Mentalizing and Synesthesia: Investigations into the Interactions

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ABSTRACT

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Synesthesia, a cross-modulation of the senses, is a rare condition existing in a small percentage of the population and has recently been discussed as a phenomenon found in a more subtle form in all individuals. In this paper we are the first to test and provide evidence for a possible cross-activating link between synesthesia and mentalizing. We also find evidence for differential patterns of cross-activation of mentalizing and synesthesia between normal individuals and demonstrated synesthetes. However, the evidence for both these claims is weak, warranting further exploration of the relationship of mentalizing in synesthesia. Additional investigations into synesthesia in normal individuals may reveal numerous insights into how senses are integrated.

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STUDY 1

Introduction

The present study examined whether two operations of human cognition are involved in a common underlying process; 1) mentalizing and 2) synesthesia (sensory cross-modulation). Mentalizing, the ability of humans to understand the intentions and mental states of other individuals (sometimes referred to as Theory of Mind), is a complex behavior essential to the proper functioning of human interactions. Synesthesia is a connection of two seemingly unrelated sensory experiences (i.e., sensory cross-modulation) that exist in the human population in two forms. One form is an extreme acute form found in a small subset of the population and the second form is found ubiquitously in the normal population in certain subliminal, non-conscious occasions. The extreme form, which is referred to simply as synesthesia in most literature, is a form that is explicitly a conscious experience, elicited automatically and involuntarily, by a sensory stimuli. For the clarity of this paper, synesthesia in the conscious form will be referred to as extreme synesthesia. In extreme synesthesia, the synesthete (an individual with extreme synesthesia) experiences a shape or color consciously in synchronization with the original sensory stimulus. In contrast, the second form of synesthesia is found in all humans in a strictly non-conscious form, such as the use in metaphors or descriptions involving two senses, such as sharp cheese. This form of synesthesia will be referred to as ubiquitous synesthesia. In the case of ubiquitous synesthesia, the individual never experiences a sharp tactile feeling, but is aware of the "sharpness" of the taste in a more subtle, less explicit form. In order to fully understand the thesis that the two operations of mentalizing and synesthesia may be cross-activated (simultaneously employed), it is first necessary to understand the development, neuroanatomy, evolution, and interactions currently known of mentalizing and synesthesia in humans.

The ability of all humans to mentalize serves a very important function in leading to a better prediction of others' behavior, understanding of others, and even personally feeling emotions when observing others in an emotional state (**1**). Mentalizing is a function that is acquired universally in children and refined into the adult function during development (**2**). Children often indiscriminately mentalize by attributing extra-sensory characteristics to inanimate objects. From ages two to four, expressive mirroring of the physical world in relation to the self, such as "poor tired cup" or "this fog is like whispering" is observed (**2**). By the ages of five or six, this tendency is limited to things that move, and soon after it is only applied to self-initiated movements of living organisms (**3**). During this normal developmental time, it is theorized that an internal image is associated with the semantic meaning of a word, a key element for symbolic communication (**4**). Interestingly, adults maintain the ability to comprehend a phrase such as "poor tired cup", but spontaneous expression of such phrases by adults is notably absent. The present thesis proposes that the indiscriminate mentalizing observed in young children is still present in some mode in adults and is utilized in ubiquitous synesthesia.

Research on primates and humans has led to insights into the neurological substrates for mentalizing. The superior temporal sulcus, premotor cortex, and inferior parietal lobe are activated in primates and humans when observing others (**5**), of which the activation of the superior temporal sulcus is the most robust finding in the literature

(**6**). Broca's area (located in the premotor cortex) also seems to be a key component in language. Its known functions include phonology, semantics, hand actions, ingestive actions, and syntax, endowing it with functions in both the active action and language domains (**7**). Broca's area can be subdivided into two divisions, the pars triangularis and the pars opercularis. These subdivisions are of particular interest to the present study due to their close spatial proximity but differential connectivity. The pars triangularis receives more afferent connections from prefrontal cortex, the superior temporal gyrus, and the superior temporal sulcus than the pars opercularis, which receives more inputs from motor, somatosensory and inferior parietal regions (**8**). The pars triangularis and the pars opercularis also have a high degree of interconnectivity through afferent and efferent pathways (**9**). The pars triangularis, through its own intrinsic activation during mentalizing, as well as its interconnectivity with the superior temporal lobe, is a relevant neuroanatomical correlate for mentalizing . The pars opercularis receives inputs from an area of interest that will be later discussed involving the integration of sensory information, the parietal lobe. The massive interconnection of these regions then makes the integration of mentalizing and sensory inputs neuroanatomically feasible.

It is also well known that the ability to mentalize is well developed in primates, allowing them to form better social groups that are vital to primate survival (**10**). Further, mentalizing is also much more pronounced in humans according to non-linguistic behaviorally matched tests with other primate species, suggesting it may be a recent advance in our evolution (**10**). Broca's area is one of the areas neuroanatomically different between other primates and humans that may be responsible for the difference in mentalizing abilities.

Other researchers have suggested that gestural neurons (located in part in Broca's area) may be involved in the evolution of language though integration and cross-modulation (**11**, **12**). In this paradigm, neurons responsible for executing fire additionally when observing a similar action, providing a neural network of integration. If this theory of language is correct, a major evolutionary step must have been to transfer gestural meaning into a different sensory modality in the form of abstract sound meaning. Under the same paradigm of integration then, gestural neurons may have integrated auditory signals as well, providing the neural substrate for the cross-modulation of the senses (**5**).

Marks (1978) continued a theory first suggested by Geschwind, which proposes that cross-modal fusions allowed for the beginning of open-ended metaphorical language and provided the basics for vocal representation of objects (**13**, **14, 22, 47**). This idea of cross-modulation is implicated in the evolutionary formation of consciousness and languages (**15**). Others have observed cross-modal fusions in apes (but not monkeys) of two different input types, where visual-motor inputs are combined with visual-gestural inputs in the performance of sign language. The large difference between human and ape cross-modal fusions are found in the addition of a third input type, articulated vocalizations. When articulated vocalizations are correlated with visual-motor and visual-gestural linkages, the form of language that humans all currently possess develops (**22, 47**).

A longer growth period to sexual maturity and greater parental attendance has been speculated to allow the compilation of all three of the required inputs for cross-modal fusions (**15, 47**). The extended growth period for brain development could allow for human neural plasticity to include the third factor into the cross-modal fusions. The same cross-modal fusions may be a source for the abstract semantic capacity required for language usage. The outstanding question that still remains in modern humans is how the brain makes the connection among visual, auditory, and kinesthetic senses despite their stark difference in sensory origin.

The present study proposes that transfer of signals from visual/motor to auditory meanings is made possible by cross-modulations that are still evident in humans in the form of ubiquitous synesthesia, which also combines two seemingly unrelated sensory experiences. While most individuals may not initially recognize sensory cross-modulations as an everyday part of their lives, the capacity to perform such unique combinations may be found throughout the human species. For example, forms of ubiquitous synesthesia are often seen in metaphor, exemplified by the phrases “sharp cheese”, “loud colors”, “hot anger”, or “bitter cold”, where one sensory experience is described in terms that refer to a second sense (auditory “loud” and visual “colors”) are integrated into a phrase that most individuals inherently understand at an early age (**22**). Metaphors which do not involve the cross-modulation of two senses, such as “bitter person” or “hot anger” are not understood until years later (**22**).

Neuroanatomically, several studies have shown that damage in the angular gyrus in the parietal lobe impairs an individual’s ability to mediate cross-modal fusions in the areas of verbal naming, gesture, metaphor, mathematics, and attentional binding (**14**, **16**, **17**), all associated with ubiquitous synesthesia. The pars opercularis, mentioned earlier in the discussion of mentalizing, receives many of its afferent projections from this anatomical region.

Examples of extreme synesthesia like those found in synesthetes have also been found in normal adults who report high amounts of the personality traits of imaginative absorption and openness to experience (**18**), creative artists (**19**), meditation (**20**), and psychedelic states (**21**). These alternative forms, referred to as generated synesthesia, suggest synesthesia can be developed as a natural potential of the imagistic side of human cognition.

An extremely interesting example is seen in Kohler's "Bouba" and "Kiki" structures (Figure 1). Ramachandran proposes that the naming of the "Bouba" and "Kiki" structures are also examples of a visual to auditory synesthesia that is present in all normal people and helps in the development of language (**22**). This form of ubiquitous synesthesia could be explained by the integration of the visual to the auditory sensory domains, resulting in the articulation of "hard" or "soft" sounds, an example of cross-modulation.

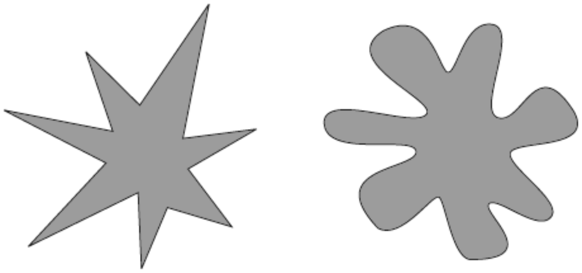

Figure 1. Köhler's Bouba/Kiki Figures.

