, 2010). The visual system extracts spatial frequency information from the environment, breaks the input into discrete neural signals, and processes the information in separate channels that appear to be tuned to a specific band of spatial frequencies.

Two of these channels are known as the magnocellular and parvocellular pathways. Magnocellular pathways are most sensitive to low spatial frequencies (LSF) and are ideal for the fast transduction of large-scale luminance variations (i.e. coarse information). Parvocellular pathways are sensitive to middle-to-high spatial frequencies (MSF-HSF) and are ideal for the transmission of small-scale luminance variations (i.e. fine information), albeit at a slower transduction rate (Bullier, 2001; Livingstone & Hubel, 1988).

Two major visual processing streams, the dorsal stream and the ventral visual, are large recipients of magnocellular and parvocellular inputs. The dorsal visual pathway, which runs from the primary visual cortex to the posterior parietal cortex, largely receives magnocellular inputs (Merigan & Maunsell, 1993). The ventral visual pathway, which runs from the primary visual cortex to the ventral temporal cortex, receives both parvocellular and magnocellular inputs (Ferrera, Nearley, & Maunsell, 1992).

Using different techniques and methodologies, spatial frequency information of a face can be manipulated to determine how different bands of spatial frequency affect face processing. One approach to manipulating spatial frequency information is pixelization.

In this method, a grid containing a number of grid squares is placed on an image. The pixel value within each grid square is set to the average gray level of each grid square, resulting in an image that appears ‘pixelized’. Using this method, accuracy for the recognition of faces dropped when the image contained spatial frequencies below 8-11.5 c/fw (Harmon, 1973; Bachmann, 1991; Costen, Parker & Craw, 1994; 1996). Although these results suggest that the critical band of spatial frequencies for facial recognition is between or above 8-11.5 c/fw, high spatial frequency information is introduced when pixelizing a face, which may influence critical bands estimates for facial recognition (Gao & Maurer, 2011).

Another more commonly used approach to manipulate spatial frequency information is filtering. Images are passed through a filter to selectively remove spatial frequencies. In comparison to pixelization, filtering does not introduce any additional spatial frequency information to the image. Since the center frequency, cut-off frequencies, and width (octave) of the filters vary between experiments, estimates on the band of spatial frequencies most useful for face identification differ. For example, Costen & Colleagues (1994; 1996) used low-pass and high-pass filtered faces to show that the spatial frequency band most useful for identifying a face was between 8 and 16 c/fw. This differs from Hayes, Morrone, and Burr (1986), who used band-pass filtered faces and found the most useful information to be located around 20 c/fw.

An alternative to filtering faces is called noise masking. Rather than filtering the faces, white Gaussian noise is filtered and added to the image. The white Gaussian noise acts as a narrowband mask that disrupts the processing of select spatial frequencies without removing any information from the image. Using this approach, Näsanen (1999) found adults are most sensitive to spatial frequency information centered around 8-11 c/fw when identifying faces.

Depending on the type of spatial frequency manipulation and methods used, estimates of the most sensitive band of spatial frequencies vary across studies. Despite these differences, a middle band of spatial frequencies between 5 and 20 c/fw has consistently been found to be most useful for face identification (reviewed in Collin, Rainville, Watier, & Boutet, 2014). However, the optimal bands of spatial frequency used in other types of face processing, namely configural and featural processing, are up for debate.

One side argues that manipulating spatial frequency can be used to encourage a certain type of face processing. Low spatial frequency manipulations encourage the processing of configural information while high spatial frequency manipulations encourage the processing of featural information.

Evidence to support these claims comes from studies on featural and configural processing using the FIE and the configural effect. When faces are manipulated to emphasize high spatial frequency (featural) information, adults are able to process inverted faces as efficiently as upright faces (Collishaw & Hole, 2000; Maurer et al., 2002; Rossion, 2008, 2009). Similarly, when faces are manipulated to emphasize low spatial frequency (configural) information, adults can efficiently process upright but not inverted faces (Goffaux & Rossion, 2006; Maurer et al., 2002; Rossion, 2008, 2009). Furthermore, adults are better at making configural discriminations between faces using low spatial frequencies, and better at making featural discriminations between faces using high spatial frequencies (Goffaux, Hault, Michel, Vuong, & Rossion, 2005).

While these studies imply that configural and featural processes rely on a different optimal band of spatial frequencies, differences across studies may arise as the methods used in the FIE and the configural effect may not access these processes in an orthogonal way. For example, configural changes may be more difficult to discriminate than featural differences (reviewed in Collin et al., 2014). In addition, configural changes can influence the perception of individual features, and featural changes can influence the perception of configuration (Serget, 1984; Haig, 1984; Rakover, 2002; Rhodes Brake, & Atkinson, 1993).

Furthermore, other evidence suggests that featural and configural processing is dependent on the same optimal band of spatial frequencies as adults have been shown to use the same mid-spatial frequencies to process both upright and inverted faces (Boutet, Collin, & Faubert, 2003; Gaspar, Sekuler, & Bennett, 2008; Watier, Collin, & Boutet, 2010; Willenbockel et al., 2010).

To determine if configural and featural processes rely on the same, or different optimal bands of spatial frequency, Collin and colleagues (2014) compared performance of an ideal observer to a human observer in discrimination among upright and inverted faces manipulated across different spatial frequencies. For the ideal observer, the most objectively useful information for making configural and featural discriminations was at 5 c/fw. For human observers, adults were most efficient at making configural and featural discriminations at 10 c/fw. This suggests that the middle band of spatial frequencies is most optimal for both configural and featural discriminations and that these results are not due to physical differences of face stimuli.

Fewer studies have looked into how manipulating spatial frequency influences face processing in children. Using a noise-masking paradigm, Leonard & Karmiloff-Smith (2010) tested adults and 7-10 year-olds on discriminating between upright and inverted faces masked at low, middle, and high spatial frequencies. Similar to adults, 9- and 10-year-old children were more sensitive to middle spatial frequency bands when processing upright, but not inverted faces. However, 7- and 8-year-old children did not demonstrate a mid-spatial frequency bias for upright or inverted faces. In another study, 10- and 14-year-olds were able to use low and mid spatial frequency information when judging facial identity, but required more contrast to reach adult-like levels of accuracy (Gao & Maurer, 2011). This suggests that the mid-spatial frequency bias prevalent in adults when processing upright faces develops gradually during childhood, and that performance in these tasks may be influenced the maturity of other processes such as the ability to extract a signal from noise, general attentional abilities, or other visual processes.

In regard to synaesthetes, there have been no studies investigating the relationship between face processing and spatial frequency. However, a few studies have suggested that there may be differences between the magnocellular and parvocellular pathways in synaesthetes. In an ERP study using different stimuli to preferentially promote the use of parvocellular and magnocellular pathways, 15 linguistic-colour synaesthetes were compared to 15 non-synaesthetes. When shown high and low spatial frequency Gabor patches, synaesthetes showed an increase in cortical responsiveness to high but not low spatial frequency Gabor patches compared to non-synaesthetes. When shown check stimuli at different contrasts, cortical responsiveness in synaesthetes decreased as contrast decreased to a greater extent compared to non-synaesthetes, demonstrating a decreasing response to stimuli that promote magnocellular pathways (Barnett et al., 2008). These results demonstrate that synaesthetes show an increase response to stimuli that promote the use of parvocellular pathways, while showing a decrease in response to stimuli that promote the use of magnocellular pathways.

Additional evidence comes from an MRI study of 9 grapheme- and tone-colour synaesthetes, and 42 non-synaesthetes. Compared to non-synaesthetes, synaesthetes had an increase in gray matter volume in the left posterior Fusiform Gyrus, an area implicated in colour processing, and a decrease in gray matter volume in the left MT/V5, an area implicated in motion perception (Banissy et al., 2012). A follow up study using different participants found behavioural differences between synaesthetes and non-synaesthetes using a motion and a colour perception task. In a random-dot kinematogram, the percentage of dots moving together in one direction is varied as subjects indicate the overall direction of motion. By varying the percentage, a motion-coherence threshold is obtained, defined as the percentage of coherently moving dots needed to correctly determine the direction of motion. A higher threshold indicates that more dots are needed to determine the direction of motion. Compared to non-synaesthetes, synaesthetes had higher motion-coherence threshold than non-synaesthetes. In a colour perception task that varied hue, luminance, or saturation, synaesthetes performed better across all colour dimensions compared to non-synaesthetes. Together these results suggest that synaesthesia may be associated with a reduction in motion-coherence perception and an increase in colour perception (Banissy et al., 2013). However, Banissy et al. (2013) urged caution with this interpretation of the results since only one motion speed was examined.

In sum, structural and functional analysis support the idea that there are differences in the brains of synaesthetes compared to non-synaesthetes, and that these differences may lead to changes in observable behaviour. For example, synaesthetes demonstrate an abundance of connections within and between sensory areas of the brain (reviewed in Maurer et al., 2012), and these excess connections, the possible result of less-than-normal pruning during development, may explain why synaesthetes demonstrate an enhanced ability to discriminate stimuli from non-native categories (chimp faces and inverted human faces), with no differences discriminating among native categories (Ghloum et al., 2013). In addition, considering the differences in cortical responsiveness to stimuli that promote the use of the magnocellular and parvocellular pathways (Barnett et al., 2008), as well as the structural and behavioural differences between colour and motion perception (Banissy et al., 2012; 2013) in synaesthetes compared to non-synaesthetes, it is reasonable to expect that there might be differences in how synaesthetes process spatial frequency information of a face. Specifically, synaesthetes might have difficultly when faces express mainly low spatial frequencies, and/or excel when faces express mainly high spatial frequencies.

These potential differences between processing spatial frequencies might also help explain the reduced face inversion effect seen in synaesthetes. Difficulty processing inverted faces filtered at low spatial frequency might indicate a greater reliance on local based information available at high spatial frequencies or possibly a reduced capability to use global information at low frequencies.

Therefore, the purpose of this study is to determine if synaesthetes show evidence of a spatial frequency bias compared to non-synaesthetes by comparing differences in discrimination between upright and inverted faces filtered at different spatial frequencies. We predict that synaesthetes will have difficulty discriminating faces at low spatial frequencies with equal or greater performance when discriminating faces at high spatial frequencies. We also predict, similar to the results in Ghloum et al. (2013) that synaesthetes will show a reduced face inversion effect compared to non-synaesthetes, with no differences discriminating upright unfiltered faces. Alternatively, there may be no differences in accuracy or reaction times between synaesthetes and non-synaesthetes.

The present study looked at perceptual differences in discrimination between adults with and without synaesthesia on six face discriminations tasks: Upright and inverted faces filtered at different spatial frequencies. The spacing between facial features was modified in each task such that each set contained the original face and 8 modified stimuli. Each task involved the simultaneous presentation of three faces for 2000ms: one face on the top, and two on the bottom in opposite corners. Participants identified which bottom face matched the top.

All participants completed the David Eagleman Online synaesthesia battery (www.synaesthete.org). The battery was selected due to the accessibility online, inclusion of many standardized tests for different forms of synaesthesia, and questionnaires assessing visual imagery, projectors vs. associators, drug use and its effects on synaesthesia to name a few. Importantly, the online battery quantified the consistency of synaesthetic precepts, allowing the objective measure of subjective, but consistent experiences.

Additionally, all participants completed visual screening as well as language, music, ethnicity, and handedness questionnaires. While further testing was completed on an additional second and third day using different tests, those results are not reported here.

Method

Participants

Participants were recruited from McMaster University using flyers posted around campus, through an online experimental sign-up website for students in psychology courses, and from a database of synaesthetes tested the year prior. Participants were compensated with cash or course credit.

Each participant completed David Eagleman's Online Synaesthesia Battery (Eagleman et al., 2007). Out of the fifty participants tested, twenty reported no forms of synaesthesia, eighteen reported at least one form of synaesthesia that was verified by the battery, and seven participants reported forms of synaesthesia that were not tested on the battery.

For these seven participants, an interview was conducted to determine the genuineness of that form of synaesthesia. Based on these interviews, only two participants demonstrated consistency of verbal responses for non-colour types of synaesthesia and were included in the study. The remaining five were excluded from the analysis on the basis of inconsistent responses. Five additional subjects were excluded because of procedural and experimental errors.

The final sample consisted of twenty Synaesthetes and twenty Non-Synaesthetes. All participants were Caucasian and had normal or corrected-to-normal vision. Demographic information for participants can be found in Table 1.

Overall Design

The study was approved by the McMaster University Research Ethics Board. Testing was conducted over three 2-hour sessions at the Visual Development Lab at McMaster University (See Appendix A). Results from the first session are reported below. Results from the second and third session are not reported here.

Upon arrival, consent was obtained and each participant was assigned a random 4-digit ID number. Participant names were kept separate from any data file. Participants were then tested for normal adult vision (Appendix B), filled out ethnicity, handedness,

Table 1: Demographic information for synaesthetes and non-synaesthetes.

	Synaesthetes (n=20)	Non-Synaesthetes (n=20)
Mean Age (years)	22.6 +/- 4.28	20.15 +/- 1.66
Gender (Female)	12	14
Handedness (right)	17	17
Undergraduate Students	14	19
Born in Canada	17	18
Mean VVIQ Score*	3.74 +/- 1.13	3.38 +/- 1.37
Projector/Associator/None**	6/11/2	1/5/13
Mean Associator Score	-2.05 +/- .786	-1.27 +/- .879
Mean Projector Score	1.66 +/- 1.63	-

*A score above three suggests a higher level of vividness relative to the general population
** A positive score is classified as a projector and a negative score is classified as an associator

language/education, and musical experience questionnaires (Appendix C-F), completed the online synaesthesia battery (Appendix G), and a spatial frequency discrimination task.

Following completion of the first session, participants were compensated for their time and booked for a second session. A debriefing form was given to all participants after the last session and all were thanked for their participation (Appendix H).

Procedure and Design

David Eagleman's online synaesthesia battery

Apparatus

Participants completed the online synaesthesia battery on a Macintosh OSX 10.6.3 laptop. Each participant was registered on http://www.synesthete.org. To maintain participant confidentiality, no personal information was used and all participants were assigned a 4-digit ID number.

Procedure and Design

Each participant completed the David Eagleman online synaesthesia battery (Eagleman et al., 2007). Consistency is a hallmark of synaesthesia (Baron-Cohen et al., 1993) and the online battery is used to determine the consistency of the different types of synaesthesia relative to individuals without those types. Not all forms listed in the battery were tested. Tested types of synaesthesia include: Numbers-Colour, Letters-Colour, Weekdays-Colour, Months-Colour, Music Pitch-Colour, Chords-Colour, and Instrument-Colour. All participants were instructed to indicate any form of synaesthesia they thought they had to ensure each participant reported all forms.

Each test yielded a consistency score for each form of synaesthesia. However, instead of using the RGB values from the battery to calculate Euclidean Distance and assess consistency against the criterion set by (Eagleman et al., 2007), RBG values were converted to CIELUV coordinates and assessed using the criteria adopted by (Rothen et al., 2013), which is considered to be a more specific and sensitive measure of consistency in synaesthetes.

Other types were verified using the test-retest method. After each battery, the experimenter conducted a short interview questioning the nature of their experiences. If colour was involved in these experiences (e.g., taste-colour), an online colour wheel was used to obtain RBG values and compare them across interviews. For non-coloured forms of synaesthesia, the first interview questioned the participant about their experiences, and the second interview determined the consistency of their claims. If most verbal responses were identical across each interview, the participant was considered to have that form of synaesthesia. The re-test was conducted on a separate day. Reported types and corresponding consistency scores can be found in Table 2.

