ASSESSMENT OF TRANSIENT NEGATIVE AFFECT IN SYNESTHESIA

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ABSTRACT

The purpose of this dissertation was to investigate how synesthesia may influence affect and sensorimotor gating in synesthetes. Synesthesia is the phenomenon in which a sensory experience triggers a conscious perception that is in addition to perceptions most people would experience in response to the stimulus. The type of synesthetic experience involving colors for letters and/or numbers is indicative of *grapheme to color synesthesia;* the most frequently reported type of synesthesia. For example, a synesthete may report seeing the color green in response to hearing or seeing a particular number or letter. Anecdotal reports by synesthetes describe negative affect when viewing a number or letter in a color that does not match (i.e., is incongruent) the synesthete's automatic perceptions. In addition, many reports by synesthetes indicate a greater propensity for experiencing "sensory overload" than non-synesthetes.

It was predicted that briefly viewing an incongruent grapheme would produce a transient negative affective state, temporarily increasing the magnitude of startle reflex as measured by eyeblinks among grapheme → color synesthetes. Results did not support an interaction effect involving Presence of Synesthesia and Picture Condition, $F(2, 23) = 1.35$,

$p > .05$. Although magnitude of startle was greater for grapheme → synesthetes than when viewing an incongruent grapheme compared to viewing a congruent grapheme or in the baseline (no picture) condition, these results were not statistically significant.

It was also predicted that, when examining sensorimotor gating in synesthetes and non-synesthetes with prepulse inhibition (PPI) as the index, synesthetes would show less PPI, indicating increased sensory overload susceptibility. This hypothesis was not supported. Although synesthetes did not display reduced PPI, significantly more synesthetes than non-synesthetes reported experiencing sensory overload, and significantly higher levels of sensory sensitivity and sensation avoiding.

The undersigned, appointed by the Dean of the College of Arts and Sciences, have examined a dissertation titled “Assessment of Transient Negative Affect in Synesthesia,” presented by Katherine D. Gimmestad, candidate for the Doctorate of Philosophy degree, and hereby certify that in their opinion it is worthy of acceptance.

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CHAPTER 1

INTRODUCTION

The primary aims of this study were 1) to investigate whether, under certain circumstances, synesthesia may induce transient negative affect in synesthetes, and 2) to examine potential differences in sensorimotor gating (SMG) in people with synesthesia (synesthetes) compared to non-synesthetes.

Synesthesia is the phenomenon in which a sensory experience (inducer) triggers a conscious perception (concurrent) that is in addition to perceptions that most people would experience in response to the inducing stimulus (Grossenbacher & Lovelace, 2001). For example, someone who experiences synesthesia may report seeing the color green (concurrent) in response to hearing or seeing a particular number or letter (inducer).

The type of synesthetic experience involving colors for letters and/or numbers is indicative of what researchers call *grapheme to color synesthesia,* which is the most frequently reported type of synesthesia. In synesthesia literature, it is common to denote a given *form* of synesthesia in the following way: inducer → concurrent. Hence, *grapheme to color synesthesia* would be denoted as grapheme → color synesthesia, which describes letters and/or numbers inducing, in synesthetes, the experience of colors for letters and/or numbers. However, synesthetes have reported myriad forms. Other examples of forms of synesthesia include perceptions of color in response to musical sounds, sensations of shapes in response to taste, and sensations of colors in response to words. Scientists have studied grapheme → color synesthesia much more than other forms, because grapheme → color is one of the most frequently reported type of synesthesia (Robertson & Sagiv, 2005).

Current synesthesia research focuses mainly on examining the perceptual nature of the phenomena that constitute synesthesia, as well as the neural underpinnings of synesthetic experience (Hubbard & Ramachandran, 2005). Although interest in synesthesia research has greatly increased in the past decade, there is a paucity of research on how synesthesia may affect an individual's life beyond the synesthesia itself. That is, how might synesthesia influence everyday aspects of a synesthete's life, such as performance on cognitive tasks, behavioral performance, or even personality?

When asked whether or not synesthetes would prefer to be synesthetic, it is highly unusual for them to say that they would not prefer it. Most synesthetes report enjoyment from their experiences, and relate having a difficult time imagining – and also not wanting to imagine – their lives without synesthesia (CBS News, 2002; National Public Radio, 2000). Synesthesia has also been reported to have practical benefits aside from self-reported enjoyment of synesthetic experiences. Examples of potential benefits include enhanced memory (Luria, 1968; Yaro & Ward, 2007) and superior ability in discrimination of hues (Gimmestad & Lovelace, 2011; Yaro & Ward, 2007). Recent research has postulated that benefits, such as enhanced memory, confer a memory advantage specific to the type of synesthesia (Rothen & Meier, 2009). Further, some researchers have suggested, when examining groups of synesthetes rather than isolated cases, that the potential benefits of synesthesia may be smaller in degree than a number of studies have indicated until recently (Rothen & Meier, 2009).