The figures were matched with their respective names (Bouba or Kiki) by native speakers of English and Tamil with a ninety-five to ninety-eight percent consistency (**23**). Considering the extreme differences of those two respective languages and subsequent trials with similar results on other languages, it is reasonable to claim that there is a connection in the human brain that matches the sounds of Bouba/Kiki with the shape of these figures. The Bouba/Kiki experiment thus suggests that synesthetic pathways exist in everyone, but are not normally activated at a conscious level.

The present study is the first to our knowledge to propose that the functions of mentalizing about inanimate objects and the attribution of extra-sensory information, labeled as ubiquitous synesthesia in this paper, are inherently related through cross-activated neurons.

Our hypothesis predicts that the naming of certain inanimate figures, shown to consistently elicit ubiquitous synesthesia through sensory cross-modulation, will simultaneously increase the likelihood of mentalizing. In order to test the hypothesis, physiological indicators of emotional responses were used to compare the amount of emotional arousal resulting from adverse treatment of the figures before and after the naming task in normal subjects. According to the hypothesis, difference between pre and post tasks would be greater in individuals assigned the naming task while the labeling task would generate no difference in emotional arousal. An increased emotional arousal during adverse treatment of the inanimate object can most likely be understood by an empathetic response towards the figures, generated by mentalizing (**28**).

Methods

Participants

Participants (N= 60, 24 male) were recruited from the online research participant pool in the Department of Psychology at Ohio University. Age (Mean= 19.4, SD= 2.29) and educational range was thus similar to the general OU student population. Participants who indicated in the online questionnaire that they did not have color/word synesthesia were selected to participate.

Equipment

All participants were attached to an EMG machine (MP 100, Biopac, Inc.) via disposable 4mm Ag-AgCl electrodes attached to the skin overlying the corrugator and orbicularis oculi muscles. The electrodes were attached to an MP100 amplifier (Biopac, Inc.). Two recording electrodes and a ground electrode were used for each muscle. Data collection was accomplished with the Biopac Acknowledge software and stored in thumb drives. A built in band pass filter was set at the optimum bandwidth for facial muscles, 25-500-Hz (**63**). Recordings were rectified and digitally smoothed the data by averaging every six data points from a sampling rate of 1000 Hz using Gaussian weighting to further reduce variability. The data was quantified by integrating the rectified and smoothed signal.

Procedure

All subjects provided consent for participation (See Appendix A). Participants filled out a short demographic survey in order to obtain simple demographic information (such as age, gender, academic major, etc.) (See Appendix B). Following EMG hookup, as described above, participants were asked to view figures displayed on a computer screen. First, to acclimate to the setting, participants were asked to sit quietly for 1 minute while viewing a blank white screen. Then the two structures designed by Wolfgang Kohler in the Bouba/Kiki experiment (**29**) were displayed 3 times each for 10 seconds each with an inter-video interval of 30 seconds. During all trials, the figures were manipulated on the screen to make them appear to be impacted by arrows at 2, 4, 6, 8, and 10 seconds (a form of adverse treatment). The order of the figures was randomized for the first trial, and remained the same for all subsequent trials. Following the display, participants were then required either to label or to name the figures (see below). The figures were then displayed again in the exact same order and treatment as the initial presentations. Each 10 second presentation period was subdivided into 2 sec epochs for purposes of analysis. The experiment order and design may be better understood in a diagram (Figure 2). The baseline and rest timing were determined using standardized procedures for facial EMG (**25**).

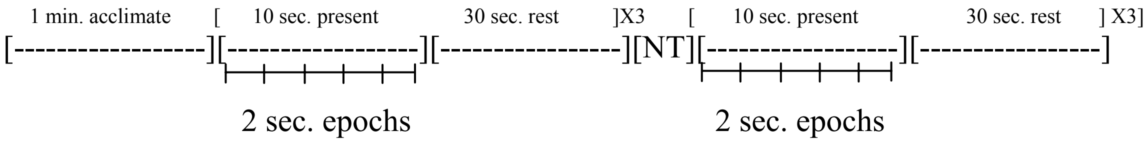

Figure 2. Experimental Procedure: Study 1. NT = naming/labeling task

Electromyography (EMG) recordings were taken from the corrugator and orbicularis oculi muscles which are commonly used psychophysiological assessments correlated with emotional arousal (**24**, **25**, **26**, **27**). Participants were alternately, after each successive subject, placed in two experimental groups by the assignment of the task, either the Naming Task or the Labeling Task. One group was asked during the task to name the figures either “Bouba” or “Kiki” (see Figure 1). The question for the Naming Group was: "If these two characters were letters in a foreign alphabet, which of these characters would be Bouba and which would be Kiki?”. The Labeling Group was asked, “If these two characters were letters in a foreign alphabet, which of these characters would be a vowel and which would be a consonant?” The answers received in both conditions were recorded. The participants’ responses matched the naming trend first observed by Kohler originally found (**29**) with one hundred percent accuracy. The labeling group was a control for the possibility that any cognitive contemplation could employ a mentalizing mechanism.

EMG was recorded during the entire experiment. The recordings during the 10 second presentation were broken down into 2 second epochs for differential statistical analysis. The integrated mean voltage over the two second epochs was recorded.

A percent change was calculated between the 2 seconds immediately before the animation was displayed and each of the 2 second animation epochs, showing the effect of the animation display. As preliminary statistical analyses did not show any significant variation across the 10 second presentation, all 2 second epochs for each presentation were averaged.

Pre-task and post-task data were then separately averaged for the 3 congruent figure repetitions. The resulting values were then expressed as an average percent change from pre-animation for each figure and each muscle per participant. Preliminary analyses showed that there were not differences between the two figure types for either muscle group (corrugator $t(59) = 0.21$, $p = .84$; obicularis $t(59) = 1.90$, $p = .06$), therefore the data from the two figure types were collapsed across muscles.

Results

In Study 1 it was hypothesized that the naming group would have a significantly greater score in the post-task measurements than in the pre-task animations, while in the labeling group, no differences were expected between pre and post task measurements. To evaluate the results, two repeated measures ANOVAs were performed, one for each muscle, to analyze the EMG percent change scores, with main effects defined by time period (pre-task/post-task) and task (naming/labeling). A significant interaction effect was then predicted between time period and task.

For the corrugator muscle, the time period (pre-task/post-task) within subjects main effect was significant ($F_{(1, 58)}= 25.96$, $p<0.001$). Conversely, there was no significance in the group (naming/labeling) between subjects main effect ($F_{(1, 58)}=0.10$, *p*=0.757). In line with the hypothesis, the interaction term of time period X group showed a significant effect (*F*=4.20, *p*=0.045), indicating a greater difference between the groups in the response between the time periods. See Table 1.

Post-hoc t-tests were performed to examine the nature of the interaction. The paired t-tests for differences between time periods was significant for both the naming group (*t*(29) = -4.61, p<0.001) and the labeling group (*t*(29) = -2.41, *p*=0.023). Thus, both naming and labeling groups showed significant EMG changes in the corrugator muscle. In order to test for differences between the groups at each time period, two independent t-tests were performed. The differences between labeling and naming groups were not significant in the pre-task condition (t(58)= -1.15, p=0.257) or the post-task condition (t(58)= 1.28, *p*=0.207). See Figure 3.

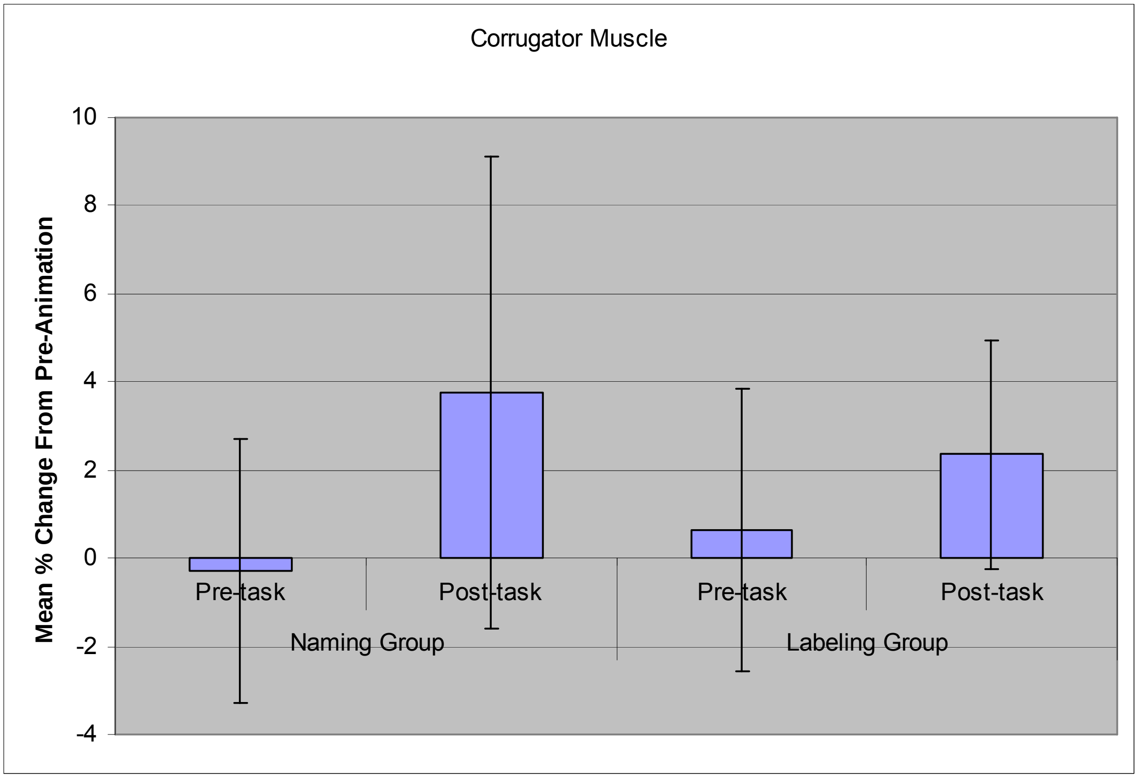

Figure 3. Corrugator pre-task and post-task by group. Error Bars indicate +/- Standard Deviation