Spatial Frequency Discrimination Task

Apparatus

Using SuperLab Version 4.0.7b, stimuli were presented on a monochrome Radius 21-GS monitor operated by a (Macintosh OSX 10.4.2) computer with a resolution of 1280x960 and a refresh rate of 85 Hz. Participant responses (accuracy) and reaction times were recorded using a standard Macintosh computer keyboard.

Stimuli (Unfiltered Faces)

The stimuli consisted of cropped (to remove the hair and the background), re-sized, and gray scaled images of an adult female Caucasian face in a neutral expression. The original photo (referred to as Jane) was modified using Adobe Photoshop CS3 to produce eight additional faces (referred to as Jane's Sisters), each with different spacing among the features (eyes were moved up/down or in/out 4mm and the mouth was moved

Table 2: Types of synaesthesia reported by synaesthetes and corresponding consistency scores using the Online Synaesthesia Battery (www.syaesthete.org; Eagleman et al., 2007) and (Rothen et al., 2013).

Subject ID	Synaesthesia types	Consistency Score using the Online Battery*	Mean Euclidean Distance using CIELUV**
967	Emotion -> Colour	Two Interviews	14.2
	Personalities -> Aura/Colour	Two Interviews	14.2
	Musical Chords -> Colour	1.97/2.64	144/187.6
	Musical Pitch -> Colour	2.216	150.8
	Sound -> Smell		
	Sound -> Taste		
1026	Months->Colour	0.53/0.47	125.14
	Musical Instruments -> Colour	0.315	87.02
	Taste->Colour	N/A	
	Orgasm->Colour	N/A	
1073	Letters -> Colour	1.06/0.61	110.5/99
	Weekdays -> Colour	0.53/0.45	88.7/101.3
	Months -> Colour	0.8/0.54	96.6/109
	Musical Pitch -> Colour	1.264/1	90.8/94
	Musical Instruments -> Colour	0.435/0.45	93.2/111.9
	Sequences -> Spatial Locations	Consistent (need verification)	
	Pain -> Shape, Colour	Consistent (need verification)	
1137	Numbers -> Colour	0.64	97
	Letters -> Colour	0.64	87.36
	Weekdays->Colour	0.9	124
	Months->Colour	1.01	80.69
	Cyrillic Alphabet->Colour Test	0.61	No Access
	Sequences->Spatial locations	N/A	
	Sound->Touch	N/A	
1165	Numbers -> Colour	1.42	166.41
	Letters -> Colour	1.42	134.31
	Weekdays->Colour	0.49	151.9
	Sequences->Spatial locations	N/A	
1181	Numbers -> Colour	1.43	153.92
	Letters -> Colour	1.43	149.34
	Weekdays->Colour	1.05	123.93
	Months->Colour	0.66	117.93
	Sequences->Spatial locations	N/A	
	Numbers -> Colour	0.59	105.91
	Letters -> Colour	0.59	94.86

1264	Weekdays->Color Months->Color Musical Instruments->Color Musical Chords->Color Sequences->Spatial locations Temperature->Color	0.48 0.48 0.395 1.078571429	112.92 108.1 101.24 105.85
1493	Numbers -> Colour Letters -> Colour Chinese Numbers -> Colour Chinese SP/PS Character -> Colour Chinese Radical -> Colour Japanese Characters -> Colour	0.48/0.4 0.48/0.4 0.42/0.46 1.39 1.84	116.8/118.5 86/90.8 118.7/111.6 117.4 108
3201	Numbers -> Colour Letters -> Colour Weekdays -> Colour Months -> Colour Personalities -> Colour Emotion -> Colour	0.69 0.69 0.41 0.62 No Interviews No Interviews	107.3 88.4 92.5 104.5
7879	Numbers -> Colour Letters -> Colour Weekdays->Colour Months->Colour Musical Instruments->Colour	0.28 0.28 0.29 0.36 0.32	116.61 89.92 132.06 104.37 101.81
8015	Weekdays->Colour Months->Colour Sequences->Spatial locations	0.6 0.8 N/A	93.82 103
9117	Letters->Colour Weekdays->Colour Months->Colour Sequences->Spatial locations Personalities->Colour	0.37 0.22 0.44 N/A N/A	102.49 109.12 108.28
9572	Numbers -> Colour Letters -> Colour Months -> Colour Weekdays -> Colour Sequence -> Spatial Locations Guitar Finger Position -> Colour	0.44/0.56 0.44/0.56 0.42/0.37 0.35/0.23 No Interviews No Interviews	92.2/97.15 116.7/115.9 118.7/106.3 132.6/137.6
1408	Numbers -> Colour Letters -> Colour Weekdays -> Colour Months -> Colour Sequence -> Spatial Locations	0.37 0.37 0.28 0.57 N/A	108.66 78.3 62.65 81.04

	Taste -> Colour Pain -> Colour Personalities -> Colour	N/A N/A N/A	
1427	Numbers -> Colour Letters -> Colour Weekdays -> Colour Months -> Colour Pain -> Colour Temperature -> Colour Vision -> Sound	0.79 0.79 0.66 0.61 N/A N/A N/A	137.98 113.24 115.73 127.6
1435	Numbers -> Colour Letters -> Colour Weekdays -> Colour Months -> Colour Sequence -> Spatial Locations Smell -> Colour Pain -> Colour	0.27 0.27 0.31 0.32 N/A N/A N/A	100.66 93.41 97.63 99.49
1481	Numbers -> Colour Letters -> Colour Weekdays -> Colour	0.28 0.28 0.26	101.86 84.63 93.58
1527	Sound -> Taste	Consistent (two interviews)	
1565	Musical Instruments -> Colour Sound -> Smell Vision -> Smell	 N/A N/A	95.18
1039	Numbers->Colour Weekdays->Colour Months->Colour Sequences->Spatial locations	1.33 1.65 0.85 N/A	113.45 68.51 99.37

* For the online battery, a score less than one is reflective of the consistency seen in synaesthetes.
** Using CIELUV coordinates, a score less than 135 is reflective of the consistency seen in synaesthetes.
N/A – Consistency not tested

up/down 2mm). The spacing among the features is within normal variation; ability to discriminate between the spacing set would indicate an ability to discriminate among the faces of the majority of the population (Mondloch et al., 2002). The final spacing set contained nine images (one original and eight modifications). Stimuli were identical to those used in (Mondloch et al., 2002; Robbins et al., 2010) except with the additional creation of four faces. Inverted stimuli were identical to the upright stimuli with the exception of being inverted (Fig. 1).

Stimuli (Filtered Faces)

Four additional sets of faces were created that were identical to full spectrum faces, with the exception of being filtered at a different spatial frequency. Using Matlab R2012a, a 2.5 octave wide Gaussian filter (full width half height) was used on each face image. Each face set was filtered with a center frequency of 6, and 48 cycles per face width (c/fw)[1]. Filters with centre frequencies at 6 and 48 c/fw were low and high pass filters, respectively. RMS contrast was calculated for the original unfiltered face set, and applied to the other filtered sets (Fig. 2).

From a testing distance of 100cm, the spacing modifications of the eyes and the mouth across all face sets (i.e., unfiltered and filtered faces) corresponds to a visual angle of 0.2 and 0.12 degrees, respectively. The size of each image presented on screen was ~10.2 cm wide and ~15.2 cm high (5.8 degrees and 8.7 degrees, respectively).

Procedure and Design.

Participants sat in a dark room 100cm from the screen with the monitor as the only source of light. The task began with a brief introduction to Jane and her sisters. Three faces were presented simultaneously on screen for 2000ms: one top-centered target and two in opposite bottom corners. One face on the bottom was identical to the face on

[1] Bandpass filters with center frequencies of 12 and 24 c/fw were also tested, but not reported here.

Figure 1: Upright human and inverted face sets. Each set contained the original photo (left) and the eight modifications (eyes down-mouth up, eyes in-mouth down, eyes up-mouth up, eyes out-mouth up, eyes down-mouth down, eyes up-mouth down, eyes in-mouth up, and eyes out-mouth down).

A)

B)

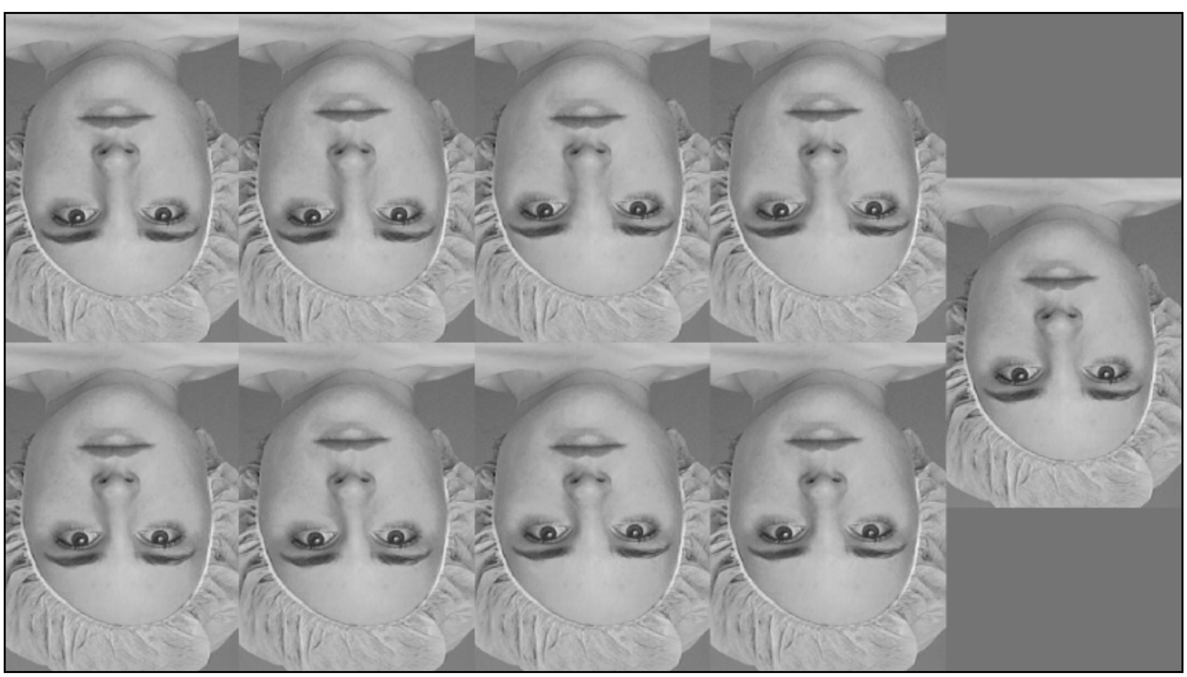
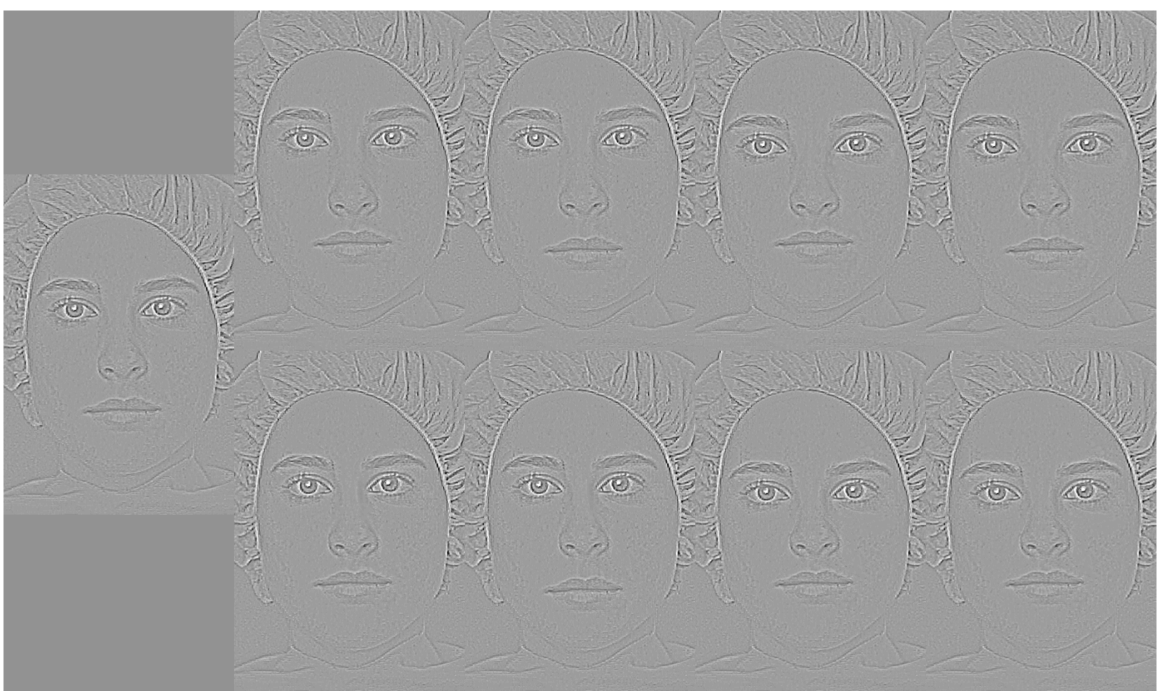


Figure 2: Filtered face set A) Lowpass filter centered at 6 cycles/fw and B) Highpass filter centered at 48 cycles/fw.

A)

B)



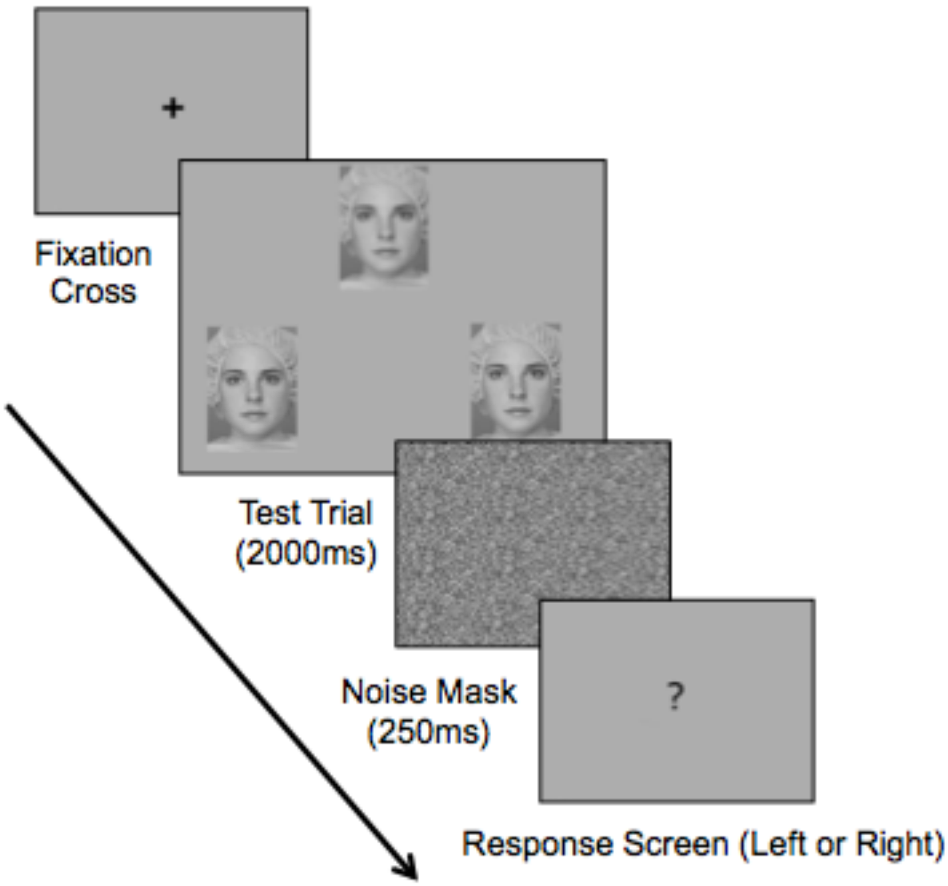
the top. Participants were asked to select (using the corresponding Left and Right keys) which face on the bottom matched the top (See Appendix I for detailed instructions). After the four practice trials, participants completed 36 randomized experimental trials for each condition. The presentation and instructions in test trials were identical to practice trials.