However, there have been reports of synesthesia causing distress, in varying degrees, in a synesthete's daily life. For example, distress may occur when a synesthete views an incongruent grapheme – that is, they view a number or letter in a color that does not match their synesthetic color for the grapheme. They often describe the experiences as immediately “upsetting” and describe the incongruent color as “wrong” (Duffy, 2001). This experience can be likened to involuntary negative emotional responses in people listening to unpleasant (dissonant) as opposed to pleasant (consonant) music (Blood, Zatorre, Bermudez, & Evans, 1999). Such experiences of difficulty in the daily realm for synesthetes most likely cause greater levels of distress than the previous example of differing reaction times in a contrived lab setting. For example, anecdotal reports have included difficulty with math due to having to add numbers together that in the synesthete’s mind do not match (Green & Goswami, 2008).

Another larger source of distress anecdotally reported by synesthetes is that of sensory overload (Hochel & Milan, 2008). Sensory overload can be thought of as something anyone can experience — the brain receiving more stimulation than it can process or attend to at one time (Lipowski, 1975). When people cannot effectively filter out sensory information to attend to tasks at hand, they have been reported to suffer in a variety of ways – including disruptions to cognition, affect, and social functioning (Brown & Dunn, 2002). Cognitive functioning *may* suffer in that a person will have trouble focusing upon the task at hand. Such difficulty in focusing is due to an inability to concentrate on relevant information that gets lost in the midst of other sensory information. Thinking may become disorganized and fragmented. Such experiences can give rise to frustration and irritability, due to difficulty in sorting through sensory information. Such difficulties can lead people suffering from sensory overload to withdraw from stimulation, which can include social interactions (Brown & Dunn, 2002; Lipowski, 1975).

Anecdotal reports of synesthesia have included descriptions of possible sensory overload fitting the description above (Baron-Cohen & Harrison, 1997; Luria, 1968). Baron-Cohen (1997) discussed a case of synesthesia causing sensory overload and, consequently, social withdrawal. Their case study described synesthete Julie Roxburgh, who saw colors in response to sounds and heard sounds in response to colors. Her synesthesia was described as causing "massive interference, stress, dizziness, a feeling of information overload, and a need to avoid those situations that are either too noisy or too colorful" (Baron-Cohen, 1997, p. 4).

Although there are a number of anecdotal reports by synesthetes of feeling negative affect (distress) when viewing an incongruent grapheme or at times feeling the amount of incoming sensory information is overwhelming and exhausting (sensory overload), little empirical data exists to support these reports. The only study to date (which provides scant support for experiencing negative affect for incongruent graphemes and words) has been conducted by Callejas, Acosta, and Lupianez (2007). In following paragraphs, I have proposed two methods that can be used to measure these subjective reports of negative affect and sensory overload in an objective manner.

Sensorimotor gating is an information-processing ability not yet investigated in the synesthetic population. Sensorimotor gating can be described as a process that regulates information in the form of sensory input to the brain (Filion, Dawson, & Schell, 1998). As the environment is filled with more sensory information than the brain can process, sensorimotor gating has been suggested to be a basic mechanism by which irrelevant information is buffered or screened out of incoming sensory input (Blumenthal, 1999). Such strategic information processing and screening of sensory input is necessary for efficient processing of information and in navigation through one's environment.

Sensorimotor gating abilities vary among adults with psychological disorders (Braff, Geyer, & Swerdlow, 2001) and without them (Bitsios, Giakoumaki, & Frangou, 2005). Dispositional traits such as neuroticism and anxiety have been found to affect sensorimotor gating abilities (Duley, Hillman, Coombes & Janelle, 2007). Deficits in sensorimotor gating have been linked to psychological disorders such as Post-Traumatic Stress Disorder, Autism, Schizophrenia, and Bipolar Disorder, among others (see Braff et al., 2001, for a review). Sensory overload is a symptom of each of the psychological disorders mentioned above (Braff et al., 2001).

Given that sensorimotor gating impairments have been linked to conditions in which sensory overload has been reported, it is plausible that synesthetes may demonstrate some sensorimotor gating deficits as well. Although synesthetes' reports of sensory overload do not appear comparable to the interference with daily life that a person with, for example, autism may experience (Myles et al., 2004), the described sensory overload could be similar to that which occasionally happens in everyone, as described by Lipowski (1975). I did not wish to pathologize synesthesia in this research study; the sensory overload described in synesthetes was not predicted to interfere with daily life or overall functioning in a detrimental manner. Rather, I aimed to investigate a possible physiological marker for the large number of anecdotal reports by synesthetes describing occasional difficulty processing sensory input.

To investigate grapheme → color synesthetes' anecdotal reports of distress when viewing incongruent graphemes, I proposed utilizing affective modulation of the startle eyeblink reflex in this study. Affective modulation of the startle eyeblink reflex has been used to investigate emotional processes in human studies. Most mammals produce a rapid, involuntary startle response to a sudden, intense sensory event — which is interpreted as being defensive in response to the abrupt stimulus (Blumenthal et al., 2005; Cacioppo, Tassinary, & Berntson, 2007). To investigate how affect might modulate the startle eyeblink reflex, researchers have often shown participants affect-invoking stimuli, such as a picture of an attractive person or a picture of an injured child (Lang, Bradley, & Cuthbert, 1990; Vanman, Dawson, & Brennan, 1998). During the presentation of such stimuli, researchers present a loud and startling burst of noise. The amplitudes of the startle eyeblink, immediately following such bursts of noise have been found to be larger while viewing negative stimuli compared to positive stimuli (Filion et al., 1998). Such modulation of the startle eyeblink reflex is posited to reflect a change in affect such that the reflex in response to a stimulus with a negative emotional value (valence) is increased. However, size of startle eyeblink reflex has been found to lessen during a stimulus with a positive emotional value (valence) (Lang, 1995; Lang et al., 1990).