For the obicularis oculi muscle, the time period main effect was significant ($F_{(1, 58)}$= 17.15, p<0.001). As in the corrugator, there was no significance in the main effect for group ($F_{(1, 58)}$=0.13 , p=0.909). There was no significant interaction term ($F_{(1, 58)}$=0.01, p=0.921). Therefore, the results demonstrate that both groups showed a greater EMG response in the post-task condition. See Table 1 and Figure 4.

Table 1. Descriptive Statistics for Study 1. % Change from Pre-Animation

% Change from Pre-Animation	Naming Group (N=30)		Labeling Group (N=30)	
	Pre-task Mean (SD)	Post-task Mean (SD)	Pre-task Mean (SD)	Post-task Mean (SD)
Corrugator Muscle	-0.28 (3.00)	3.75 (5.36)	0.64 (3.19)	2.35 (2.60)
Obicularis Muscle	-0.11 (3.47)	1.85 (4.32)	-0.09 (2.21)	1.98 (1.76)

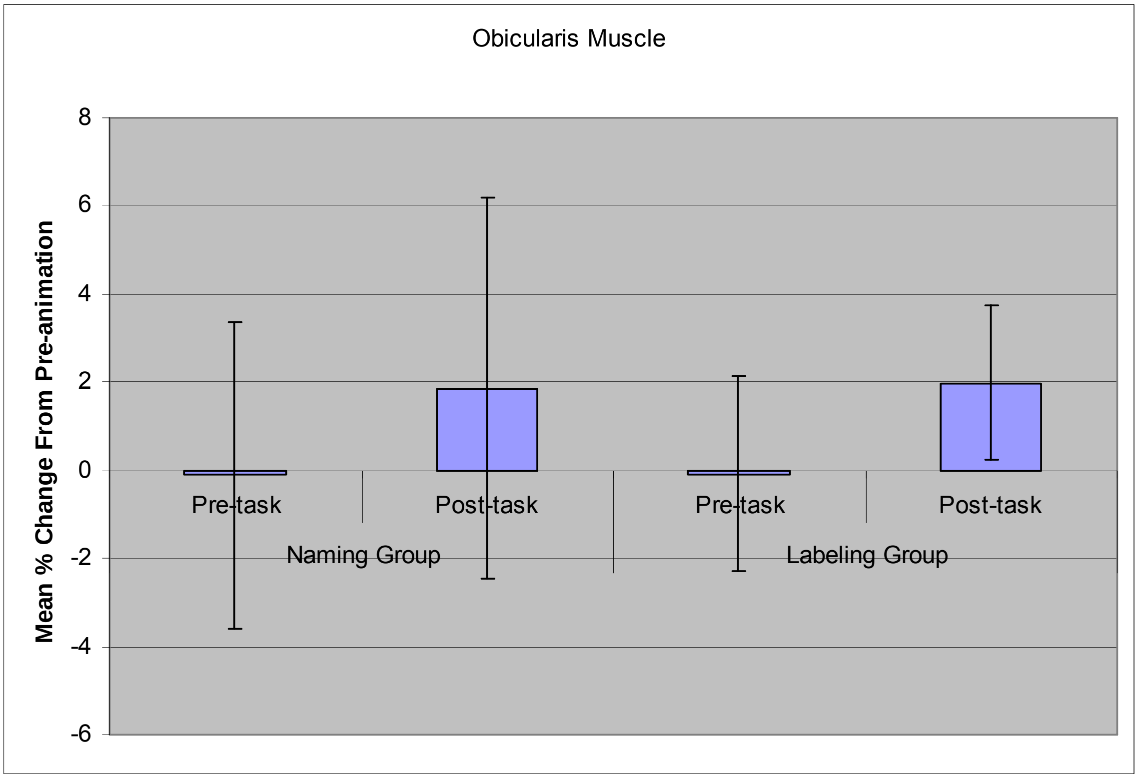

Figure 4. Obicularis Oculi pre-task and post-task by group. Error Bars indicate +/- Standard Deviation

Discussion

In Study 1, a significant interaction effect was hypothesized between time period (pre-task/post-task) and group (naming/labeling) for both corrugator and obicularis oculi muscles. The results revealed a significant interaction effect, but only for the corrugator muscle. Both naming and labeling groups showed the higher muscle activity in the post-task time period than the pre-task period. Contrary to the hypothesis, the labeling group did in fact show an after labeling task increase in EMG. However, consistent with the hypothesis, the naming group showed a significantly larger change post-task than the labeling group. As for the other muscle, obicularis oculi, although the main effect of time period was also demonstrated, interaction effect was not significant.

The significant follow up t-tests for the corrugator muscle imply that both labeling and naming an inanimate shape result in a change in perception that allows an emotional response to the figures, possibly due to mentalization (because inanimate objects are normally not emotional). The interaction result provides corroboration that the naming of these objects enhances the mentalizing effect. Consequently, this experiment provides evidence that the cognitive processes of naming or labeling of inanimate objects cross-activates the processes involved in mentalizing, with the stronger effect produced by naming.

Given that the labeling group also displayed a greater activation of the mentalizing process during the viewing of the animations after the task compared to before the task, it seems that any cognitive contemplation about figure characterization may cross-activate mentalizing. In addition, although there was a larger effect for the condition in which the participants were required to cross-modulate between two senses (the naming group) to complete the task, the simple act of giving a name to an inanimate object may have been the reason the emotional arousal was seen in both tasks. That is, the naming itself, rather than sensory cross-modulation, may explain the present results. Future studies should include other control conditions to further examine these alternative explanations for the findings.

The lack of significance of the interaction term in the obicularis oculi muscle may be due to the lack of specificity of the emotions it is known to be correlated with. Obicularis oculi has been shown to be correlated with overall emotional arousal, contrasting with the corrugator muscle, which is correlated with emotional arousal more strongly in negative emotions (**25**). In addition, the corrugator muscle is considered a better overall indicator of emotional arousal in facial electromyography (**24**). In the context of the experimental paradigm, a greater response by the corrugator muscle was not completely surprising, because the stimuli were designed to elicit negative emotions. Nonetheless, the significant difference between pre and post-task in the combined groups does indicate that it was a responsive measure of emotions.

There were several additional limitations to the study design that may have contributed to the lack of strong support for the hypotheses. First, the animations were very rudimentary and several subjects indicated that the concept of adverse treatment to the figures was not always conveyed. Secondly, the motivations and attention spans of the participants may not have been great enough to produce an effect for the duration of the experiment. Finally, facial electromyography was a very indirect measure of the processes we were looking to investigate. Although EMG responses are highly correlated with emotional arousal, an assumption had to be made in order to connect emotional arousal with mentalizing. Previous research involving peripheral manifestations of arousal indicate a connection between the two in experiments in which humans are mentalizing with other humans (**64**).

Future studies could further validate the present results by using more recent technology, such as functional neuroimaging, to examine if brain areas correlated with mentalizing, such as the superior temporal sulcus, are activated in the same experimental design. Additionally, in replicated studies of this experiment, the video animations could be improved to garner more attention and express adverse treatment more clearly. Furthermore, the discovery that a labeling task generates emotional arousal opens an interesting direction for future research where a series of different tasks, in addition to labeling and naming tasks, could lead to distinctions on which cognitive processes cross-activate mentalizing.

If future studies did find a strong connection between mentalizing and sensory cross-modulations, the results could indicate the ability for complex mentalizing was tied to the evolution of sensory cross-modulations, as suggested earlier. In the evolution of humans, selective pressures could create similar cross-wiring that transcends the individual by creating a species-specific perspective. In this case, a cross-activation between sensory modalities and simultaneous mentalizing could create a common auditory inclination for an outside object with certain visual or tactile properties, allowing the linguistic naming of an object to be intuitive across the species. The result of this process would be a common agreement between individuals on the linguistic representation of objects encountered in a shared environment.