Figure 3 is an example of a trial. Each trial begins with a fixation cross. Once the spacebar was pressed, three faces appeared on screen for 2000ms, followed by a 250ms noise mask. A response screen (question mark) appeared where participants entered their response (Left or Right). The time it took for participants to enter a response was recorded. To decrease variability, participants were instructed to keep both hands on the keyboard at all times. Nine different faces were tested four times for a total of 36 trials. There were 10 conditions in separate blocks. Half the participants would see upright faces first, and the other half would see inverted faces first. The order of the conditions was randomly assigned to each participant (See Appendix J for the order sheet). The correct responses were counterbalanced between corresponding left and right keys.

Results

The data consisted of accuracy and reaction times for synaesthetes and non-synaesthetes for unfiltered and filtered faces in upright and inverted orientations. To allow comparison with previous data in Ghloum et al. (2013), data from unfiltered full spectrum faces was analyzed separately from the two filtered conditions. Separate ANOVAs were performance on accuracy and correct reaction times, with upright and inverted faces as a within-subject factor and group, synaesthete or non-synaesthete, as a between-subject factor. An additional within-subject factor, high and low spatial frequency, was used in the analysis of filtered faces.

Figure 3: Example of a trial. Participants pressed the spacebar to indicate the start of a trial. Three faces would appear simultaneously for 2000ms followed by a 250ms noise mask. Participants indicated if the left or right face is identical to the face on the top. Only one face on the bottom is the same as the top.



Unfiltered Faces

Accuracy

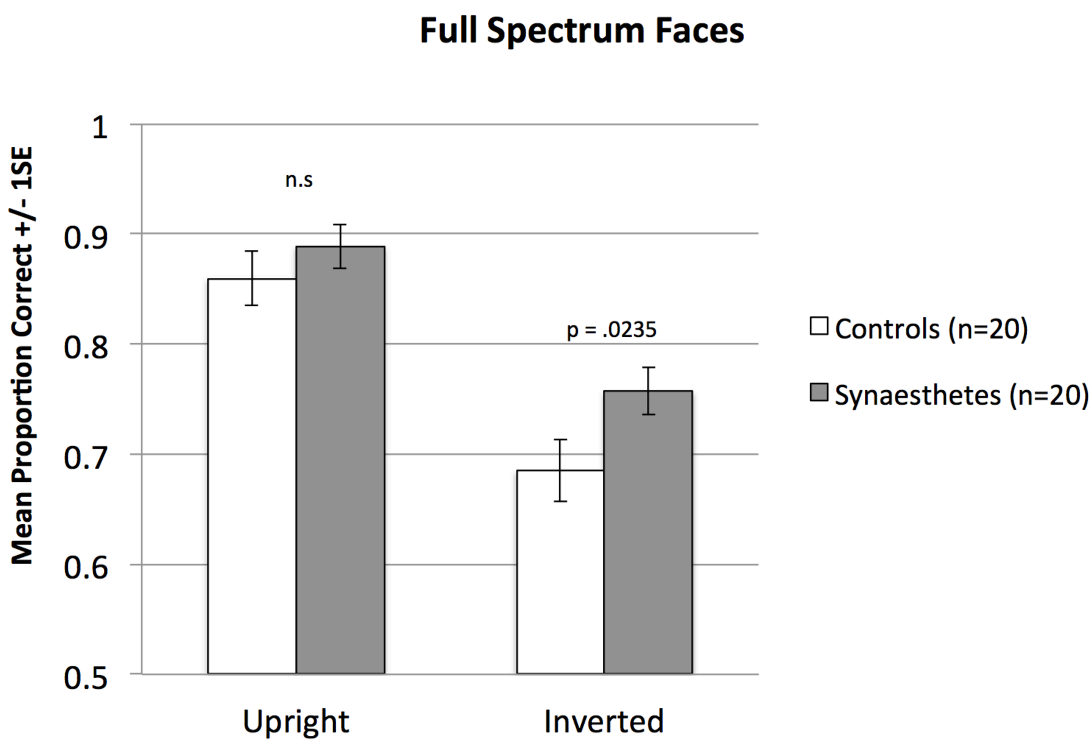
To determine if synaesthetes differed from non-synaesthetes in accuracy for the two unfiltered orientations, a 2 x 2 repeated measures ANOVA was conducted using mean proportion correct for each orientation (upright and inverted) as the within-subject factor, and group (synaesthetes and non-synaesthetes) as the between-subject factor. As predicted, the analysis revealed a main effect of orientation ($F (2,38) = 102.212$, $p < 0.001$) as both synaesthetes and non-synaesthetes were significantly better at discriminating among upright faces compared to inverted faces (Fig. 4).

In addition, the analysis revealed a marginally significant main effect of group ($F(1,38)= 2.895$, $p=0.097$) as synaesthetes performed slightly better overall ($M=0.823$, $SD=0.021$) than non-synaesthetes ($M=0.772$, $SD=0.021$) across the two orientations of faces with different spacing among the features. However, there was no significant interaction between orientation and group ($F(2,38)= 2.011$, $p=0.164$).

Despite the lack of interaction, an inspection of the graph indicated that the marginally significant effect of group for correct responses came mainly from the inverted condition. We had also predicted, based on previous findings, that synaesthetes would be better than controls at discriminating among inverted faces, with no difference for upright faces. Thus, we conducted planned comparisons for each orientation between synaesthetes and non-synaesthetes, with the prediction that if there were a difference, synaesthetes would be better. To do so, we performed two one-tailed independent sample t-tests and corrected for multiple comparisons with a Bonferroni correction ($\alpha=0.025$).

As predicted, synaesthetes ($M= 0.7569$, $SD = 0.0953$) were significantly more accurate than non-synaesthetes ($M= 0.6847$, $SD = 0.1249$) in discriminating among

Figure 4: Mean proportion correct for synaesthetes (dark gray) and non-synaesthetes (white) for full spectrum upright and inverted human faces ± 1 SE. Synaesthetes were significantly more accurate than non-synaesthetes in discriminating among inverted faces. There were no significant differences between synaesthetes and non-synaesthetes for upright human faces. All independent-sample p-values reported are one-tailed.



inverted faces ($t(38) = -2.055$, $p= 0.0235$). Also as predicted, synaesthetes (M= 0.8889, SD = 0.0897) did not differ significantly from non-synaesthetes (M= 0.8597, SD = 0.1094) in discriminating among upright faces ($t(38) = -0.922$ $p= 0.181$).

Reaction Times

An identical analysis was conducted to determine if reaction time for correct responses differed between synaesthetes and non-synaesthetes for either orientation. The analysis revealed no main effect of orientation ($F (2,38) = 1.548$, $p=0.221$), as reaction times for both synaesthetes and non-synaesthetes did not differ across orientations (Fig. 5). In addition, there is no significant interaction for reaction times between orientation and group ($F(2,38)= 0.048$, $p=0.828$).

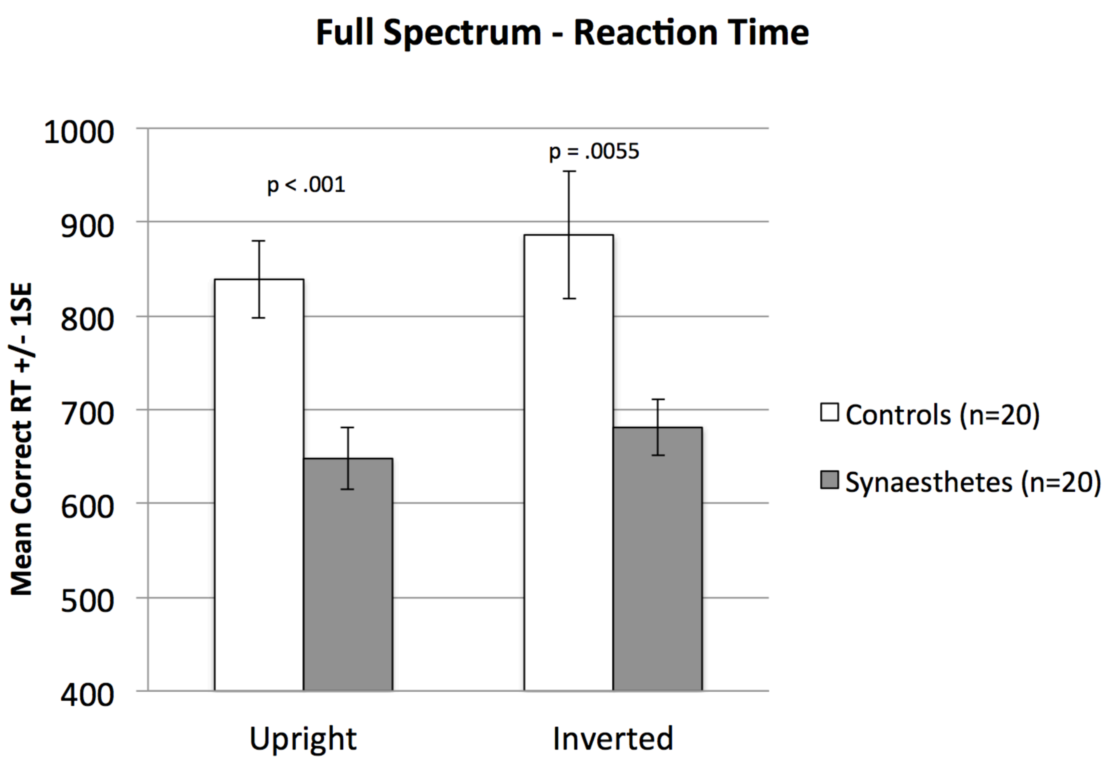
However, contrary to our predictions, the analysis revealed a significant main effect of group ($F(1,38)= 12.449$, $p=0.001$), as synaesthetes responded faster than non-synaesthetes overall. Additional independent sample t-tests performed on each orientation and corrected for multiple comparisons with a Bonferroni correction ($\alpha=0.025$) confirmed that synaesthetes (M= 648.37, SD = 148.65; M= 681.70, SD= 135.06) responded significantly faster compared to non-synaesthetes (M= 839.37, SD = 186.29; M= 886.84, SD= 305.10) for both upright ($t(38) = 3.583$, $p < 0.001$) and inverted ($t(38) = -2.750$, $p= 0.0055$) faces, respectively.

Filtered Faces

Accuracy

To determine if synaesthetes differed from non-synaesthetes across each spatial frequency manipulation, a 2 x 2 x 2 repeated measures ANOVA was conducted using proportion correct. Spatial frequency (6 c/fw, and 48 c/fw) and orientation (upright and inverted) were used as the within-subject factors, and group (synaesthetes and non-

Figure 5: Mean reaction time ± 1 SE for correct responses for synaesthetes (dark gray) and non-synaesthetes (white) when viewing full spectrum upright and inverted human faces. Synaesthetes responded significantly faster than non-synaesthetes. All independent-sample p-values reported are one-tailed.



synaesthetes) was used as the between-subject factor.

As predicted, the analysis revealed a main effect of orientation ($F(2,38) = 34.361$ $p < .001$) suggesting that synaesthetes and non-synaesthetes were significantly better at discriminating upright compared to inverted faces. In addition, the analysis revealed a main effect of spatial frequency ($F(2,38)= 31.084$, $p < .001$) as both synaesthetes and non-synaesthetes performed better at discriminating faces containing high spatial frequencies compared to faces containing low spatial frequencies (Fig. 6).

Also, the analysis revealed a marginally significant main effect of group ($F(1,38)= 3.622$, $p=0.065$) as synaesthetes performed slightly better overall ($M=0.716$, $SD=0.019$) than non-synaesthetes ($M=0.665$, $SD=0.019$) across each orientation and spatial frequency.

Crucially, there was no significant three way interaction between group, spatial frequency, and orientation ($F(2,38)= 0.291$, $p= 0,593$), nor any two-way interactions between spatial frequency and group ($F(2,38)= 0.147$, $p=0.703$), orientation and group ($F(2,38)=1.013$, $p= 0.321$), or spatial frequency and orientation ($F(2,38)=1.104$, $p= 0.300$).

Reaction Times

An identical analysis was conducted to determine if reaction time for correct responses differed across orientation and spatial frequency between synaesthetes and non-synaesthetes. As predicted, the analysis revealed marginally significant main effect of orientation ($F(2,38)=3.161$, $p= 0.083$), as both synaesthetes and non-synaesthetes were slightly faster at discriminating among upright faces compared to inverted faces (Fig. 7). However, there was no main effect of spatial frequency ($F(2,38)=0.176$, $p= 0.677$), no two-way interactions between spatial frequency and group ($F(2,38)= 1.627$, $p=0.210$),

Figure 6: Mean proportion correct ± 1 SE for synaesthetes (dark gray) and non-synaesthetes (white) when viewing filtered upright and inverted human faces. Faces were filtered using low and high-pass filters centered at 6 cycles/fw and 48 cycles/fw, respectively.