STUDY 2

Introduction

Synesthesia is a cognitive phenomenon broadly defined as sensory cross-modulation. Synesthesia has been more precisely separated into two separate types as research in the field has matured, as discussed in the previous introduction; ubiquitous synesthesia occurring in all individuals, discussed in Study 1, and extreme synesthesia present in a select few individuals, which is the focus of Study 2.

Extreme synesthesia, existing in a minority of individuals, has been neglected as a simple poetic fancy but was suggested to be an atypical perception at least one hundred and twenty years ago (**30**). Due to the uncertainty in investigating a phenomenon that manifests itself in a markedly different perception, synesthesia has not received serious investigation until the last decade. A recent flurry of investigation after the development of validation measures has provided many insights into the nature of synesthesia. During this time, a general definition of synesthesia was developed; an unusual perceptual phenomenon in which incongruous additional sensory experiences are elicited from normal perceptions (**31, 32**) These cross-modulations have been identified in a wide range of domains, including digits eliciting colors, noises eliciting colors, tastes creating tactile sensations, sounds eliciting tactile, and many other variations. The most common form of synesthesia is an association between a visual number/letter and a perceived visual color (**33**). Most of the current research focuses on this specific example, and the below review focuses on letter-color synesthesia.

Several demographic trends indicate correlations between synesthesia and creativity; the proportion of actual synesthetes in visual artists (**19**), musicians (**34**), and those high on measures of imaginative creativity (**35**) is much higher than in the general population. Large-scale demographic studies have confirmed early, small scale observations that synesthetes tend to be female, left-handed, poor at mathematics and direction finding, and prone to "precognitive" experiences such as predictive dreams and déjà vu (**36**). A subsequent large scale study of 192 synesthetes did find a 6:1 ratio of females to males, and a large genetic factor (50% prevalence in relatives of confirmed synesthetes to 0.05% in the general population), and a reportedly poor sense of direction, but no prevalence of left-handedness, and, contrary to earlier findings, an actual strength in mathematics (**33**). Early observations indicated clear familial tendencies in synesthesia (**37**). Occurrence in the general population has been estimated to be between 1 in 200 people (**22**) to 1 in 2000 people (**38**). The large scale study also showed that letter/digit-color synesthesia was by far the most common form (56.3% with the next closest at 1%), and that almost all forms involved colors in some way, as noted above.

Consistent methodology had to be established so that synesthesia could be verified as a valid neurological phenomenon and not a delusionary perception or perhaps related to other mechanisms, such as language. The original test was for a synesthete to designate the specific color they perceived for each letter, and then after a substantial amount of time, a surprise retest would be administered. The consistency with which individuals matched the previous letter with an identical color identified previously was assessed (**39**). It was found that synesthetes would more consistently match the same scheme (around 95% the same) versus controls, who averaged around 35% (**33**). This shows that, although the sensory pairs are idiosyncratic between people, the perception remains highly consistent over time within one synesthete's report. Consistency, subsequently, has been used as a measurement of validity in the majority of studies following synesthesia's discovery.

Another piece of evidence that synesthesia is a valid perceptual phenomenon is Stroop-like interference in specifically designed schemes (**40**). A Stroop test is a paradigm in which the semantic meaning of the word is incongruous with the actual physical color of the word. When asked to report the less salient feature (physical color), it is believed that the more salient feature (semantic meaning) causes interference. In normal individuals, this leads to a slower reaction time and a greater number of mistakes (**41**). In a Stroop test designed for synesthesia, the color a word is printed in is incongruous with the synesthetes' reported color that they associate with that word (**40**). With such a task, synesthetes are significantly slower to name colors incongruent with their synesthetic experience than colors congruent with their experience. Controls show no significant difference between colors. The Stroop interference provides support that synesthesia is an experience that is elicited outside of conscious control, since the perceptions are not able to be suppressed when they are disadvantageous.

The intriguing question of why certain people are synesthetes and others are not is one that has received much speculation, but few testable theories. Most scientists have employed some variation of a developmental theory in combination with genetic predispositions for the development of synesthesia. Some scientists see synesthesia as a residual from a reduced pruning of neurons and neural connections during early childhood development, which coincides with hyper-connectivity theories(**42**). Hyper-connectivity theories of synesthesia propose that the phenomenon is a result of more connectivity between sensation and integration areas of the brain in synesthetes than normal individuals.

Geschwind first put forward a model of cross-modulation capacity in normal human cognitive processing (**45**). This idea led to the suggestion that synesthetes have abnormal connectivity between different (but often adjacent) brain areas utilized in different processing modules (**46**). The areas most implicated in synesthesia based on functional neuroimaging are the visual cortices, specifically the color area V4, and the higher order parietal lobe (**47**).

Other studies have explored whether synesthesia is merely an over-trained association from learning letters and numbers during development. In one study, Baron-Cohen and Day found no correlation between children's book publications or teaching methods and the colors elicited by their synesthetic experiences. Two studies found non-random patterns in the letter-color associations of synesthetes, but not one common to all synesthetes (**43**, **44**). Control groups of non-synesthetes also show significant biases in naming letters with colors. This study was unique in testing non-English speaking participants and using them as an additional comparison, although no significant differences in naming biases were found. The relationship found between the English and German speaking synesthetes was a correlation between the frequency of usage of the letter and the colors; with the more commonly used letters being associated with the more regularly used colors. They also found that letters tend to trigger the perception of the color by association of the first letter in the color and the target letter, also known as initial letter priming (eg. the letter R generates a red photism). When the non-synesthetic population is asked to assign associations, the associations are matched by the same intial letter priming, but through cognitive and not perceptual associations.

Several studies have explored whether synesthesia is due to bottom-up processing or top-down processing. The Stroop findings reported above are an example of evidence of bottom-up processing in synesthesia because the higher order cortices cannot control the phenomenon generated, even when it is disadvantageous. More supporting evidence can be found in a classic test for synesthesia diagnosis. An individual attempts to find black and white target objects (such as a ‘2’) among distracting objects (many ‘5’s) which appear to be visually similar to non-synesthetes. Because of the color attribution, synesthetes will find the target objects much faster than controls, which many synesthetes subjectively attribute to the target popping out at them (**49**). This study implies that conscious perception and number recognition are not necessarily essential for the elicitation of synesthetic experiences, indicating again that synesthesia has a bottom-up component.

While these experiments indicate a bottom-up component to synesthesia, there is also evidence that synesthesia is influenced by top-down processing. Using the figure below (Figure 5), synesthetes indicate the perception of colors matching the “H” and the “A” percepts despite the two figures being physically identical (**22**). Since the “H” and the “A” are identical in their physical state, the semantic meaning of the letter must play a part in the perception of the letters. Since semantic evaluation occurs after basic visual processing, the fact that synesthetes perceive different colors for the identical letters is evidence that the higher order cortices must play some part in synesthesia.

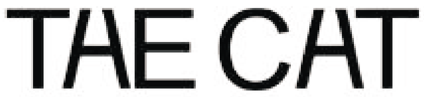

Figure 5. Top-Down Processing: Example 1.

An interesting supplemental question is which attribute of the number elicits the color experience. For example, what part of "threeness" is the activating concept for the synesthetic phenomenon? Because some synesthetes report the same color experience for both the visual and auditory version of a specific number, it is not likely to be the initial sensory cortices that generate this phenomenon. In one case study, a synesthete, when presented with three white buttons, only saw the original white color, until asked how many buttons there are, at which point she immediately perceived the color red, which is her color association for the number three (**50**). Subsequently, the subject reported that she only experienced the color when she identified the number of objects, and the vividness of the color was greater if she actually pronounced the word aloud. A similar phenomenon is observed when Figure 6 is presented to synesthetes.

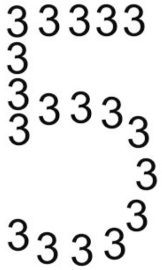

Figure 6. Top-Down Processing: Example 2.

When the synesthete is asked to pay attention to the “3s”, the color associated for three is elicited, but the color for five is elicited when the synesthete is asked to view the “5”, without any crossover of the colors (**51**). These introspective reports are consistent with the theory that synesthesia for digits is related more to the concept of the digit than to the actual seeing or hearing of it. The reports indicate that the synesthetic experience is generated at a higher level of processing, such as number recognition, rather than at the level of basic visual processes.

A competing model, the feedback model, proposes that synesthetic percepts are the result of feedback to earlier stages of visual processing, creating a the synesthetic image (**52**). In support, a PET study of six spoken word-color synesthetes revealed that there was significantly greater (than controls) activation in higher-order visual cortical areas (posterior inferior temporal cortex and the parieto-occipital junctions) contrasted with no significant activity in the lower visual areas (V1,V2, and V4) (**53**). This activity pattern suggests that synesthetic color perceptions result from parietal activation of earlier levels of occipital area processing (**54**). This neurological finding coincides nicely with the priming experiments of Mattingley et al. (**40**), which showed that synesthetic interactions occur after initial processing by lower-order visual cognition areas. Also consistent with these findings is an Event Related Potential (ERP) study measuring ERPs to letter stimuli in letter-color synesthetes, in which a detectable response in average brain activity did not occur until 200 milliseconds after presentation of the stimuli, with greater frontal activation seen in the synesthetes, implying involvement of a top down process (**55**).

Another unusual aspect of synesthesia is the apparent unidirectionality of the phenomenon reported by synesthetes. For example, the number four may always induce the color yellow, but at no point does the subject consciously experience the number four when presented with the color yellow. Conversely, in one experiment synesthetes showed a significant bias for choosing their synesthetic colors (for numbers 1-6) over controls when asked to generate random colors with their eyes closed (**56**). The findings indicate that synesthetic digit–color associations are not exclusively unidirectional. In fact, results of the study indicate an automatic activation of the scale properties of numbers in a random generation sequence. According to scale properties in normal generation tasks, when compared to random generation, humans produce too few repetitions of a particular digit on consecutive trials (e.g., 5 followed by 5), and too much counting in steps of one (e.g., 5 followed by 6, 3 followed by 2). Participants in this experiment were asked to generate random colors instead of numbers. In the case of synesthetes, the colors that corresponded with numbers showed the same scaling bias properties as normal number generation when matched with their numerical counterparts. Controls were not affected by the training they received to associate a specific color with a specific number. The experiment thus provided evidence that, although an explicit perception is not generated, an implicit co-activation of digits by colors can occur at a subconscious level of processing for synesthetes.

In another study, colors were shown to implicitly elicit digits in a modified Stroop experiment (**57**). Participants were told to decide which of the two digits was numerically larger and ignore the color effects, which was intuitive for controls. Synesthetes on the other hand, would have Stroop-like interference if the colors were incongruent with their normal number-color associations. These same authors demonstrated their single synesthete was slower on the incongruent trials, and conversely faster than controls on the congruent trials, proving that some sort of bidirectional interference was occurring since colors also influenced number processing speed. Interestingly, this effect disappeared as the distance between numbers became larger. The experimenters even trained a learning group to associate certain colors with numbers in order to see if synesthesia was stronger than mere conditioning. These conditioned controls did not show the facilitation observed in synesthetes when presented with the same paradigm, but did show the interference effect. This finding seems to provide more evidence for an associative learning effect in synesthesia than for bidirectionality, and is consistent with recent studies that have shown differences in brain activity patterns between similar behaviorally trained control groups and synesthetes (**58**).

There is also an important distinction gaining acceptance between two forms of extreme synesthesia, even within the same sort of stimuli-response set. Scientists have found neurological distinctions between “high” parietal-temporal based and “low” fusiform synesthetes (**59**). The original distinction was described as a behavioral discrepancy between subjects that was labeled as “projectors” and “associators” (**60**). Associators subjectively reported experiences either “in the mind’s eye” while projectors reported photisms (a luminous image) in the actual external space between the subject and the stimuli. The “projectors” were subsequently identified as the “low” fusiform based synesthetes, while the “associator” synesthetes were matched with the “high” parietal-temporal based form. In an attempt to establish an objective distinction between the two, the experimenters utilized another version of a Stroop test, after initially matching the synesthetes’ photism color with a specific letter. The letters were then shown on a video screen with corresponding colors either congruent or incongruent to their photisms and the subjects were asked to name the color on the screen, ignoring their photism. A second trial was administered, in which the synesthetes were asked to name their photism instead of the video color. The relative difficulty of the task was measured in terms of reaction times. The projectors were quicker when naming the video color, while associators were faster naming their own photism. Therefore, the Stroop effect induced by the photisms was greater than Stroop effect of the presented colors in projectors, but the relative strength of the two Stroop effects was reversed in associators. They hypothesized that projected photisms would be harder to ignore for a number of reasons. Stroop tests in normal subjects show that spatial proximity between the incongruous words and color patches are directly correlated with the difficulty of the test as measured by naming speeds (**61**). When applied to the differences between the "projector" and "associator" synesthetes, the prediction would be that "projectors" would have a more difficult time disassociating because of the closer spatial proximity of their photism.

When asked whether the perceptual photism or actual color of a letter was stronger, there was a surprising discrepancy between projectors and associators. Projectors reported that their own synthesized color was stronger, whereas associators reported that the actual color had a greater intensity. The results lead to the conclusion that projector synesthetes more aware of their anomalies, and that their synesthesia is more automatic in nature. The major conclusion that can be drawn from this paper, as indicated in the title, is that all synesthetes are not equal, and that there is a definite distinction between both the behavioral and neurological processes underlying these differences. However, since associator synesthetes are far more common than projector synesthetes, the associator subtype has been more thoroughly investigated.

The purpose of Study 2 was to investigate whether cross-activations, other than the sensory cross-activations that define synesthesia, simultaneously occur in synesthetes. The investigation of the study develops from variation of the developmental hyper-connectivity theory of synesthesia discussed previously in this section. The hypothesis is, like in Study 1, that there is a simultaneous co-activation of mentalizing during sensory cross-modulations normally observed in synesthetes. In individuals who already demonstrate more cross-modulations in the form of extreme synesthesia, an even larger than normal mentalizing response is predicted. Previous studies, in addition to surveys done in our lab, report additional cross-activations in synesthetes in the form of color, sound, or texture associated with emotion, suggesting that numerous forms of cross-activations can occur (**62**, Subject A and T in the present study).

After recruiting four synesthetic individuals (all of the associator subtype), the synesthetes were compared in the same experiment to the normal controls recruited for Study 1. In Study 2, black and white letters that elicit the synesthetes' extra-sensory phenomenon were used in an animation that shot arrows into the letters in the same manner as Study 1's Bouba/Kiki figures. In Study 2, a within subjects control of shapes (a circle, triangle, and square) were displayed between the letters.

As in Study 1, electromyography (EMG) recordings were taken from the corrugator and orbicularis oculi muscles, which are regularly used psychophysiological assessments correlated with emotional arousal. (**24**, **25**, **26**, **27**). In Study 2, it was hypothesized that synesthetes would show increased emotional valence when the letters were adversely treated compared to when the shapes were mistreated. Secondly, the synesthetes were hypothesized to show a stronger reaction to letters than controls, but an equivalent reaction for both groups was hypothesized for the shape animations.

Methods

Participants

Synesthete participants (N=4, 3 male) were selected based on the presence of word-color synesthesia as validated by a repeated survey of their letter associations. Controls for Study 2 were the last 40 participants from Study 1. The two groups were not different in age (Synesthete Mean= 21.25, SD = 0.96; Control Mean = 19.4, SD = 2.70, t= 1.59, p= 0.12).

Equipment

The equipment used for Study 2 was identical to the equipment used for Study 1

Procedure

To confirm the presence of synesthesia, synesthete participants were asked to fill out a questionnaire matching letters to their perceived colors during an initial screening and then again, during a different session before the experiment.

After confirming the presence of synesthesia, examples of stimuli that elicit cross-modal experiences in our synesthetes were displayed. Letters were used as stimuli, because all of our synesthetic subjects experienced a cross-modal phenomenon associated with letters. In each trial, 3 black and white letters were presented interspersed with 3 black and white simple shapes (e.g. triangle, circle, ▲, ●, █, ■). The order of letters and shapes were initially randomized and then the sequence was fixed for all participants. Each letter or shape was presented 1 time for 10 seconds, while waiting 30 seconds between stimuli. The letters/shapes were subjected to the same arrow impacting as in the first part of the experiment. Figure 7 demonstrates the sequence of events. Trials in this second study were identical for controls and synesthetes.

```
1 min. baseline   10 s. present  30 s. rest      10 sec.      30 s. rest       10 s.     30 sec. rest
                      (B)                        (D)                          (circle)
[------------------][----------][----------------][---------][----------------][---------][-------------]
                    (triangle)                   (U)                          (square)
                    [----------][----------------][---------][----------------][---------]
```

Figure 7. Experimental Procedure: Study 2. B, D and U are the stimuli used

The percent change score was calculated in the exact manner as in Study 1. Each of the 2 second epochs were then averaged separately for either the 3 shapes or the 3 letters. Thus, for each participant an average shape and letter percent change for each muscle was obtained.

Results

In Study 2 it was hypothesized that the synesthetes would have a significantly greater EMG response for the letters than the shapes. For the controls, no difference between letter and shape measurements was predicted. To test this hypothesis, two repeated measures ANOVAs, one for each muscle, with main effects defined by stimuli (letter/shape) and group (synesthetes/controls) were used to analyze the EMG percent change scores. A significant interaction effect was then predicted between stimuli and group.

For the corrugator muscle, the stimuli (letter/shape) within subjects main effect was not significant but did show a trend ($F_{(1, 42)}= 3.67$, $p=0.062$). In addition, there was no significance in the group (synesthetes/controls) main effect ($F_{(1, 42)}=0.36$, $p=0.566$). The interaction between stimuli and group was also non-significant ($F=0.19$, $p=0.67$). Follow up t-tests were not performed due to the lack of any significant effects. See Table 2.