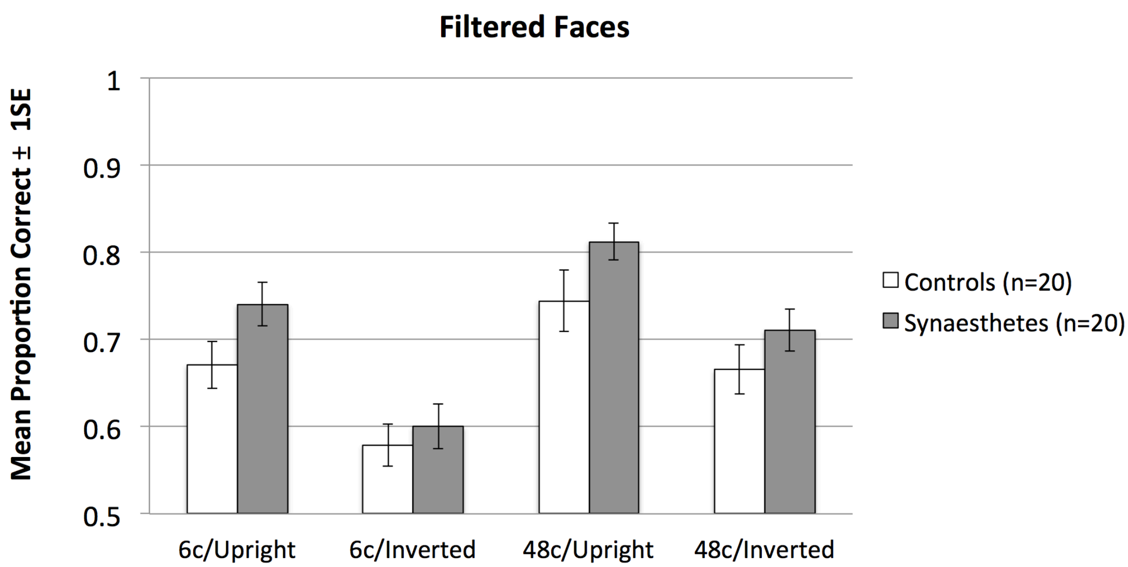
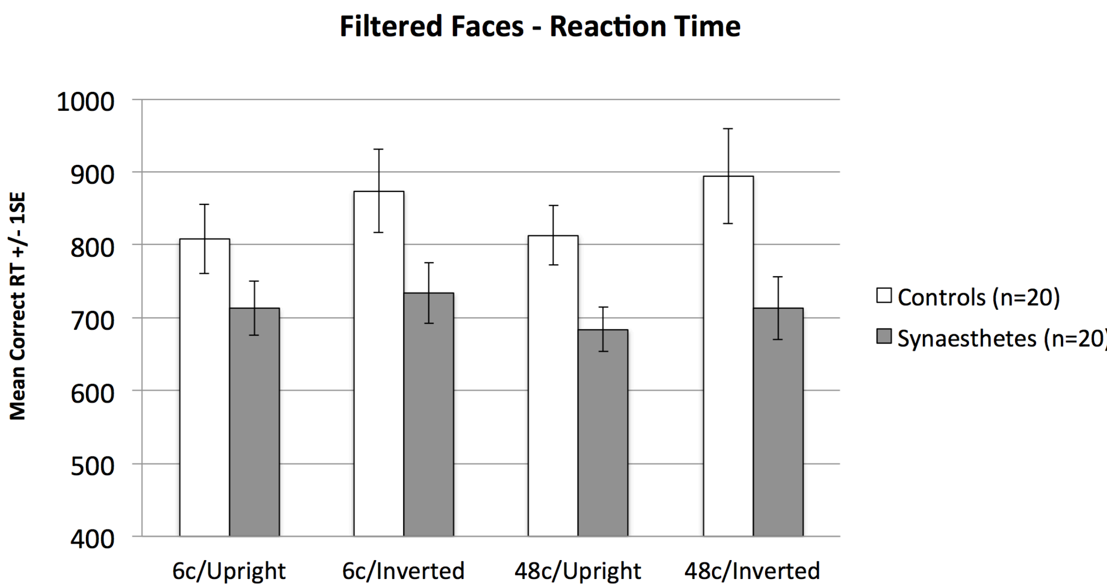


Figure 7: Mean reaction time ± 1 SE for correct responses for synaesthetes (dark gray) and non-synaesthetes (white) when viewing filtered upright and inverted human faces. Faces were filtered using low and high-pass filters centered at 6 cycles/fw and 48 cycles/fw, respectively.



spatial frequency and orientation ($F(2,38)=0.203$, $p= 0.655$), and orientation and group ($F(2,38)=0.745$, $p= 0.393$), as well as no significant three-way interaction between spatial frequency, orientation, and group ($F(2,38)= 0.024$, $p= 0.878$).

Contrary to our predictions, the analysis revealed a significant main effect of group ($F(1,38)= 5.842$, $p=0.021$), as synaesthetes responded faster than non-synaesthetes overall.

Discussion

The purpose of this study was to investigate whether synaesthetes process faces differently compared to non-synaesthetes. Specifically, we investigated whether faces filtered at high and low spatial frequencies, presented in upright and inverted orientations, are processed differently in synaesthetes compared to non-synaesthetes.

Expecting to replicate the results in Ghloum et al. (2013), we predicted that synaesthetes would be more accurate at processing inverted faces, with no differences for upright faces. For upright faces, we predicted that differences might be apparent at different spatial frequencies. Specifically, we predicted that synaesthetes would perform worse for faces filtered at low spatial frequencies, and equal or better for faces filtered at high spatial frequencies.

The increased accuracy for inverted faces has been related to evidence that synaesthetes may undergo less-than-typical postnatal pruning. Synaesthetes have an abundance of connections within and between sensory areas of the brain that are not seen in typical adults. Evidence for this excess connectivity is not only observed structurally, but also functionally (reviewed in Maurer et al., 2012). This excess connectivity has been attributed to less-than-typical amounts of postnatal pruning and used to explain synaesthete's unusually good ability to discriminate items from non-native categories, such as foreign speech sounds and inverted faces (Maurer et al., in prep).

As predicted, synaesthetes were more accurate than controls in discriminating among full spectrum inverted faces, with no differences in accuracy for discriminating among upright faces. These results replicate my previous study (Ghloum et al., 2013) with a longer stimulus presentation time (2000ms, rather than 1000ms), and a sample limited to Caucasian participants to eliminate any potential other-race effects. These results, along with evidence of superior discrimination of non-native speech sounds (Maurer et al., in prep), support the hypothesis that synaesthetes undergo less perceptual attunement than typical children. It is consistent with the evidence summarized in the introduction on the hyperconnectivity in the brains of adult synaesthetes.

Interestingly, synaesthetes also made judgements significantly faster for both upright and full-spectrum inverted faces, as was true for the filtered faces. One interpretation, as suggested by Ghloum et al. (2013), is that synaesthetes may process faces more efficiently. Prior research has shown how different types of face information is preserved or lost during face inversion. While processing of configural information within the eye region is preserved during inversion, processing of information within the lower region of the face is disrupted by inversion (Tanaka et al., 2009). However, if participants are cued to the lower region of the face, the size of the inversion effect is reduced (Sekunova & Barton, 2008). While the lack of difference in accuracy for upright faces makes it unlikely that synaesthetes are inherently focusing on the lower regions of the face, it is possible that synaesthetes scan faces more efficiently, either by obtaining the relevant information needed to make judgements faster, or by using strategies that are more efficient. This would allow them to have faster reaction times under all conditions.

Consider the perceptual field hypothesis. When a face is upright, the necessary information needed for configural processing is contained within the observer's perceptual field. When a face is inverted, there is evidence that the perceptual field decreases in size, shifting the participant's strategy from a global to more local-based processes (Rossion 2008; 2009; 2013; Xu & Tanaka, 2013). Synaesthetes may have a larger perceptual field during inversion. A larger perceptual field could serve to increase attention to lower regions of the face, explaining the greater accuracy and faster reaction times for inverted faces. Future research using an eye-tracking paradigm could be used to determine if synaesthetes are scanning faces differently, and if differences in visual attention are driving the faster reaction times and improved accuracy for inverted faces.

We also predicted that synaesthetes might differ from non-synaesthetes in the effects of spatial frequency filtering on their face processing because of reported differences in their magnocellular and parvocellular pathways. Synaesthetes show an increase in response to stimuli that promote the use of parvocellular pathways, which play a critical role in colour perception, while showing a decrease in response to stimuli that promote the use of magnocellular pathways, which play a critical role in motion perception (Barnett et al., 2008). Additional evidence to support differences in the pathways of synaesthetes comes from an MRI study that found an increase in gray matter volume in the left posterior Fusiform Gyrus, and a decrease in gray matter volume in the left MT/V5 (Banissy et al., 2012) in synaesthetes compared to non-synaesthetes. The fusiform gyrus is one of the largest structures in the ventral temporal cortex (Weiner & Zilles, 2016), and a major recipient of parvocellular inputs. Conversely, area MT/V5 is a major recipient of magnocellular inputs, and plays an important role in motion perception (Banissy et al., 2012). Given the observed structural differences in these areas in synaesthetes, it is not surprising that a follow up study found synaesthetes performed better than controls in a colour perception task, and worst in a motion perception task (Banissy et al., 2013). To test for differences in synaesthetes, we used stimuli that bias perception toward to the use of the magnocellular and parvocellular pathways by filtering faces at low and high spatial frequencies. Faces filtered at low spatial frequencies promote the use of the magnocellular pathway, and faces filtered at high spatial frequencies promote the use of the parvocellular pathways.

Contrary to our predictions, there was no difference between groups in the effect of spatial frequency filtering. As expected, both groups were more accurate for upright than inverted faces. Both groups were also more accurate for high pass than low pass faces, consistent with the literature (Boutet et al., 2003; Goffaux et al., 2005). However, the two groups did not differ under any of these conditions.

The failure to find a difference between groups may have been related to our stimuli. Face stimuli were filtered using 2.5 octave low- and high-pass filters, with a center frequency of 6 and 48 cycles/fw, respectively. The filters may have been too broad to differentially bias processing toward the magnocellular and pavrocellular pathways, especially since both high and low pass faces contained portions of the middle spatial frequency band most useful for face identification (reviewed in Collin et al., 2014). A better approach to studying spatial frequency would have been to use a narrow-band noise-masking paradigm.

Filtering removes select spatial frequencies from a face, reducing the generalizability of the results to real-world examples. In contrast, noise-masking disrupts the processing of select spatial frequencies without removing any face information. This is achieved by imposing filtered Gaussian white noise on the image as opposed to filtering the face image. Using this technique, the contrast of each image can be manipulated and tested to obtain thresholds across different spatial frequencies. The contrast threshold values can then be used in combination with an ideal observer analysis to obtain efficiency (ratio of ideal to human performance), providing a more complete picture of properties of human information processing. For example, a noise-masking paradigm used in combination with an ideal observer analysis found that while more information is available at low spatial frequencies, human observers use the middle band of spatial frequencies most optimally for face identification (Näsänen, 1999). Future studies using a noise-masking paradigm with an ideal observer analysis should be conducted on synaesthetes to determine if the lack of differences observed here was caused by the filtering technique or by a lack of perceptual difference.

Another possibility is that there is no difference in processing faces filtered at different spatial frequencies between synaesthetes and non-synaesthetes. Only a handful of studies have found evidence to suggest that the magnocellular and pavrocellular systems in synaesthetes might differ from those of controls, and none of these studies has been replicated in an independent lab. For example, Banissy et al. (2013) used random-dot kinematograms to obtain motion-coherence thresholds in synaesthetes and non-synaesthetes. A higher threshold indicates that more dots are needed to determine the direction of motion. Synaesthetes were found to have a reduced motion-coherence threshold compared to non-synaesthetes. While this supports the idea that synaesthesia may be associated with a reduction in motion-coherence perception, and possibly a difference in the magnocellular pathways, caution with this interpretation of the results is needed since only one motion speed was examined. Building off Banissy et al. (2013), we tested a larger group of synaesthetes using a more extensive set of stimuli (three different motion speeds), and found that synaesthetes did not show any differences in motion perception compared to non-synaesthetes (Ghloum & Maurer, in prep). If there are differences between the magnocellular and pavrocellular pathways in synaesthetes, further evidence is needed to support this hypothesis.

Conclusion

In conclusion, we replicated the finding that synaesthetes are better than controls at processing inverted faces and found that synaesthetes are faster at making judgements of both upright and inverted faces, with no sacrifice in accuracy even when the faces are filtered to remove low or high spatial frequencies. Recording of eye movements could help to elucidate the basis of this greater efficiency. While we found no difference between groups in the effects of spatial frequency filtering, further investigation using a noise-masking paradigm with an ideal observer analysis is needed before concluding there are no differences between synaesthetes and non-synaesthetes in the range of spatial frequencies used for processing faces.

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APPENDIX A

Synaesthesia Timeline 2013-2014

New Participant –Synaesthete

Day 1 Approx. One Hour or More

Consent form (5 mins)

Visual screening (5-10 mins)

Language, music, handedness, drug usage, and ethnicity questionnaires (10 mins)

Synaesthesia Battery (20 mins or more)

Day 2 Approx. Two Hours

Composite Face Tasks for Human, Chimp, Monkey and Sheep (20 mins)

Feature Spacing Jane set at different Spatial Frequencies (50 mins)

External Contour and Feature Jane set upright and inverted (20 mins)

Feature spacing Human, Chimp, Monkey, and Sheep Jane sets (20 mins)

Day 3 Approx. Two Hours

Ishihara test for colour blindness (5 mins)

Farnsworth-Munsell 100 Hue test (10-15 mins)

Global Motion at 0.5 and 18 degrees per second (30 mins)

Biological Motion (30 mins)

Glass Pattern Recognition (30 mins)

APPENDIX A

New Participant – Non-Synaesthete

Day 1	Approx. One Hour or More
Consent form (5 mins)	
Visual screening (5-10 mins)	
Language, music, handedness, drug usage, and ethnicity questionnaires (10 mins)	
Synaesthesia Battery (20 mins)	
Feature Spacing Jane set at different Spatial Frequencies (50 mins)	

Day 2	Approx. One Hour
Composite Face Tasks for Human, Chimp, Monkey and Sheep (20 mins)	
External Contour and Feature Jane set upright and inverted (20 mins)	
Feature spacing Human, Chimp, Monkey, and Sheep Jane sets (20 mins)	

Day 3	Approx. Two Hours
Ishihara test for colour blindness (5 mins)	
Farnsworth-Munsell 100 Hue test (10-15 mins)	
Global Motion at 0.5 and 18 degrees per second (30 mins)	
Biological Motion (30 mins)	
Glass Pattern Recognition (30 mins)	

APPENDIX A

Timeline for Returning Synaesthete

Day 1	Approx. Two Hours
Consent form (5 mins)	
Visual screening (5-10 mins)	
Language, drug usage, and ethnicity questionnaires (5 mins)	
Composite Face Tasks for Human, Chimp, Monkey and Sheep (20 mins)	
Feature Spacing Jane set at different Spatial Frequencies (50 mins)	
External Contour and Feature Jane set upright and inverted (20 mins)	
Feature spacing Human, Chimp, Monkey, and Sheep Jane sets (20 mins)	

Day 2	Approx. Two Hours
Ishihara test of colour blindness (5 mins)	
Farnsworth-Munsell 100 Hue test (10-15 mins)	
Global Motion at 0.5 and 18 degrees per second (30 mins)	
Biological Motion (30 mins)	
Glass Pattern Recognition (30 mins)	

APPENDIX B

Visual Acuity and Behavioural Vision

Acuity

Each participant stood four meters away from a Lighthouse eye chart. The Lighthouse chart is preferred over the Snellen eye chart as it is equally sensitive to crowding effects at each level of acuity. This is because the lighthouse eye chart contains the same number of letters at each level of acuity whereas the standard Snellen eye chart has a different number of letters at each level of acuity. Beginning with the right eye while covering the left, participants read every letter in each line until unable to continue. Criterion for normal adult acuity is to reach the 20/20 line with no more than two errors (tested twice). Participants who do not meet this criterion were given a -0.5 Dioptre add increasing in half-dioptre steps until the participant reaches criterion. If unable to reach criterion despite a -2.0 D add, participants fail visual screening and are excluded from the analysis.

Test of far-sightedness

Participants stood four meters away from a lighthouse eye chart and were asked to read letters on the 20/20 line using a +3 D add. Far-sightedness is ruled out if acuity worsens with the addition of a +3D lens. Any participant who does not report a worsened acuity in each eye with a +3 D add fails visual screening and is excluded from the analysis.

Randot Test of Stereoacuity

Participants wore polarizing lenses and viewed symbols that ―popped out‖. Each symbol is constructed based on the minimum amount of disparity required to separate and fuse the symbol from the background to perceive a 3D image. Participants held the RANDOT stereotest 40 cm away under adequate lighting. In order to pass (stereoacuity of 25 arc seconds), participants needed to correctly identify the symbol in each rectangle (8/8), the animal in each row (3/3), and the circle in each box (9/10).

Worth 4 Dot test

To test for normal binocular fusion, participants wore special glasses with a red filter over the right eye and a green filter over the left. A flashlight is shown approximately 30 cmaway in a dark room. The flashlight contains four dots of light: one red, two green, and one white/yellow. Participants were instructed to report the number of dots and their respective colours. The white/yellow light is filtered into its green and red components such that each eye sees a different colour of light. If participants has normal binocular fusion, the separated red and green components would fuse into the original white/yellow light and be perceived as four dots. Any response other than four dots indicates abnormal binocular fusion and exclusion from the analysis.

APPENDIX B

VISUAL SCREENING

Name: ____

D.O.B.: ________________ Date of Test: ________________

Name of Study: _________________________________

Screening Results:

Acuity: No Add OD _________ OS _________

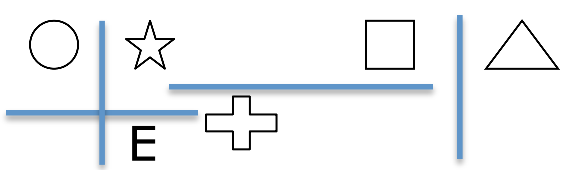
With +3 Add OD _________ OS _________

Worth Four Dot:

Fused (sees 4) ______ Diplopia (sees 5) ______
Suppresses (sees 2 or 3) OD ______ OS ______
Alternator (sees 2,3,2,3…) ______

Randot:

Forms: ___ / 4 and ___ / 4 Animals: ___ / 3



Cat (4th); Rabbit (2nd); Monkey (3rd)

Circles: ___ / 10 (6 yo's and older need 7 correct)

1. L	6. M
2. R	7. L
3. L	8. R
4. M	9. M
5. R	10. R

Suppression Test:

R	R	
+	I	-
L		L

Screening Conclusion: Pass ______ Fail ______

APPENDIX C

Participant ID #:________________
Date:__________________________

Ethnicity Questionnaire

Were you born in Canada? ____

If not, where were you born? ____

What age did you come to Canada? ____

Have you lived elsewhere? Please provide details and ages. (i.e. Born in France, then moved to Sweden at age 2. Lived there until age 4 then moved to Canada).

____

____

____

____

____

What is your ethnicity? ____

APPENDIX D

HAND PREFERENCE QUESTIONNAIRE

Subject ID#:____________________
Date: ______________________ Sex: _________ Age: _________

For each of these activities, please decide which hand you normally use (circle).
In each case, imagine that you actually carry out the activity before answering.

(aL) = always Left (uL) = usually Left (eq) = either hand equally
(uR) = usually Right (aR) = always Right ? = no experience or not sure

	1	2	3	4	5	6
1. Which hand do you use to write?	aL	uL	eq	uR	aR	?
2. Which hand is used to throw a ball?	aL	uL	eq	uR	aR	?
3. Which hand is used to draw?	aL	uL	eq	uR	aR	?
4. Which hand is used to cut with a knife?	aL	uL	eq	uR	aR	?
5. Which hand is used to hold a tennis racquet?	aL	uL	eq	uR	aR	?
6. Hammering a nail, which hand wields the hammer?	aL	uL	eq	uR	aR	?
7. Which hand uses scissors?	aL	uL	eq	uR	aR	?
8. Strike a match – which hand strikes a match?	aL	uL	eq	uR	aR	?
9. Thread a needle (which hand moves)?	aL	uL	eq	uR	aR	?
10. Which hand deals cards?	aL	uL	eq	uR	aR	?

SCORE: /50

To be considered right-handed, subject must have a score of 30 and must be right-handed on writing and drawing.

APPENDIX E

Participant ID #:____________
Date:________________________

Language Questionnaire

Languages Spoken
Were languages other then English spoken around you while you grew up? ___________

If so, which languages were spoken? ____

What percentage of time and at what age were these other languages spoken?

Have you ever lived/vacationed in any country **where you heard a language other than English?** ______________

If yes, where? __________

When? ____

How long? ____

Are you fluent in languages other than English? If so, what are they? ________________

At which age did you acquire those languages? ___________________________

What age did you acquire English? ______________________________________

Other
Any other relevant information (language-related)? ______________________________

Education Questionnaire

Please indicate your highest level of education by checking off all that apply:

- ☐ Working on/ not yet completed high school
- ☐ Completed high school
- ☐ Working on undergraduate degree
- ☐ Completed undergraduate degree
- ☐ Working on graduate/professional degree
  Circle which degree applies (M.A., M.Sc., Ph.D., MD, LLB)
- ☐ Completed graduate/professional degree
  Circle which degree applies (M.A., M.Sc., Ph.D., MD, LLB)

APPENDIX F

Participant ID#: __________

Date: ___________________

Music Questionnaire

Did or does anyone in your immediate family play a musical instrument or sing?

Parents: Yes No Siblings (older/younger?): Yes No Does

anyone in your family have absolute pitch (perfect pitch)? Yes No Have you

received formal instruction for playing an instrument? Yes No

If yes, indicate instrument(s): ____

When did you commence training (age)? __________________________________

How long did you practice and how long was your active participation (listening, theory) in music (hours/day)?

	Practicing	Additional Participation
Under 10 years of age		
Between 10 and 15 years		
Between 16 years and college/university		
In college/university		
Now		

Do you participate in musical groups (choir, orchestra, etc.)? Please specify: __________

Do/did you take part in musical competitions? If so, what were your achievements?

Do you have absolute pitch (AP) (perfect pitch)? Yes No Unsure

Can you name any tone without a reference tone? Yes No Unsure

At what age did you know you had AP? ____

Is your AP dependent on the instrument? Yes No Not Applicable

Do you have good relative pitch? Yes No Unsure

APPENDIX F

Participant ID#: __________

Date: ___________________

Do you have dance experience (lessons, amateur or professional)? Yes No

If yes, please provide the following information for each dance style you are familiar with.

Style of dance	Ages during which you danced this style	Ages during which you took lessons in this style	Hours per week that you dance(d) this style

Please indicate the highest formal music levels (instrumental/vocal performance, dance or theory) that you have achieved (e.g., Royal Conservatory, Theory, Suzuki Books, etc.).

Instrument/Course/Subject	Level

Have you had any formal ear training*? Yes (_____years) No Not sure
*In ear training or "aural skills" lessons, musicians learn to identify musical elements such as intervals, chords and rhythms, simply by hearing them.

Do you play by ear*? Yes No
*Playing or learning to play a piece of music by listening to a musical rendition, without the aid of printed material.

How many hours per week do you spend listening to music? _________ hours/week

Please describe your regular listening habits (e.g., listen to mp3/iPod on the bus, play stereo at home, etc.):

APPENDIX F

Participant ID#: __________

Date: ___________________

Do any of your close friends or family members play a musical instrument (or did so in the past)? If so, please provide the following information:

Their relation to you	Instrument that they play(ed)	How old were you (age range) when you heard them play?	Number of hours per week that you hear/heard them play?

Do you have any hearing problems that you are aware of? If yes, please specify.

APPENDIX G

David Eagleman's Online Synaesthesia Battery - Questionnaires

Pre-test Assessment: David Eagleman Synaesthesia Battery Questionnaire

"About you" Questionnaire:

a) What is your year of birth?
b) What is your gender?
c) I live in the Houston, Texas area and I would like to participate in local studies (option to check box) *[because that is where Eagleman works]*
d) Select your race/ethnicity
e) Select your country
f) What state/province do you live in?
g) What city do you live in?
h) What is your zip code?
i) What type of synaesthesia do you have? (Check all that apply)
    a. Number -colour (seeing, thinking of or hearing a number causes a perception of colour)
    b. Letters -colour (seeing, thinking of or hearing a letter causes a perception of colour)
    c. Months -colour (the concepts of January February, and so on trigger colour)
    d. Chinese numbers -colour (Chinese numbers cause perceptions of synesthetic colours)
    e. Sequences -spatial locations (visualize numbers, letters, or time units like weekdays or months as spread out in 3D space around you)
    f. Musical pitch -colour (individual keys on a piano, or other instrument cause colour perceptions)
    g. Musical chords -colour (different musical chords cause perceptions of different colours)
    h. Musical instruments -colour (different musical instruments cause perception of different colours)
    i. Chinese characters -colour (seeing a Chinese character causes a perception of colour)
    j. Taste -colour (for example, the tast of chocolate, citrus, or banana)
    k. Smell -colour (for example, the odor of steak or fries causes the perception of a colour in you)
    l. Pain -colour (different levels of pain you experiences at different times, say while having a headache, cause you to perceive colour)
    m. Personalities -colour (seeing of thinking of a person makes you perceive a colour)
    n. Touch -colour (when you experience touch sensations of different kinds, on different parts of your body you also perceive colour)
    o. Temperature -colour (like touching cold water or feeling warm water in a shower causes you to perceive different colours)
    p. Czech grapheme -colour (seeing, thinking of or hearing a Czech letter causes a perception of colour)

APPENDIX G

q. Orgasm -colour (you perceive different colours while experiencing a sexual orgasm)
r. Emotion -colour (different emotions like joy, gloom cause perception of colour)
s. Vision -sound (seeing a picture or a scene also causes you to hear a sound)
t. Sound -smell (hearing a sound causes a distinct odor, like the noise of water gushing arouses the smell of a rose)
u. Sound -touch (hearing an airplane fly passed causes a distinct sensation of touch)
v. Sound -taste (hearing a sound causes a sensation of taste, like ticking of a clock causes a sour taste in your mouth)
w. Vision -taste (seeing a picture, oBject or a scene causes the sensation of taste)
x. American Sign Language -colour (American Sign Language causes a perception of colour)
y. British Sign Language -British Sign Language causes a perception of colour)
z. Cyrillic alphaBet -colour
aa. Greek alphaBet -colour
BB. HeBrew alphaBet -colour
cc. Other. Please explain Below.

j) What is your mother tongue/native language?
k) Does anyone else in your family experience synaesthesia?
   a. If you answered 'yes' or 'I'm not sure', please briefly note who is/might be synaesthetic and what kind of synaesthesia they have. (We may follow up with you in person for more detail).
l) Are you left or right handed?
m) Do you have perfect musical pitch?
n) Did you have chronic ear infections as a child?
o) Have you ever experienced a traumatic Blow to the head?
   a. If yes, please explain with respect to your synaesthesia.
p) Do you suffer from migraine headaches?
   a. If yes, please explain with respect to your synaesthesia.
q) Have you ever had an epileptic seizure?
   a. If yes, please explain with respect to your synaesthesia.
r) Do you take or have you taken any antidepressant or antipsychotic medications?
   a. What is the name of the drug that you take or have taken?
s) Do you take or have you taken any medications for ADD (attention deficit disorder), ADHD (attention deficit/hyperactivity disorder) or a related condition?
   a. What is the name of the drug that you take or have taken?
t) Have you noticed a change in your synaesthesia after taking over-the-counter or prescription pain relievers?
   a. What is the name of the drug that you take or have taken?
u) Do you take or have you taken any recreational drugs or suBstances?
   a. What is the name of the drug that you take or have taken?
v) Please comment on any additional drugs that have affected your synaesthesia and please include the name of the drug.

APPENDIX G

w) Have you ever Been professionally diagnosed with autism or Asberger's syndrome?
    a. Optional comments.
x) Have you ever been diagnosed for having a tumor in your brain?
y) Have you been diagnosed with any of the following?:
    a. Dyslexia (difficulty reading)
    b. Dyscalculia (difficulty with numbers)
    c. Dysgraphia (difficulty writing)
        i. Optional comments.
z) Is there anything else you want to tell us about your synaesthesia?
aa) I can't tolerate experiences I dislike (like certain smells, sounds, textures, colours).
    a. True now and when I was young
    b. True only now
    c. True only when I was young
    d. Never true
bb) I don't like to be touched or hugged.
    a. True now and when I was young
    b. True only now
    c. True only when I was young
    d. Never true
cc) If I am in a place with many smells, textures to feel, noises, or bright lights, I can get overwhelmed with sensations and feel panicky, anxious, or frightened.
    a. True now and when I was young
    b. True only now
    c. True only when I was young
    d. Never true
dd) The same sound sometimes seems very loud or very soft, even though I know it has not changed.
    a. True now and when I was young
    b. True only now
    c. True only when I was young
    d. Never true
ee) Sometimes things that should feel painful are not (for instance, when I hurt myself or burn my hand on a stove).
    a. True now and when I was young
    b. True only now
    c. True only when I was young
    d. Never true
ff) Sometimes when I feel overwhelmed by my senses, I have to isolate myself to shut them down.
    a. True now and when I was young
    b. True only now
    c. True only when I was young
    d. Never true
gg) Sometimes I have to cover my ears to block out painful noises (like vacuum cleaners or people talking too much or too loudly).
    a. True now and when I was young
    b. True only now
    c. True only when I was young

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d. Never true

hh) I am more sensitive to smells than anyone I know.
   a. True now and when I was young
   b. True only now
   c. True only when I was young
   d. Never true

ii) Some ordinary textures that do not bother others feel very offensive when they touch my skin.
   a. True now and when I was young
   b. True only now
   c. True only when I was young
   d. Never true

jj) My sensations can suddenly change from very sensitive to very dull.
   a. True now and when I was young
   b. True only now
   c. True only when I was young
   d. Never true

kk) Sometimes the sound of a word or a high-pitched noise can be painful to my ears.
   a. True now and when I was young
   b. True only now
   c. True only when I was young
   d. Never true

ll) Sometimes I talk too loudly or too softly, and I am not aware of it.
   a. True now and when I was young
   b. True only now
   c. True only when I was young
   d. Never true

oo)I don't remember people's faces. I am more likely to remember something about them that others may consider peculiar (like a person's scent).
   a) True now and when I was young
   b) True only now
   c) True only when I was young
   d) Never true

oo)I always notice how food feels in my mouth. This is just as important to me as how it tastes.
   a) True now and when I was young
   b) True only now
   c) True only when I was young
   d) Never true

oo) I am very sensitive to the way my clothes feel when I touch them. How they feel is more important to me than how they look.
   a) True now and when I was young
   b) True only now
   c) True only when I was young
   d) Never true

APPENDIX G

Vividness of Visual Imagery Questionnaire

Rate each item on a scale of 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):

In answering items 1-4, think of some relative or friend whom you frequently see (but who is not with you at present) and consider carefully the picture that comes before your mind's eye.

1) The exact contour of the face, head, shoulders and body.
2) Characteristic poses of head, attitudes of body, etc.
3) The precise carriage, length of step, etc. in walking.
4) The different colours worn in some familiar clothes.

Think of the rising sun. Consider carefully the picture that comes before your mind's eye.

1) The sun is rising above the horizon into a hazy sky.
2) The sky clears and surrounds the sun with blueness.
3) Clouds. A storm blows up, with flashes of lightening.
4) A rainbow appears.

Think of the front of a shop which you often go to. Consider the picture that comes before your eye.

1) The overall appearance of the shop from the opposite side of the road.
2) A window display including colours, shape and details of individual items for sale.
3) You are near the entrance. The colour, shape, and details of the door.
4) You enter the shop and go to the counter. The counter assistant serves you. Money changes hands.

Think of a country scene which involves trees, mountains, and a lake. Consider the picture that comes before your mind's eye.