For the obicularis oculi muscle, the stimuli main effect was significant (($F_{(1, 42)}=$ 5.00, $p=0.031$). As in the corrugator, there was no significance in the main effect for group ($F_{(1, 42)}= 2.64$, $p=0.112$). The interaction term was also not significant ($F_{(1,}$

$_{42)}$=1.99, *p*=0.166). Follow up t-tests were performed for exploratory purposes, but are mentioned only in discussion speculation. See Figure 8.

Table 2. Descriptive Statistics for Study 2. % Change from Pre-Animation

% Change from Pre-Animation	Synesthetes (N= 4)		Controls (N=40)	
	Letters	Shapes	Letters	Shapes
Corrugator Muscle	2.34 (3.50)	0.67 (3.71)	1.15 (3.43)	0.10 (2.92)
Obicularis Muscle	2.24 (2.66)	0.21 (1.57)	0.18 (1.82)	-0.28 (1.79)

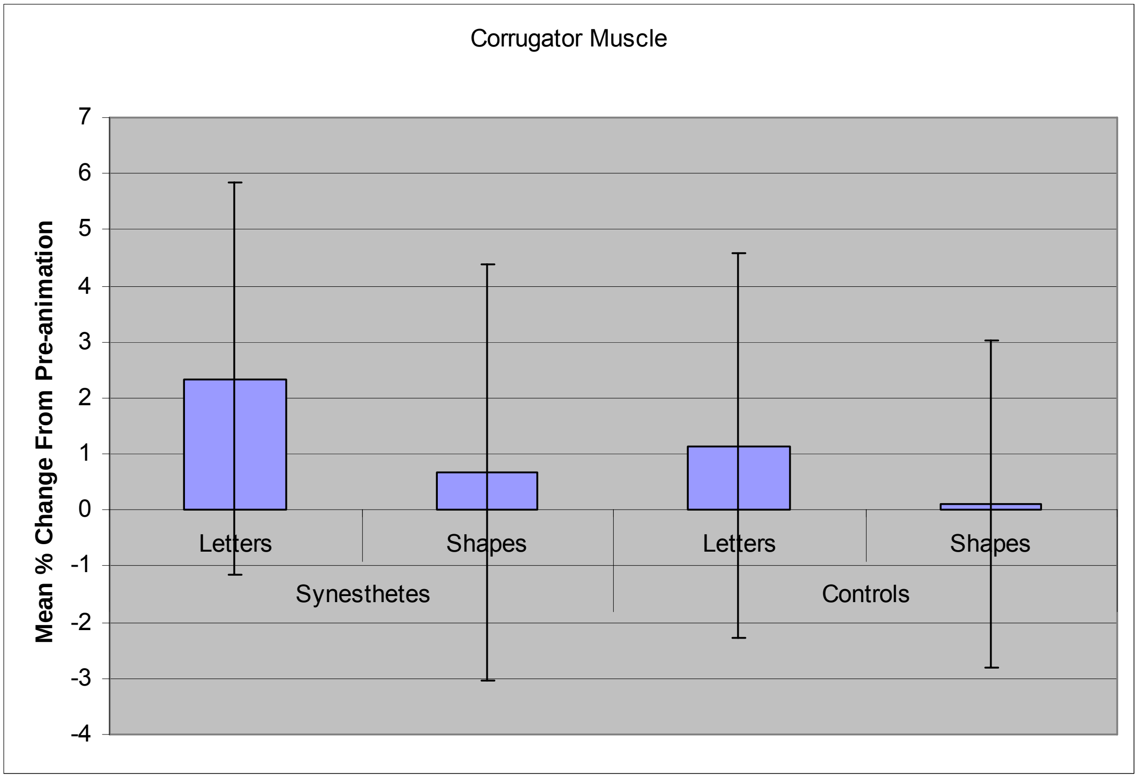

Figure 8. Obicularis Oculi Letters and Shapes by group. Error Bars indicate +/- Standard Deviation

Discussion

We hypothesized a significant interaction effect for both muscle groups between the main effects of stimuli (letter/shape) and group (synesthetes/controls). Investigation of the interactions was expected to find that the synesthetes would have a significantly greater EMG response for the letters than the shapes, while no effect was expected in controls. In addition, synesthetes would show a significantly greater response for letters than the controls. Overall, these hypotheses were not supported by the present data.

Results for the corrugator muscle, which should be more greatly activated in negative stimuli paradigms (**25**), were not significant. In addition, the response in the obiularis oculi produced no significant results. However, for the obicularis oculi muscle, the p values suggested a trend towards significance and the sample sizes were small. For exploratory reasons, outside of generating broad conclusions on the hypothesis, we examined the power of the analyses conducted. For the obicularis oculi ANOVA, the group effect, the partial eta squared was ($\eta_p^2 = 0.059$) and power was ($1 - \beta = 0.355$). For the interaction effect, the partial eta squared ($\eta_p^2 = 0.045$) and power ($1 - \beta = 0.28$). Both of these terms are much lower than the suggested power values for a study (usually adequate power is $1 - \beta = 0.80$). Additional post-hoc t-tests were performed, despite the lack of significant ANOVA effects, which found that synesthetes were more responsive for letters compared to controls ($t(42) = 2.07$, $p = .044$) or shapes ($t(3) = 3.19$, ($p = 0.050$).

The exploratory analyses suggested that the present study was underpowered, which may be related to the small sample sizes, or it may also indicate that the effect is extremely small. In the case of the present study, both interpretations are feasible. The effect of emotional arousal detected through facial muscles is expected to be subtle, and thus could be the cause of lack of power. However, the synesthete group was analyzed with very few data points (N=4). Although this data was not strong enough to draw any conclusions, it is worth noting that the study was underpowered, whatever its causes may be, for the aid of future investigations.

Additionally, in exploratory post-hoc tests, letter stimuli showed a greater response from synesthetes than controls, but the response to shapes was not statistically different. Thus, findings suggest that, consistent with the hypothesis, synesthetes were slightly more emotionally responsive to the letter stimuli, which automatically educe sensory cross-modulations in the synesthetes, relative to shapes, which should not cause automatic cross-modulations in synesthetes. Furthermore, in line with predictions, the synesthetes responded more to letter stimuli than did controls, who should not have any automatic cross-modulations to any stimuli. Statistical analyses show that these findings may be representative a real effect that could be significant in a larger sample.

Experimental caveats from Study 1 were again valid in Study 2, as much of the methodology remained the same. The intended adverse treatment of the letters and shapes were likely to be missed by several individuals, as several subjects indicated that this concept was not conveyed to them by the animations. Additionally, Study 2 was run after the completion of Study1, where the motivations and attention spans of the psychology pool students may have waned (if they were present to begin with), causing a smaller effect that did not reflect normal processes. As well, one control subject subjectively reported an emotional response to the randomly selected letters due to their match with her mother's initials. This observation implies that control subjects may have responded emotionally to letters for motives not relevant to this study. Finally, the indirect nature of measuring emotions through the dependant variable of facial electromyography rather than the brain presents an additional level of variation that this study could not account for. A more direct measure of emotions would have aided in the investigation of the thesis.

GENERAL DISCUSSION

Study 1 and Study 2 provide evidence for some general conclusions and directions for future experimentation. Generally, Study 1 results are somewhat consistent with the hypothesis that forced sensory cross-modulation leads to emotional responsivity. However, these results could also be explained by a mentalizing effect generated by the process of simply attributing a proper name to the figures instead of cross-modulations. This explanation could be eliminated by the utilization of more control groups, such as replacing the Bouba/Kiki naming with other names Kohler found associated with the round figure, such as Maluma and Baluba (**23**). In this case, the equally “round” names could serve as a control for effects generated by just naming the figures with out cross-modulation for both figures. When sensory cross-modulation is automatic, as in synesthesia (Study 2), results do not support that the link to cross-activated emotions does exist. However, these results suggest the link may exist if the study was properly powered.

One possible explanation for the inconsistencies in the findings, aside from issues of sample size and other limitations to study design and methodology that have been previously raised, is that the two types of sensory cross-modulations, ubiquitous and synesthetic, are mediated separately in the human brain. Functional neuroimaging studies have shown differential patterns of activation during sensory cross-modulation in normal individuals in the frontal and prefrontal cortex (including Broca’s area) (**65,66**) and the superior temporal sulcus (**67, 68, 69**) not observed in synesthetic neuroimaging studies. Meanwhile, synesthetes show activation not seen in controls in the V4 region of the occipital cortex (**47, 48**). In addition, very recent work in lesion studies, coordinated with functional neuroimaging, has suggested that some of the basis of cross-modulations may not be cortical at all, but instead generated at the thalamic level of sensory integration (**70**)

Future studies of these two types of sensory cross-modulation could use functional neuroimaging in order to compare and contrast the areas activated. If completed, these studies could determine whether or not two distinct types of sensory cross-modulation are present in the human brain. If a neuroanatomical distinction is able to be correlated with the existing functional differences, it would provide an interesting development in the understanding of how sensory information is integrated, as two different modalities could be isolated and investigated separately.