1) The contours of the landscape.
2) The colour and shape of the trees.
3) The colour and shape of the lake.
4) A strong wind blows on the tree and on the lake causing waves.

Think of being driven in a fast-moving automobile by a relative or friend along a major highway. Consider the picture that comes into your mind's eye.

1) you observe the heavy traffic travelling at maximum speed around your car. The overall appearance of vehicles, their colours, sizes and shapes.
2) Your car accelerates to overtake the traffic directly in front of you. You see an urgent expression on the face of the driver and the people in the other vehicles as you pass.
3) A large truck is flashing its headlights directly behind. Your car quickly moves over to the truck pass. The driver signals with a friendly wave.
4) You see a broken-down vehicle beside the road. Its lights are flashing. The driver is looking concerned and she is using a mobile phone.

Think of a beach by the ocean on a warm summer's day. Consider the picture that comes before your mind's eye.

1) The overall appearance and colour of the water, surf, and sky.
2) Bathers are swimming and splashing about in the water. Some are playing with a brightly coloured beach ball.
3) An ocean liner crosses the horizon. It leaves a trail of smoke in the blue sky.

4) A beautiful air balloon appears with four people aboard. The balloon drifts past you, almost directly ahead. The passengers wave and smile. You wave and smile back at them.

Think of a railway station. Consider the picture that comes before your minds eye.

1) The overall appearance of the station viewed from in front of the main entrance.
2) You walk into the station. The colour, shape and details of the entrance hall.
3) You approach the ticket office, go to a vacant counter and purchase your ticket.
4) You walk to the platform and observe other passengers and the railway lines. A train arrives. You climb aboard.

Finally, think of a garden with lawns, bushes, flowers and shrubs. Consider the picture that comes before your mind's eye.

1) The overall appearance and design of the garden.
2) The colour and shape of the bushes and shrubs.
3) The colour and appearance of the flowers.
4) Some birds fly down onto the lawn and start pecking for food.

Projector Associator Questionnaire

Please indicate to what degree these statements correspond with your synaesthetic experiences (1=strongly disagree, 5=strong agree).

1) when I look at a certain letter or number, I see a particular colour.
2) When I look at a certain letter/number, the accompanying colour appears only in my thoughts and not somewhere outside my head (such as on the paper).
3) When I look at a certain letter/number, the accompanying synaesthetic colour comes in my thoughts but on the paper appears only in the colour in which the letter/number is printed (e.g. a black letter against a white background).
4) It seems that the colour is on the paper where the letter/number is printed.
5) The figure itself has no colour but I am aware that it is associated with a specific colour.
6) The colour is, if it were, projected on the letter/number.
7) I do not see letters/numbers literally in a colour but have a strong feeling that I know what colour belongs to a certain letter/number.
8) The colour is not on the paper but floats in space.
9) The colour has the same shape as the letter/number.
10) I see the colour of a letter/number only in my head.
11) I see the synaesthetic colour very clearly in proximity of the stimulus (e.g. on top of it or behind it or above it).
12) When I look at a certain letter/number, the synaesthetic colour appear somewhere outside my head (such as on the paper).

Synaesthesia Verification Task

In the first part of the battery, each individual is asked to indicate the type(s) of synaesthesia that he/she experiences. In this part, the participant performs a synaesthesia verification task catered to the specific type of synaesthesia that he/she checked off as experiencing. The task consists of the presentation of words describing a comprehensive set of synaesthetic inducers e.g., graphemes for grapheme-colour synaesthesia, numbers for sequence-space synaesthesia,etc.) an d asking the participant to identify the concurrent, or additional percept (e.g., the specific colour induced by a letter, or the exact spatial location induced by a number). Examples of the specific procedure for two common types of synaesthesia are described below.

For letters -colours synaesthesia:
1) Letter-colour matching task: participants are presented each letter in the alphabet multiple times, printed in black, and choose the induced colour from the interactive colour 79alette (16.7 million colours)
2) Speeded Congruency Test: based on colours selected for each letter in the letter-colour matching task, participants are presented for 1 second with letters that are printed in an ink congruent or incongruent with their synaesthetic colour. If the colour is congruent, participants click the "it matched" button on screen; if the colour is incongruent with their synaesthetic percept, they are to click the "it didn't match" button onscreen. Participants will be presented with 72 trials; this task will take approximately 2 minutes to complete. Participants are faster on congruent than incongruent trials.
For sequence -space synaesthesia:
1) Participants are presented with each item in a sequence they have identified as one that induces spatial forms (e.g., months of the year). Participants are instructed to utilize keyboard controls to move each sequence item onscreen until it is in the precise location induced by their spatial form. In an attempt to represent 3-dimensional space, a figure of a person appears in the centre of the screen, such that sequence items can be placed on both the horizontal and vertical planes with respect to the participants' perspective.

APPENDIX H

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A Comparison of Adults with and without Synaesthesia

Thank you for participating in our study comparing adults with and without synaesthesia. Here we explain what is known about synaesthesia and the background to our hypothesis. The last page contains a list of resources for learning more about synaesthesia.

Synaesthesia

Synaesthesia occurs in 5-10% of the adult population and can be manifest in more than 60 forms. It is a neurological phenomenon involving extra perceptions. In most forms, the extra perceptions are in a different sensory modality: for example, in "coloured hearing", stimulation by sound leads to the typical perception of a specific sound but also to an additional perception of a specific colour. The extra perceptions are highly specific, largely idiosyncratic, and consistent over time. For example, among synaesthetes with coloured hearing, E flat played on the piano may induce forest green for one synaesthete and marine blue for another, while D sharp above middle C induces fire engine red for the first and lavender for the second. Individuals often report more than one form of synaesthesia and universally report having had it "all their lives". Behavioral tests indicate that the extra perceptions are automatic and involuntary. They can be experienced as superimposed onto real world stimuli or as unavoidable associations in "the mind's eye". Synaesthetes typically regard their extra percepts as a blessing enriching their lives from which they do not wish to be "cured". In fact, those with synaesthesia score higher than adults without synaesthesia on some tests of memory and of creativity.

Synaesthesia tends to run in families and hence likely has a genetic component. In adults with synaesthesia, there is evidence for increased connectivity between contiguous areas in the sensory parts of the cortex, and in some higher-order areas where information about different properties of stimuli is bound together.

Typical Development

In the typical infant, there is also extensive connectivity between contiguous brain areas that is then sculpted by experience: connections that are used often because they match the infant's environment are consolidated while those that are rarely used are largely pruned away. Any remaining unused connections are inhibited. In the process, sensory cortical areas go from responding to input from seemingly any sense to being areas specialized for processing input from only one sense. This allows efficient and accurate processing, but at a cost of losing some capabilities that don't match our environment, such as discriminating any two faces, even when they don't belong to our own group (our own race or species).

Another consequence of pruning is the development of mechanisms that promote the integration of local features. For example, children demonstrate an improved ability to integrate local cues into a global percept as they develop. For faces, children are more sensitive to features of the face (local cues) rather than the spacing between the features (global cues). As children age and gain more experience with faces, they show an improved ability to integrate local cues.

Our Hypothesis

The current consensus is that, in those with synaesthesia, some of the initial hyperconnectivity remains because there is less pruning during development and, probably, less inhibition of any remaining hyperconnectivity. The purpose of the current study is to test whether, as a result, there is also less specialization of the brain such that adults with synaesthesia will be better than those without synaesthesia at discriminating faces that weren't part of their environment as they grew up (e.g., chimp faces). In addition, we will test whether adults with synaesthesia are biased toward using local stimulus information rather than integrating these local features into a coherent perception.

We are happy to answer any questions you have. You can get in touch by e-mail (ghloumjk@mcmaster.ca or by phone (905-525-9140 x24761).

Thanks again for your help with the study.

Daphne Maurer, Professor
Department of Psychology, Neuroscience & Behaviour
McMaster University

APPENDIX I

Synaesthesia 2014 Testing Protocol Day 1 – (SONA Exp 110)

Before the Participant Arrives

- Arrive 5-10 minutes before the start of the testing session

1) Prepare the testing room
    - Make sure the computer is on (if not wait 20 minutes for it to warm up)
    - Make sure the center of testing table is 100cm away from the center of the computer screen (tape indicates how the table should be positioned)
    - Place a Kleenex box in within reach of the participant's chair
2) Prepare the testing papers
    - Consent form, visual screening, language, music, handedness, ethnicity questionnaire
3) Have a pen (for yourself and the participant) and clipboard ready to write things down

When the Participant Arrives

- Welcome the participant
- Ask them to **leave personal belongings in a distant corner** of the testing room
- Seat them comfortably in front of the testing computer
- Ask them to **turn off/mute their cellphones** and other devices that may distract them
- Ask them if they wear glasses/contacts
- Assign the participant a 4-digit id number, and order for the spatial frequency task – record the numbers on the top right hand corner of the visual screening form
- Refer to subject sheet and **record the participant order/ID**
- Remember that the synaesthete rows are highlighted in grey
- Record the participants age, sex, and **collect a list of medications** currently taking

4) Consent form
    - Briefly explain what synaesthesia is
    - "Do you have Synaesthesia?"
        - "Do you know what synaesthesia is?"
            - *"Synaesthesia is a neurological condition where an individual experiences a specific sensation in response to a specific stimulus. For example … Explain music colour, and grapheme colour. There are more than 60 different types and a lot of individuals who have synaesthesia do not know they have it, so it is possible that you may have it. Which is what we will find out"*

APPENDIX I

- Tell participant that they may have synaesthesia, and we will test them
- **Explain Experimental Procedure** briefly by saying**:**
- *"The study will take place over 3 session, 2 hours each session. The sessions do not have to be done right after each other. You will schedule the 2nd session after this session. You are welcome to take a break between tasks, if needed. We can always offer you some water if you need refreshments. You will complete all tasks today using this computer and a laptop in a quiet testing room. I will give you detailed instructions before each task and instructions will also appear on the computer screen. We ask you to follow these instructions carefully."*
- Go over all sections of the consent form with the participant
- Emphasize the tasks done on each day "today, you will.." and the following sections
  - i) Potential Harms, Risks or Discomforts
  - ii) Potential Benefits
  - iii) Payment and Reimbursement (they can change their mind anytime
  - iv) Confidentiality
  - v) Participation and Withdrawal
- Have participant sign the form

Task 1 - Conduct Visual Screening

Task 2 - Have participant fill out each questionnaire/form

Task 3 – Spatial Frequency Discrimination

Prepare Participant for Testing

- Make sure the testing table is 100cm away from the center of the computer screen (tape indicates how the table should be positioned)
- Make sure participant is seated in the center of the screen, with the chair pulled up as close and comfortable as possible to the table.
- Adjust keyboard position so it is comfortable for the participant
- Turn lights off

Start the experiment

- Input the subjects 4-digit id after the condition number (1-0001, 2-0001 etc)
- Save the file in the proper location (Synaesthesia 2014 -> Day 1 -> Data)
- "There are 10 conditions, all of which are short in length. You will start with Upright or Inverted faces"
- Introduce Jane and her sisters.

- Explain the instructions
    - *"You will be shown three faces, one face at the top and two faces on the bottom. One of the faces on the bottom will match the face on the top. If you think the bottom left face matches the one on the top then you press the* ***left key*** *(show them the left key on the keyboard that is marked with a sticker ("C"). If you think the bottom right face matches the face on the top then you press the* ***right key*** *(shown them the right key on the keyboard that is marked with a sticker"."))."*
    - *"The way the trail will work is that you will see a fixation cross on the screen. This means that the computer is waiting for you to start the trial. When you see the fixation cross, press the spacebar when you are ready. Once pressed, the 3 faces will appear on screen for a short period of time and disappear. Then a question mark will appear. Wait for the question mark to respond. Other things to consider is to keep your hands on the keyboard at all times, only respond once, and try to pay attention to the entire face rather than any individual feature. Any Questions?"*

5) Sit and wait until they complete the practice trial **only for the first condition**
    - After the practice trials, ask if they have any questions
6) Explain that you will not be in the room during the experiment:
    - *"While you are doing a task, I won't be here in the room with you. Once you are done with the entire task you can come see me at [where the experimenter will be]. Also, if you have any technical problems (the computer freezes, the keyboard don't work etc.) let me know.*
    - Leave the Room and change what the fox says

After Each Condition:

- Ask the participant about his/her impression of the testing session.
- Ask Participant to align themselves with the center of the monitor if needed, adjust chair as needed
- Set up the new condition, introduce Jane and her sisters IN EACH NEW CONDITION
- Explain detailed instructions again, STOP AFTER THE SECOND EXPLANATION
- Remind them to:
    - **Keep your hands on the keyboard**
    - **Wait for the question mark to respond and only respond once**
    - **Try and pay attention to the entire face rather than any individual features**

Task 4 – Synaesthesia Battery

APPENDIX I

- Obtain Lab Laptop
  - Turn computer on, make sure to hold the option key to choose which operating system you want
    - We want snow leopard
  - Connect a mouse and an Ethernet cable(if applicable) to the laptop
  - Open Safari and go to www.synesthete.org
  - Click register
  - Email - Subject ID01@maurerlab.ca (e.g. 123401@maurerlab.ca)
  - Password – standard lab password
  - Name(first and last) – subject id
  - Researchers email – maurer@mcmaster.ca
  - *"Once you have a read through the opening paragraph and proceed, it will take you to another page where it will ask you some personal information as well as list all the different types of synaesthesia. Please have a read through the entire list and check off any types that you think you may have. You will be tested for those types. When you are done, please come and get me. Let me know if the Internet is not working. Good Luck."*

After Synaesthesia Battery

- Ask if they have synaesthesia, you can check the result. Just be sure to explain it
- If there is time for another task, please refer to Day 2 and Day 3 testing protocol for available tests.
- If the participant claims to have synaesthesia and indicated so on the battery, but does not have a type that is directly verifiable for the battery, the extra time in the session should be used to conduct an interview.
    - See instructions for conducting an interview with a synaesthete.
- Thank the participant for coming in for the first session
- Compensate them accordingly
- **BOOK THE SECOND SESSION**
  - **Refer to Julian's Schedule for bookings**
- Ask is they have another other Caucasian friends who would be willing to participate or if they know any other synaesthetes
- Thank them again

After Participant leaves:

- Save a backup of the data files onto another device
- Remember to turn off all lights, keep the room clean and make sure the door is locked when you leave.