If the hypotheses in Study 1 and Study 2 were validated, it would bridge the gap between normal forms of synesthesia found in all humans and extreme forms of synesthesia found in unique individuals, by presenting a scheme derived from an evolutionary viewpoint of common underlying neurological mechanisms.

Study 1's indication that different cognitive tasks, in addition to sensory cross-modulations, may cross-activate emotional pathways also suggests a large set of experiments for future investigators. There are many tasks that could be used to determine when and how these cross-modulations are activated. In addition to the control condition mentioned above, a useful control would be a group tasked with choosing which of the figures was larger, employing cognitive processing without sensory cross-modulations. Also, an interesting control could utilize positive treatment in contrast to adverse treatment, investigating if different types of emotions are differentially elicited by cross-modulation. Future studies could also use more control groups to create stimuli that cross-modulate without name usage, such as labeling the Bouba/Kiki structures as either ‘soft’ or ‘sharp’ sounding.

Finally, future investigators could validate the conclusions drawn here by performing these tests using more advanced technology, such as functional neuroimaging. The replication of this study in a neuroimaging experiment could not only further support the idea that cross-modulation activates emotional responses to inanimate objects, but also support the dichotomy in emotional arousal seen between control sensory cross-modulation and synesthetic experiences.

REFERENCES

1. Frith U., and Frith C. (1999). “Interacting Minds- A Biological Basis”. *Science* **286 (5445)**: 1692-1695.

2. Werner H. (1961). *Comparitive Psychology of Mental Development,* New York: Science Editions.

3. Piaget J. (1963). *The Child’s Conception of the World,* Littlefield, Adams, and Co.

4. Vygotsky L. (1965). *Thought and Language,* MIT Press.

5. Rizzolatti G., and Craighero L (2004). Mirror Neuron Review. *Annu. Rev. Neuroscience,* 27, 169-92.

6. Frith, U. (2001). “Mind blindness and the brain in autism.” *Neuron* 32, 969–979

7. Bookheimer S. (2002). Functional MRI of language: new approaches to understanding the cortical organization of semantic processing. *Annu. Rev. Neurosci.* 25:151–88.

8. Skipper J., Goldin-Meadow S., Nusbaum H., and Small S. (2007). “Speech-Associated Gestures, Broca's Area, and the Human Mirror System.” *Brain and Language* **101**: 260-277.

9. Greenlee J., Oya H., Kawasaki H., Volkov I., Severson III M., Howard III M., and Brugge J. (2007). "Functional connections within the human inferior frontal gyrus". *The Journal of Comparative Neurology* **503**: 550–559.

10. Barrett L. and Henzi P. (2005). “The social nature of primate cognition”. *Proc Biol Sci*. **272(1575):** 1865–1875.

11. Rizzolatti, G. and Arbib, M. A. (1998). Language within our grasp. *Trends Neurosci.* 21, 188–194.

12. Arbib, M. A. (2005) From monkey-like action recognition to human language: an evolutionary framework for neurolinguistics. *Behav. Brain Sci.* **28**, 105–124; discussion 125–167.

13. Marks L. (1978) *The Unity of Senses.* New York Academic Press.

14. Geschwind, N. (1965). Disconnection syndromes in animals and man. *Brain,* 88, pp. 237–94, 585–644.

15. Hunt H. (1995). *On the Nature of Consciousness: Cognitive, Phenomenological, and Transpersonal Perspectives*. Yale University Press.

16. Rickard, T., Romero, S., Basso, G., Wharton, L., Flitman, S., and Grafman, J. (2000). The calculating brain: An fMRI study. *Neuropsychologia,* 38, pp. 325–35.

17. Sagiv, N. and Robertson, L. (2005). ‘Synesthesia and the binding problem’, in L. Robertson and N. Sagiv, eds., *Synesthesia: Perspectives from Cognitive Neuroscience* (New York: Oxford University Press).

18. Hunt H., Dougan S., Grant K., and House M. (2002). Growth enhancing versus dissociative states of consciousness: A questionnaire study. *Journal of Humanistic Psychology,* 42, 90-106.

19. Domino G. (1989). Synesthesia and creativity in fine arts students: An empirical look. *Creativity Research Journal,* 2, 17-29.

20. Walsh R. (2005). Can synesthesia be cultivated? Possible indications from surveys of mediators. *Journal of Consciousness Studies,* 12(4-5), 5-17.

21. Hunt H. (1985). Cognition and States of Consciousness. *Perceptual and Motor Skills,* 60, 239-280.

22. Ramachandran V. and Hubbard E. (2001b). Synesthesia: A Window Into Perception, Thought, and Language. *Journal of Consciousness Studies,* 8, 3-34.

23. Köhler, W. (1947), *Gestalt Psychology (2nd. Ed.).* New York: Liveright.

24. Fridlund A. and Cacioppo J. (1986). Guidelines for human electromyographic research. *Psychophysiology, 23,* 567-589.

25. Cacioppo J, Tassinary L, and Berntson G (2000). *Handbook of Psychophysiology.* Cambridge University Press

26. Cacioppo J, Petty R, Losch M, and Kim H. (1986) Electromyographic activity over facial muscle regions can differentiate the valence and intensity of affective reactions. *Journal of Personal and Social Psychology,* 62, 110-28.

27. Dimberg U. (1990). Facial electromyography and emotional reactions, *Psychophysiology,* 27, 481-494.

28. Scholl B. and Tremoulet P. (2000). “Perceptual Causality and Animacy” *Trends in Cognitive Sciences* **4 (8)** : 299-309.

29. Köhler, W. (1929). *Gestalt Psychology*. New York: Liveright.

30. Galton, F. (1880). Visualised Numerals. *Nature*, 21, 252-256.

31. Simner J. et al. (2005). Non-Random Associations of Grapehemes to Colours in Synaesthetic and Non-Synaestetic Populations. *Cognitive Neuropsychology*, 22 (8), 1069-1085.

32. Mills C., Boteler E. and Oliver G. (1999). Digit Synesthesia: A Case Study Using A Stroop-Type Test. *Cognitive Neuropsychology,* 16 (2), 181-191.

33. Rich A. N., Bradshaw J. L., and Mattingley J.B. (2005). A systematic, large-scale study of synesthesia: implications for the role of early experience in lexical-colour associations. *Cognition,* 98 (2005), 53-84.

34. Critchley M. (1977). Ecstatic and synaesthetic experiencesduring musical perception. In Critchley M., *Music and the Brain: Studies in the Neurology of Music.* Charles C. Thomas.

35. Rader C. and Tellegen A. (1981). An comparison of synesthetes and non-synesthetes. In Klinger E., *Imagery Vol 2: Concepts, Results, and Applications.* Plenum.

36. Cytowic, R. E. (1997). Synesthesia: Phenomenology and neuropsychology. *Psyche,* 2(10).

37. Galton F. (1883). *Inquires into Human Faculty and its Development.* Macmillan.

38. Baron-Cohen, S., Burt, L., Smith-Laittan, F., Harrison, J., and Bolton, P. (1996). Synesthesia: Prevalence and familiality. *Perception*, 25, 1073-1079.

39. Baron-Cohen, S., Wyke, M., and Binnie, C. (1987). Hearing words and seeing colours: an experimental investigation of a case of synesthesia. *Perception,* 16, 761-767.

40. Mattingley J. et al. (2001). Unconscious priming eliminates automatic binding of colour and alphanumeric form in synesthesia. *Nature*, 410, 580-582.

41. Stroop, John Ridley (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18*, 643-662.

42. Maurer D. (1997). Neonatal synesthesia: Implications for the processing of speech and faces. In Baron-Cohen and Harrison *Synesthesia: Classical and Contemporary Readings.* Blackwell.

43. Day, S. A. (2001). Trends in synesthetically colored graphemes and phonemes. *Iconicity in Language*.

44. Baron-Cohen, S., Harrison, J., Goldstein, L. H., and Wyke, M. (1993). Coloured speech perception: Is synesthesia what happens when modularity breaks down? *Perception*, 22, 419-426.

45. Geschwind N. (1965). Disconnection syndromes in animals and man. *Brain*, 88, 237-294.

46. Ramachandran V. and Hubbard E.(2001a). Psyiological investigations into the neural basis of synesthesia. *Proceedings of the Royal Society of London,* 268, 979-983.

47. Hunt H. (2005). Synesthesia, Metaphor and Consciousness. *Journal of Consciousness Studies,* 12, 26-45.

48. Smilek D., Dixon M., Cudahy C., and Merikle P. (2001) Synaesthetic photisms influence visual perception. *Journal of Cognitive Neuroscience,* 13, 930-936.

49. Laeng B., Svartdal F., and Oelmann H. (2004). Does Color Synesthesia Pose a Paradox for Early-Selection Theories of Attention? *Psychological Science,* 15 (4), 277-281.