APPENDIX J

Spatial Frequency
Synaesthesia Study
Order Sheet

(A) Upright conditions: 1-5
(B) Inverted conditions: 6-10

Subject ID	Controls	Subject ID	Synaesthetes
	A-14352; B-798(10)6		A-14352; B-798(10)6
	B-87(10)96; A-24153		B-87(10)96; A-24153
	A-42513; B-(10)7698		A-42513; B-(10)7698
	B-97(190)86; A-14523		B-97(190)86; A-14523
	A-15342; B-9(10)687		A-15342; B-9(10)687
	B-(190)8976; A-25341		B-(190)8976; A-25341
	A-15324; B-79(10)86		A-15324; B-79(10)86
	B-6987(10); A-24531		B-6987(10); A-24531
	A-32154;B-6897(10)		A-32154;B-6897(10)
	B-7968(190); A-13452		B-7968(190); A-13452
	A-25431; B-89(190)76		A-25431; B-89(190)76
	B-9(10)786; A-53214		B-9(10)786; A-53214
	A-24351; B-78(10)69		A-24351; B-78(10)69
	B-6987(10); A-43512		B-6987(10); A-43512
	A-24135; B-6(10)897		A-24135; B-6(10)897
	B-6(10)897; A-23415		B-6(10)897; A-23415
	A-35412; B-(10)7968		A-35412; B-(10)7968
	B-679(10)8; A-34512		B-679(10)8; A-34512
	A-31425; B-8(10)976		A-31425; B-8(10)976
	B-(10)7986; A-45213		B-(10)7986; A-45213
	A-54231; B-879(10)6		A-54231; B-879(10)6
	B-9(10)897; A-24513		B-9(10)897; A-24513
	A-53124; B-976(10)8		A-53124; B-976(10)8
	A-31452; B-69(10)78		A-31452; B-69(10)78

APPENDIX K

McMaster University

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LETTER OF INFORMATION / CONSENT
A Comparison of Adults with and without Synaesthesia

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Purpose of the Study

In synaesthesia a stimulus elicits an extra percept in addition to the typical one. The extra percept can occur in a different sensory modality (e.g., the colour blue is perceived when C sharp is heard) or within the same one (the letter A, printed in black ink, is perceived as the colour red). Synaesthesia appears to arise from greater connectivity and/or reduced inhibition between sensory cortical regions than in the typical adult brain.

In typical development, the brain is initially hyperconnected. With experience, some connections are reinforced and others are eliminated through a process called pruning. The rarely used connections that remain become suppressed by inhibition. A consequence of pruning and inhibition is the specialization of the brain to the environment. For example, children become specialized for processing human faces while they lose sensitivity to non-human (e.g., monkey) faces. Another consequence is that they become better at global integration rather than the earlier concentration on local features.

The purpose of this study is to compare adults with and without synaesthesia on discriminations that become tuned by pruning and inhibition. We predict that adults with synaesthesia may be superior at discriminating unfamiliar categories like chimp, monkey, and sheep faces in addition to faces that are filtered to impair the ability to integrate local information. We will also test whether they are more likely to demonstrate differences in the ability to detect colour, global movements, global form and biological motion.

APPENDIX K

Procedures involved in the Research (see attached flow chart)

The study will take place at the McMaster University Visual Development Lab over 3 days. In total, the testing will take 5-6 hours of your time. The 3 days need not be consecutive and, if you prefer, you may instead come in for 2 longer sessions.

Day 1: Questionnaires, and Screening

You will be asked to bring with you a list of medications that you are currently taking and the dosage. Do not put your name on the list, as we will label it only with your ID number. We ask for the list because some medications can alter brain plasticity and hence the efficacy of training.

We will ask you to fill out questionnaires and take tests that measure background information (language and musical experience, ethnicity) and skills (vision, handedness) that can affect performance on the tasks.

There will be 3 questionnaires:

(1) a Language and Education questionnaire, which requests information about the languages you currently speak and when you first learned them, and how long you have lived in Canada as well as your education background;

(2) a Handedness questionnaire, which asks about which hand you use to perform various tasks;

(3) a Musical Experience questionnaire, which asks about the instruments you play and any music lessons you have had.

(4) an Ethnicity Questionnaire, which asks about your country of origin and when you moved to Canada.

There will be 2 tasks:

(1) a Visual Screening test, in which we will ask you to read an eye chart and to wear 3D goggles in order to point out objects in depth that you will be able to see if you have normal binocular vision.

(2) a Synaesthesia Battery, which asks if you have various forms of synaesthesia and, if so, documents them. It also asks about other conditions that are sometimes reported to co-occur with synaesthesia (synaesthesia in family members; sensitivity to strong stimuli; variation with prescription or recreational drug use) and that may affect the manifestation of synaesthesia (epilepsy, brain trauma, dyslexia, and autism). The battery also includes a test of mental visual imagery and questions about whether your synaesthetic percepts are superimposed on the world or in your head.

Days 2: Face Discrimination Tasks

There will be 4 discrimination tasks:

APPENDIX K

(1) Sensitivity to Human, Chimp, Monkey, and Sheep faces. You will see faces that differ from one another only in the distance between the eyes and/or the eyes and mouth. You will be ask to determine which of the two faces presented at the bottom of the screen match the face presented at the top of the screen for each species.

(2) Spatial Frequency Discrimination, in which you will see human faces that differ from one another only in the distance between the eyes and/or the eyes and mouth. Faces will be filtered at five different spatial frequencies and presented in two orientations (upright and inverted). You will be asked to determine which of the two faces presented at the bottom of the screen match the face presented at the top of the screen at each spatial frequency and orientation. The spatial frequency filtering will make it easier to see detail on some trials and easier to see the global gestalt on other trials.

(3) Composite Face Discrimination. You will see human, chimp, monkey, and sheep faces where one half of the face (top or bottom) is replaced with one half of another face (top or bottom). The top half of each face will be aligned or misaligned with the bottom half. You will be asked to determine if the top half of the face is the same or different from the top half of another face presented on screen simultaneously.

(4) Sensitivity to Features and External Contour. You will see human faces that differ from one another only by the features contained within them (eyes, nose, and mouth) or only by the external shape of the face. Faces will be presented in two orientations (upright and inverted). You will be ask to determine which of the two faces presented at the bottom of the screen matches the face presented at the top of the screen.

Day 3: Motion, Form, and Colour perception

There will be 5 tasks:

(1) Global Motion. You will see multiple black dots on a screen that are moving upward or downward. The dots will move at two different speeds. You will be asked to judge the apparent direction of motion (upward or downward) at each speed. Some dots will move up (or down) but others will move in random directions, making the task more difficult.

(2) Biological Motion. You will see white dots among a black background that move to give the appearance of a person performing a common activity (e.g., walking). Some dots will move randomly making this judgment more difficult. You will view two short 1-second animations and will be asked to determine if a person appeared in the first or second animation.

(3) Glass Pattern Recognition. You will see a grey circle filled with small white dots. The dots may form a pattern (swirl) within the circle or may be random. You will be asked to determine if the circle presented contains a pattern or no pattern.

(4) Test of Colour Perception. You will be given four trays that contain 21-22 removable caps. Each cap within a tray varies by hue in small increments. You will be asked to arrange the caps in order of progression starting from the reference hue on the left to the reference hue on the right for each of the four trays.

(5) a test of Colour Blindness. We will ask you to identify a number in a circle that is hidden among a background made of multiple smaller circles of different colours.

Potential Harms, Risks or Discomforts:
Some of the questions ask about private matters such as your use of drugs, or whether you experiences seizures, dyslexia, autism, etc. Those questions may make you feel uncomfortable. You may also feel uncomfortable about revealing whether or not you experience synaesthesia. You may skip any item you wish during testing or withdraw from (stop taking part in) this study at any time without penalty. We will also keep the information you give us confidential.

Potential Benefits
The research will not benefit you directly. We hope this investigation will lead to a better understanding of the neural mechanisms underlying the neurological condition of synaesthesia and of brain plasticity more generally.

Payment and Reimbursement
You will be reimbursed for your participation with course credit and/or financial compensation at the rate of $11/hour. In the case of course credit, you will be financially reimbursed for any time spent participating that is beyond the course credit allotment. Those in the synaesthesia group who travel from off campus will also be reimbursed for their travel expenses.

Confidentiality
Every effort will be made to protect (guarantee) your confidentiality and privacy. The data we collect from you will be tracked using a number rather than your name. No participants will be identified by name or other identifying information in any publications without their explicit consent.

The data you create as part of the Synaesthesia on-line test may be used by Dr. David Eagleman of the University of Texas, who created the test. He has guaranteed that he will use it only in aggregate form and never use your name or individual data in any report. You will be asked to fill in your participant number, your email address, and my email address (maurer@mcmaster.ca) as part of the test, so that your data are sent back to me, as well. As soon as I receive it, I will create a new file labeled only by your participant number and not name. The key connecting the participant's name and number will be stored separately in an encrypted file and will be destroyed after all the data have been linked, unless you give us permission to keep it (see below).

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Participation and Withdrawal
Your participation in this study is voluntary. If you decide to be part of the study, you can decide to stop (withdraw) at any time, even after signing the consent form or part way through the study. If you decide to withdraw, there will be no consequences to you and you will receive pro-rated compensation.

Information about the Study Results
We expect to have this study completed by approximately August 2014. A summary of the results will posted on the Visual Development Lab website (see letterhead). If you would like to receive the summary personally, please let us know how you would like us to send it to you.

Questions about the Study
If you have questions or need more information about the study itself, please do not hesitate to contact any of the investigators listed above.

This study has been reviewed by the McMaster University Research Ethics Board and received ethics clearance.
If you have concerns or questions about your rights as a participant or about the way the study is conducted, please contact:

McMaster Research Ethics Secretariat
Telephone: (905) 525-9140 ext. 23142
c/o Research Office for Administrative Development and Support
Email: ethicsoffice@mcmaster.ca

APPENDIX K

CONSENT

I have read the information presented in the information letter about a study on synaesthesia being conducted by Daphne Maurer of McMaster University.
I have had the opportunity to ask questions about my involvement in this study and to receive additional details I requested.
I understand that if I agree to participate in this study, I may withdraw from the study at any time. I have been given a copy of this form. I agree to participate in the study.

Signature: ____

Name of Participant (Printed): ____

Date: ____

☐ I wish to receive a summary of the results. Please send it to me as follows:

For adults with synaesthesia only:

I agree to be contacted about possible participation in future studies.

Yes_______
No________

The best way to contact me is:

I agree to allow any future data to be linked to those from this study (optional). I understand that this will require keeping a key linking my ID number to my name.

Yes_________
No__________

Signature: ____

APPENDIX L

Raw Data – Mean Proportion Correct For Synaesthetes and Non-Synaesthetes

	Full Spectrum		Low Pass (6 cycles/fw)		High Pass (48 cycles/fw)	
ID	**Upright**	**Inverted**	**Upright**	**Inverted**	**Upright**	**Inverted**
Non-Synaesthetes						
1021	0.861111111	0.611111111	0.75	0.666666667	0.833333333	0.777777778
1033	0.944444444	0.861111111	0.777777778	0.333333333	0.888888889	0.75
1083	0.722222222	0.527777778	0.555555556	0.527777778	0.5	0.694444444
1092	0.833333333	0.888888889	0.611111111	0.694444444	0.888888889	0.861111111
1094	0.833333333	0.638888889	0.555555556	0.611111111	0.638888889	0.611111111
1105	0.944444444	0.555555556	0.694444444	0.555555556	0.638888889	0.5
1116	0.805555556	0.583333333	0.583333333	0.5	0.666666667	0.472222222
1127	1	0.777777778	0.888888889	0.611111111	0.916666667	0.861111111
8135	0.916666667	0.916666667	0.694444444	0.583333333	0.916666667	0.805555556
1146	0.611111111	0.472222222	0.75	0.5	0.527777778	0.555555556
1157	0.944444444	0.777777778	0.861111111	0.666666667	0.916666667	0.638888889
1168	0.916666667	0.777777778	0.75	0.5	0.861111111	0.583333333
1176	0.916666667	0.527777778	0.583333333	0.638888889	0.805555556	0.555555556
1203	0.916666667	0.722222222	0.5	0.694444444	0.555555556	0.722222222
1227	0.694444444	0.666666667	0.527777778	0.527777778	0.666666667	0.694444444
1225	0.777777778	0.611111111	0.444444444	0.416666667	0.444444444	0.694444444
1190	0.944444444	0.75	0.777777778	0.722222222	0.888888889	0.805555556
1519	0.944444444	0.638888889	0.666666667	0.555555556	0.694444444	0.416666667
1411	0.972222222	0.722222222	0.75	0.777777778	0.888888889	0.638888889
1593	0.694444444	0.666666667	0.694444444	0.5	0.75	0.666666667
Synaesthetes						
1026	0.722222222	0.666666667	0.777777778	0.472222222	0.694444444	0.5
1039	1	0.916666667	0.555555556	0.444444444	0.833333333	0.777777778
8015	0.833333333	0.694444444	0.777777778	0.472222222	0.777777778	0.555555556
1137	0.861111111	0.833333333	0.694444444	0.416666667	0.833333333	0.722222222
1165	0.833333333	0.861111111	0.694444444	0.638888889	0.805555556	0.611111111
1181	0.916666667	0.805555556	0.583333333	0.638888889	0.638888889	0.722222222
7879	0.833333333	0.722222222	0.777777778	0.638888889	0.833333333	0.611111111
1264	0.972222222	0.805555556	0.777777778	0.555555556	0.888888889	0.722222222
1493	0.972222222	0.833333333	0.805555556	0.611111111	0.916666667	0.944444444
9572	0.916666667	0.777777778	0.833333333	0.555555556	0.777777778	0.722222222
3201	0.833333333	0.638888889	0.777777778	0.638888889	0.75	0.611111111
1073	0.805555556	0.722222222	0.5	0.583333333	0.75	0.666666667
967	0.972222222	0.833333333	0.805555556	0.75	0.888888889	0.666666667
1408	0.777777778	0.555555556	0.75	0.638888889	0.833333333	0.861111111
1427	0.972222222	0.777777778	0.805555556	0.694444444	0.861111111	0.805555556
1435	0.944444444	0.722222222	0.805555556	0.444444444	0.888888889	0.777777778
1481	1	0.888888889	0.833333333	0.666666667	0.916666667	0.777777778
1527	0.722222222	0.611111111	0.527777778	0.611111111	0.583333333	0.611111111
9117	0.972222222	0.777777778	0.861111111	0.638888889	0.944444444	0.805555556
1565	0.916666667	0.694444444	0.861111111	0.888888889	0.833333333	0.75

APPENDIX M

Raw Data – Mean Reaction Time for Correct Responses For Synaesthetes and Non-synaesthetes