50. Mills C., Boteler E. and Oliver G. (1999). Digit Synesthesia: A Case Study Using A Stroop-Type Test. *Cognitive Neuropsychology,* 16 (2), 181-191.

51. Ramachandran, V.S., and Hubbard, E.M. (2001a). 'Psychophysical investigations into the neural basis of synaesthesia', *Proceedings of the Royal Society of London, B.* 268, 979–83.

52. Hubbard E. and Ramachandran V. (2005). Neurocognitive Mechanisms of Synesthesia. *Neuron*, 48 (3), 509-520.

53. Paulesu, E., Harrison, J., Baron-Cohen, S., Watson, J. D. G., Goldstein, L., Heather, J., Frackowiak, R. S. J., and Frith, C. D. (1995). The physiology of coloured hearing: A PET activation study of colour-word synesthesia. *Brain*, 118, 661-676.

54. Grossenbacher P., Lovelace C. (2001). Mechanisms of synesthesia: cognitive and physiological constraints. *TRENDS in Cognitive Sciences,* 5, 36-41.

55. Schiltz K. et al. (1999). Neurophysiological aspects of synesthetic experience. *J. Neuropsychiatry Clin. Neuroscience,* 11, 58-65.

56. Knoch D., Gianotti L., Mohr C., and Brugger P. (2005). Synesthesia: when colors count. *Cognitive Brain Research,* 25, 372-374.

57. Kadosh et al. (2005). When Blue is Larger than Red: Colors Influence Numerical Cognition in Synesthesia. *Journal of Cognitive Neuroscience*, 17 (11), 1766-1773.

58. Elias L., Saucier D., Hardie C., and Sarty G. (2003). Dissociating the semantic and perceptual components of synesthesia: Behavioural and functional neuroanatomical investigations. *Cognitive Brain Research,* 16, 232-237.

59. Ramachandran V., Hubbard E., and Butcher P. (2004). Synesthesia, cross-activation, and the foundations of neuroepistemology.

60. Dixon M., Smilek D., and Merikle P. (2004). Not all synesthetes are created equal: Projector versus associator synesthetes. *Cognitive, Affective, & Behavior Neuroscience,* 4 (3), 335-343.

61. Gatti S. and Egeth H. (1978). Failure of Spacial Selectivity in vision. *Bulletin of the Psychonomic Society,* 11, 181-184.

62. Ward, J. (2004) "Emotionally Mediated Synaesthesia". *Cognitive Neuropsychology*. 21:7,761-772.

63. Cram J. and Kasman G. (1998). *Introduction to Surface Electromyography.* Aspen Publisher Inc.

64. Völlm B., Taylor A., Richardson P., Corcoran R., Stirling J., McKie S., Deakin J., and Elliott R. (2006). Neuronal correlates of theory of mind and empathy: a functional magnetic resonance imaging study in a nonverbal task, *Neuroimage* **29**, 90–98**.**

65. Fuster J., Bodner M. and Kroger J. (2000). Cross-modal and cross-temporal association in neurons of frontal cortex. *Nature* **405**, 347-351.

66. Romanski, L. M. *et al*. Dual streams of auditory afferents target multiple domains in the primate prefrontal cortex. *Nature Neurosci.* **2**, 1131–1136 (1999).

67. Beauchamp M., Lee K., Argall B. and Martin A., Integration of auditory and visual information about objects in superior temporal sulcus, *Neuron* **41** (2004), pp. 809–823.

68. Beauchamp M.S., Yasar N.E., Frye R.E., and Ro T. (2008). Touch, sound and vision in human superior temporal sulcus. *Neuroimage*. **41(3):**1011-20.

69. Campanella S, and Belin P. (2007). Integrating face and voice in person perception. *Trends Cogn Sci.* **11(12):**535-43.

70. Beauchamp M.S., and Ro T. Neural substrates of sound–touch synesthesia after a thalamic lesion. *J Neurosci* 28: 13696–13702, 2008.

APPENDIX A: CONSENT FORMS

Control Consent Form

Ohio University Consent Form

Title of Research:	Assessing for Color/Word Synesthesia
Principal Investigator:	Noah Hagen
Co-Investigator:	Julie Suhr, Ph.D.
Department:	Psychology

Federal and university regulations require signed consent for participation in research involving human subjects. After reading the statements below, please indicate your consent by signing this form.

Explanation of Study

The purpose of this research project is to explore Theory of Mind (the perception of consciousness in others) mechanisms associated with the sensory cross-modulation phenomenon of synesthesia. This exploration will give us insight into how the senses interact with each other in normal individuals and synesthetes, who have an exaggerated form of synesthesia.

If you agree to participate in this research project, your emotion response to different computer generated images of inanimate objects will be measured. The study should take about one hour to complete.

During the task, electrodes will be attached on two of your face muscles using adhesive on the electrodes to record your muscles' electrical activity. This procedure does not involve any discomfort.

Risks and Discomforts

There is a slight chance of irritation with the removal of the adhesive electrodes, although any discomfort will be minimal.

Benefits

The primary benefits of the study are scientific, as studying the phenomenon of synesthesia will hopefully lead to a better understanding of the brain. However, you will be provided with post-study information about synesthesia, including a list of websites with detailed information about the phenomenon.

Confidentiality and Records

All data collected from you will be stored in locked files in the Clinical Neuropsychology Research Laboratory of Dr. Suhr. This consent form will be stored separately from the data collected. All data will be coded by a participant identification number, which will allow us to keep the data confidential, but match the data should you participate in any follow-up studies.

Compensation

You will receive 1 experimental credit for your participation in this study.

Contact Information

If you have any questions regarding this study, please contact Dr. Julie Suhr at 593-1091, suhr@ohio.edu.

If you have any questions regarding your rights as a research participant, please contact

Jo Ellen Sherow, Director of Research Compliance, Ohio University, (740)593-0664.

I certify that I have read and understand this consent form and agree to participate as a subject in the research described. I agree that known risks to me have been explained to my satisfaction and I understand that no compensation is available from Ohio University and its employees for any injury resulting from my participation in this research. I certify that I am 18 years of age or older. My participation in this research is given voluntarily. I understand that I may discontinue participation at any time without penalty or loss of any benefits to which I may otherwise be entitled. I certify that I have been given a copy of this consent form to take with me.

Signature____ Date____________
Printed Name________________________________

Synesthete Consent Form

Ohio University Consent Form

Title of Research: Assessing for Color/Word Synesthesia
Principal Investigator: Noah Hagen
Co-Investigator: Julie Suhr, Ph.D.
Department: Psychology

Federal and university regulations require signed consent for participation in research involving human subjects. After reading the statements below, please indicate your consent by signing this form.

Explanation of Study

The purpose of this research project is to explore Theory of Mind (the perception of consciousness in others) mechanisms associated with the sensory cross-modulation phenomenon of synesthesia. This exploration will give us insight into how the senses interact with each other in normal individuals and synesthetes, who have an exaggerated form of synesthesia.

If you agree to participate in this research project, your emotion response to different computer generated images of inanimate objects will be measured. The study should take about one hour to complete.

During the task, electrodes will be attached on two of your face muscles using adhesive on the electrodes. The electrodes will be used to record your muscles' electrical activity. This procedure does not involve any discomfort.

Risks and Discomforts

There is a slight chance of irritation with the removal of the adhesive electrodes, although any discomfort will be minimal.

Benefits

The primary benefits of the study are scientific, as studying the phenomenon of synesthesia will hopefully lead to a better understanding of the brain. However, you will be provided with post-study information about synesthesia, including a list of websites with detailed information about the phenomenon.

Confidentiality and Records

All data collected from you will be stored in locked files in the Clinical Neuropsychology Research Laboratory of Dr. Suhr. This consent form will be stored separately from the data collected. All data will be coded by a participant identification number, which will allow us to keep the data confidential, but match the data should you participate in any follow-up studies.

Compensation

You will receive 10 dollars for your participation in this study.

Contact Information

If you have any questions regarding this study, please contact Dr. Julie Suhr at 593-1091, suhr@ohio.edu.

If you have any questions regarding your rights as a research participant, please contact Jo Ellen Sherow, Director of Research Compliance, Ohio University, (740)593-0664.

I certify that I have read and understand this consent form and agree to participate as a subject in the research described. I agree that known risks to me have been explained to my satisfaction and I understand that no compensation is available from Ohio University and its employees for any injury resulting from my participation in this research. I certify that I am 18 years of age or older. My participation in this research is given voluntarily. I understand that I may discontinue participation at any time without penalty or loss of any benefits to which I may otherwise be entitled. I certify that I have been given a copy of this consent form to take with me.

Signature________________________ Date___________________
Printed Name___________________

APPENDIX B: DEMOGRAPHIC SURVEY

Demographic Survey

Name: ____

Class Standing: ____

Age: __________________

Sex (circle one): M F

Major: ____

Handedness (circle one): L R both

Best Academic Subject: ____

Worst Academic Subject: ____

Hobbies: ____

____