	Full Spectrum		Low Pass (6 cycles/fw)		High Pass (48 cycles/fw)	
ID	**Upright**	**Inverted**	**Upright**	**Inverted**	**Upright**	**Inverted**
Non-Synaesthetes						
1021	1063.193548	745.9090909	670.9259259	765.6666667	711.2666667	737.2857143
1033	647.7941176	787.8064516	714.75	877.75	667.96875	855.0740741
1083	744.6153846	782.9473684	847.05	847.7368421	884	876.32
1092	654.2666667	562.5	902.4545455	697.64	810.3125	581
1094	1031.3	1669.869565	975.45	1214.590909	891.7391304	1425.818182
1105	861.8529412	745.35	954.2	683.35	829.7826087	739.1111111
1116	722.6206897	838.3809524	627.5238095	642.4444444	646.2916667	681.9411765
1127	749.84	737.25	770.46875	675.1818182	711.4242424	808.2580645
8135	881.4242424	1165.727273	626.2	1026	763.8787879	793.9655172
1146	767.7727273	1223.647059	892.7037037	1141.833333	841.3684211	1249.05
1157	631.3235294	548.25	643.5483871	585.0833333	643.2424242	548.6521739
1168	693.9090909	753.1428571	784.5555556	702.0555556	947.516129	678.2380952
1176	892.0606061	963.4736842	802.8095238	1150.391304	805.862069	1411.8
1203	1231.030303	1082.346154	1192.944444	1337.28	1024.9	1032.192308
1227	855.56	683.4166667	648.5263158	753.3157895	748.6666667	672.28
1225	962.7142857	888.5909091	798.4375	668.3333333	992.8125	948.24
1190	777.5	776.4444444	755.9285714	959.8461538	905.625	1319.724138
1519	642.4411765	642.1304348	528.375	564.85	550.2	570.8
1411	723.0285714	613.3076923	606.5555556	778.6785714	546.9375	681.6086957
1593	1253.2	1526.375	1426	1399.388889	1341.666667	1270.791667
Synaesthetes						
1026	634.1923077	700.0416667	659.25	723	612.4	639.0555556
1039	831	836	838.8	1165.5	903.2333333	1133.607143
8015	811.1666667	527.04	620.8571429	542	664.3571429	632.3
1137	981.2580645	647.7	1092.04	1147.6	853.3	1100.884615
1165	824.8	918.516129	817.92	1030.956522	848.2413793	1068.318182
1181	633.3333333	694.5172414	587.8095238	783.3913043	717.826087	627.9615385
7879	530.9666667	700.4615385	417.5357143	816.3043478	462.6333333	521.7272727
1264	720.9714286	641.4137931	1051.5	629.8	971.59375	657.9230769
1493	568.7714286	555.6333333	583.6896552	650.9090909	636.6666667	567.6764706
9572	599.3333333	1016.357143	764.8	744.85	696.7857143	947.4615385
3201	481.7333333	667.6521739	611.1785714	578.173913	555.7407407	712.5454545
1073	478.5517241	530.6923077	870.0555556	556.8095238	622.3703704	518.1666667
967	557.9428571	803.3	579.3103448	747.0740741	641.625	633.5833333
1408	638.5357143	648.2	677.0740741	626.6086957	602.7333333	670.9032258
1427	585.2	658.5	701.5172414	732.2	585.8064516	654.6206897
1435	819.3235294	543.8076923	675.1034483	582.375	581.90625	572.8214286
1481	481.3611111	468.65625	571	505.2083333	701.9393939	533
1527	537.2692308	637.2272727	606.5263158	636	547.3809524	582.6363636
9117	467.5714286	682.9285714	721.483871	801.5217391	593.9117647	748.137931
1565	785.4545455	755.28	809.4516129	685.03125	877.4	736.7777778

APPENDIX N

Descriptive Statistics and Statistical Analysis for Mean Proportion Correct – Unfiltered Faces

1 – Non-synaesthetes
2 – Synaesthetes

Within-Subjects Factors

Measure: MEASURE_1

Orientation	Dependent Variable
1	Upright_Full
2	Inverted_Full

Between-Subjects Factors

		N
Group	1.00	20
	2.00	20

Descriptive Statistics

	Group	Mean	Std. Deviation	N
Upright_Full	1.00	.8597	.10944	20
	2.00	.8889	.08967	20
	Total	.8743	.09985	40
Inverted_Full	1.00	.6847	.12497	20
	2.00	.7569	.09532	20
	Total	.7208	.11564	40

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Orientation	Sphericity Assumed	.471	1	.471	102.212	.000
	Greenhouse-Geisser	.471	1.000	.471	102.212	.000
	Huynh-Feldt	.471	1.000	.471	102.212	.000
	Lower-bound	.471	1.000	.471	102.212	.000
Orientation * Group	Sphericity Assumed	.009	1	.009	2.011	.164
	Greenhouse-Geisser	.009	1.000	.009	2.011	.164
	Huynh-Feldt	.009	1.000	.009	2.011	.164
	Lower-bound	.009	1.000	.009	2.011	.164
Error(Orientation)	Sphericity Assumed	.175	38	.005		
	Greenhouse-Geisser	.175	38.000	.005		
	Huynh-Feldt	.175	38.000	.005		
	Lower-bound	.175	38.000	.005		

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	50.889	1	50.889	2866.603	.000
Group	.051	1	.051	2.895	.097
Error	.675	38	.018		

APPENDIX N

Descriptive Statistics and Statistical Analysis for Mean Proportion Correct – Unfiltered Faces

1 – Non-synaesthetes
2 – Synaesthetes

Group Statistics

	Group	N	Mean	Std. Deviation	Std. Error Mean
Upright_Full	1.00	20	.8597	.10944	.02447
	2.00	20	.8889	.08967	.02005
Inverted_Full	1.00	20	.6847	.12497	.02794
	2.00	20	.7569	.09532	.02132

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Upright_Full	Equal variances assumed	.651	.425	-.922	38	.362	-.02917	.03164	-.09321	.03488
	Equal variances not assumed			-.922	36.585	.363	-.02917	.03164	-.09330	.03496
Inverted_Full	Equal variances assumed	1.743	.195	-2.055	38	.047	-.07222	.03515	-.14337	-.00107
	Equal variances not assumed			-2.055	35.518	.047	-.07222	.03515	-.14353	-.00091

APPENDIX O

Descriptive Statistics and Statistical Analysis for Mean Reaction Time for Correct Responses – Unfiltered Faces

1 – Non-synaesthetes
2 – Synaesthetes

Within-Subjects Factors

Measure: MEASURE_1

Orientation	Dependent Variable
1	Upright_FullRT
2	Inverted_FullRT

Between-Subjects Factors

		N
Group	1.00	20
	2.00	20

Descriptive Statistics

	Group	Mean	Std. Deviation	N
Upright_FullRT	1.00	839.3725	186.29554	20
	2.00	648.4368	148.64857	20
	Total	743.9047	192.40785	40
Inverted_FullRT	1.00	886.8433	305.10128	20
	2.00	681.6963	135.05807	20
	Total	784.2698	255.00503	40

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Orientation	Sphericity Assumed	32586.805	1	32586.805	1.548	.221
	Greenhouse-Geisser	32586.805	1.000	32586.805	1.548	.221
	Huynh-Feldt	32586.805	1.000	32586.805	1.548	.221
	Lower-bound	32586.805	1.000	32586.805	1.548	.221
Orientation * Group	Sphericity Assumed	1009.810	1	1009.810	.048	.828
	Greenhouse-Geisser	1009.810	1.000	1009.810	.048	.828
	Huynh-Feldt	1009.810	1.000	1009.810	.048	.828
	Lower-bound	1009.810	1.000	1009.810	.048	.828
Error(Orientation)	Sphericity Assumed	800124.612	38	21055.911		
	Greenhouse-Geisser	800124.612	38.000	21055.911		
	Huynh-Feldt	800124.612	38.000	21055.911		
	Lower-bound	800124.612	38.000	21055.911		

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	46706342.9	1	46706342.9	741.264	.000
Group	784407.587	1	784407.587	12.449	.001
Error	2394343.50	38	63009.039		

APPENDIX O

Descriptive Statistics and Statistical Analysis for Mean Reaction Time for Correct Responses – Unfiltered Faces

1 – Non-synaesthetes
2 – Synaesthetes

Group Statistics

	Group	N	Mean	Std. Deviation	Std. Error Mean
Upright_FullRT	1.00	20	839.3725	186.29554	41.65695
	2.00	20	648.4368	148.64857	33.23883
Inverted_FullRT	1.00	20	886.8433	305.10128	68.22272
	2.00	20	681.6963	135.05807	30.19990

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Upright_FullRT	Equal variances assumed	.665	.420	3.583	38	.001	190.93569	53.29279	83.05008	298.82130
	Equal variances not assumed			3.583	36.215	.001	190.93569	53.29279	82.87521	298.99617
Inverted_FullRT	Equal variances assumed	7.961	.008	2.750	38	.009	205.14702	74.60813	54.11075	356.18330
	Equal variances not assumed			2.750	26.171	.011	205.14702	74.60813	51.83653	358.45752

APPENDIX P

Descriptive Statistics and Statistical Analysis for Mean Proportion Correct – Filtered Faces

1 – Non-synaesthetes
2 – Synaesthetes

Within-Subjects Factors

Measure: MEASURE_1

Orientation	Spatial_Frequency	Dependent Variable
1	1	Upright_6
	2	Upright_48
2	1	Inverted_6
	2	Inverted_48

Between-Subjects Factors

		N
Group	1.00	20
	2.00	20

Descriptive Statistics

	Group	Mean	Std. Deviation	N
Upright_6	1.00	.6708	.12134	20
	2.00	.7403	.11158	20
	Total	.7056	.12031	40
Upright_48	1.00	.7444	.15677	20
	2.00	.8125	.09404	20
	Total	.7785	.13217	40
Inverted_6	1.00	.5792	.10900	20
	2.00	.6000	.11414	20
	Total	.5896	.11066	40
Inverted_48	1.00	.6653	.12633	20
	2.00	.7111	.10830	20
	Total	.6882	.11844	40

APPENDIX P

Descriptive Statistics and Statistical Analysis for Mean Proportion Correct – Filtered Faces

1 – Non-synaesthetes

2 – Synaesthetes

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Orientation	Sphericity Assumed	.425	1	.425	34.361	.000
	Greenhouse-Geisser	.425	1.000	.425	34.361	.000
	Huynh-Feldt	.425	1.000	.425	34.361	.000
	Lower-bound	.425	1.000	.425	34.361	.000
Orientation * Group	Sphericity Assumed	.013	1	.013	1.013	.321
	Greenhouse-Geisser	.013	1.000	.013	1.013	.321
	Huynh-Feldt	.013	1.000	.013	1.013	.321
	Lower-bound	.013	1.000	.013	1.013	.321
Error(Orientation)	Sphericity Assumed	.470	38	.012		
	Greenhouse-Geisser	.470	38.000	.012		
	Huynh-Feldt	.470	38.000	.012		
	Lower-bound	.470	38.000	.012		
Spatial_Frequency	Sphericity Assumed	.294	1	.294	31.084	.000
	Greenhouse-Geisser	.294	1.000	.294	31.084	.000
	Huynh-Feldt	.294	1.000	.294	31.084	.000
	Lower-bound	.294	1.000	.294	31.084	.000
Spatial_Frequency * Group	Sphericity Assumed	.001	1	.001	.147	.703
	Greenhouse-Geisser	.001	1.000	.001	.147	.703
	Huynh-Feldt	.001	1.000	.001	.147	.703
	Lower-bound	.001	1.000	.001	.147	.703
Error(Spatial_Frequency)	Sphericity Assumed	.360	38	.009		
	Greenhouse-Geisser	.360	38.000	.009		
	Huynh-Feldt	.360	38.000	.009		
	Lower-bound	.360	38.000	.009		
Orientation * Spatial_Frequency	Sphericity Assumed	.007	1	.007	1.104	.300
	Greenhouse-Geisser	.007	1.000	.007	1.104	.300
	Huynh-Feldt	.007	1.000	.007	1.104	.300
	Lower-bound	.007	1.000	.007	1.104	.300
Orientation * Spatial_Frequency * Group	Sphericity Assumed	.002	1	.002	.291	.593
	Greenhouse-Geisser	.002	1.000	.002	.291	.593
	Huynh-Feldt	.002	1.000	.002	.291	.593
	Lower-bound	.002	1.000	.002	.291	.593
Error (Orientation*Spatial_Frequency)	Sphericity Assumed	.227	38	.006		
	Greenhouse-Geisser	.227	38.000	.006		
	Huynh-Feldt	.227	38.000	.006		
	Lower-bound	.227	38.000	.006		

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	76.276	1	76.276	2651.181	.000
Group	.104	1	.104	3.622	.065
Error	1.093	38	.029		

APPENDIX Q

Descriptive Statistics and Statistical Analysis for Mean Reaction Time for Correct Responses – Filtered Faces

1 – Non-synaesthetes
2 – Synaesthetes

Within-Subjects Factors

Measure: MEASURE_1

Orientation	Spatial_Frequency	Dependent Variable
1	1	Upright_6RT
	2	Upright_48RT
2	1	Inverted_6RT
	2	Inverted_48RT

Between-Subjects Factors

		N
Group	1.00	20
	2.00	20

Descriptive Statistics

	Group	Mean	Std. Deviation	N
Upright_6RT	1.00	808.4704	213.52666	20
	2.00	712.8452	164.71406	20
	Total	760.6578	194.35657	40
Upright_48RT	1.00	813.2731	183.60369	20
	2.00	683.8926	137.20794	20
	Total	748.5828	172.87786	40
Inverted_6RT	1.00	873.5708	254.72985	20
	2.00	734.2657	187.61651	20
	Total	803.9183	231.81099	40
Inverted_48RT	1.00	894.1075	289.96192	20
	2.00	713.0054	193.14977	20
	Total	803.5565	259.89594	40

APPENDIX Q

Descriptive Statistics and Statistical Analysis for Mean Reaction Time for Correct Responses – Filtered Faces

1 – Non-synaesthetes
2 – Synaesthetes

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Orientation	Sphericity Assumed	96499.476	1	96499.476	3.161	.083
	Greenhouse-Geisser	96499.476	1.000	96499.476	3.161	.083
	Huynh-Feldt	96499.476	1.000	96499.476	3.161	.083
	Lower-bound	96499.476	1.000	96499.476	3.161	.083
Orientation * Group	Sphericity Assumed	22753.645	1	22753.645	.745	.393
	Greenhouse-Geisser	22753.645	1.000	22753.645	.745	.393
	Huynh-Feldt	22753.645	1.000	22753.645	.745	.393
	Lower-bound	22753.645	1.000	22753.645	.745	.393
Error(Orientation)	Sphericity Assumed	1160177.48	38	30530.986		
	Greenhouse-Geisser	1160177.48	38.000	30530.986		
	Huynh-Feldt	1160177.48	38.000	30530.986		
	Lower-bound	1160177.48	38.000	30530.986		
Spatial_Frequency	Sphericity Assumed	1546.720	1	1546.720	.176	.677
	Greenhouse-Geisser	1546.720	1.000	1546.720	.176	.677
	Huynh-Feldt	1546.720	1.000	1546.720	.176	.677
	Lower-bound	1546.720	1.000	1546.720	.176	.677
Spatial_Frequency * Group	Sphericity Assumed	14270.357	1	14270.357	1.627	.210
	Greenhouse-Geisser	14270.357	1.000	14270.357	1.627	.210
	Huynh-Feldt	14270.357	1.000	14270.357	1.627	.210
	Lower-bound	14270.357	1.000	14270.357	1.627	.210
Error(Spatial_Frequency)	Sphericity Assumed	333228.300	38	8769.166		
	Greenhouse-Geisser	333228.300	38.000	8769.166		
	Huynh-Feldt	333228.300	38.000	8769.166		
	Lower-bound	333228.300	38.000	8769.166		
Orientation * Spatial_Frequency	Sphericity Assumed	1371.977	1	1371.977	.203	.655
	Greenhouse-Geisser	1371.977	1.000	1371.977	.203	.655
	Huynh-Feldt	1371.977	1.000	1371.977	.203	.655
	Lower-bound	1371.977	1.000	1371.977	.203	.655
Orientation * Spatial_Frequency * Group	Sphericity Assumed	161.672	1	161.672	.024	.878
	Greenhouse-Geisser	161.672	1.000	161.672	.024	.878
	Huynh-Feldt	161.672	1.000	161.672	.024	.878
	Lower-bound	161.672	1.000	161.672	.024	.878
Error (Orientation*Spatial_Frequency)	Sphericity Assumed	256948.809	38	6761.811		
	Greenhouse-Geisser	256948.809	38.000	6761.811		
	Huynh-Feldt	256948.809	38.000	6761.811		
	Lower-bound	256948.809	38.000	6761.811		

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	97139145.7	1	97139145.7	763.046	.000
Group	743688.404	1	743688.404	5.842	.021
Error	4837566.49	38	127304.381		