Grapheme → color synesthetes have often relayed accounts of feeling brief discomfort or distress when viewing a grapheme that is incongruent with the color elicited by their synesthesia (Callejas et al., 2007; Duffy, 2001). I proposed to objectively measure the potential negative affect (distress) by examining the eyeblink startle reflex in synesthetes when presented with incongruent versus congruent graphemes specific to their synesthetic responses. I predicted that briefly viewing an incongruent grapheme would produce a transient negative affective state, which would then temporarily increase the magnitude of startle reflex from baseline as measured by eyeblinks among grapheme → color synesthetes. Alternatively, as transient positive affective states have been shown to reduce eyeblink amplitude (Dawson, Schell, & Bohmelt, 1999), I expected congruently colored graphemes to reduce size of startle eyeblink for synesthetes.

The purpose of this dissertation was to objectively investigate how synesthesia may influence affect and sensorimotor gating in synesthetes. By examining the sensorimotor gating in synesthetes, I examined whether they were more prone to sensory overload. In addition, presenting synesthetes with incongruently-colored graphemes provided the opportunity to observe potential effects on their startle reflex while in a negative affective state directly related to their synesthesia.

Overall, this dissertation provided an original and objective approach to examine subjective experiences reported by synesthetes. Although research on the perceptual nature and neural basis of synesthesia has burgeoned in recent years, little research has been conducted on the effect of synesthesia on a person's life outside the synesthesia itself. This dissertation aims to address this void and contribute to the literature by investigating, in an objective manner, reported negative affect in the presence of an incongruently-colored grapheme and also by investigating whether synesthetes are more prone to sensory overload. I hypothesized that the results would support negative affect in response to incongruently-colored graphemes and that these results would be the first empirical demonstration of their kind. I also hypothesized that synesthetes would be different in their sensorimotor gating abilities as compared to non-synesthetes and that these results would also represent the first empirical study to shed light upon reports by synesthetes of sensory overload. Increased understanding in this domain could yield further insights into sensory processing in people with and without synesthesia.

CHAPTER 2

REVIEW OF THE LITERATURE

Characteristics and Properties of Synesthesia

"Synesthesia" is from the Greek word "syn," meaning "together," and "aesthesis," meaning "perception." Interest in synesthesia was great between the mid-1800s and before the behaviorist trend in psychology around the early to mid-1900s (Cytowic, 1998). With the rise of behaviorism, scientists generally regarded synesthesia as unsuitable for scientific study, judging subjective experiences as immeasurable (Baron-Cohen & Harrison, 1997). In the past few decades, however, interest in synesthesia has returned (Jansari, Spiller, & Redfern, 2006). Presently, researchers employ an increasing variety of methods to assess synesthetic experiences, including functional neuroimaging, behavioral tests, and also measures that rely upon self-report.

Aside from a literal translation of the Greek origins of the word, what is synesthesia? Although there are at present varying definitions of synesthesia and what makes one a synesthete, one definition is that synesthesia constitutes an "extra" perceptual experience in addition to what could be considered more usual experiences in most people (Ward & Mattingley, 2006). Synesthesia often implies a stimulus (inducer) triggering a response (concurrent) in another sense, such as a spoken word (hearing) provoking the experience of color (sight), which could be called cross-modal (Grossenbacher & Lovelace, 2001). By "cross-modal," it is meant that the stimulus in one sense (for example, hearing, as described above) induces an experience in another sense (for example, sight, as described above). However, synesthesia also occurs with the inducer and concurrent belonging to the same sense modality (Grossenbacher & Lovelace, 2001). For example, a synesthete may see a number such as "4," which may trigger the corresponding visual color orange. In this example, both the number "4" and the orange color belong to the sensory modality of vision.

Genuineness of Synesthesia

Reports of synesthesia may go back as far as the 1700s (Galton, 1883), but until recently, synesthesia was a difficult phenomenon to study. Many people have doubted the genuineness of synesthesia, given that exploration of synesthesia has historically been largely dependent upon the self-report of the person experiencing it. "Genuineness," in this sense, differentiates synesthesia from imagination and metaphor by it being an actual perceptual phenomenon—a perceptual experience over which that the synesthete has little, if any, control (Mills, Boteler, & Oliver, 1999). Further, most synesthetes report that they recall the synesthetic experiences going back as far as they can remember (Lupianez & Callejas, 2006). The development of brain imaging techniques such as functional Magnetic Resonance Imaging (fMRI) and other objective tests developed by researchers (Cytowic, 2005) has helped synesthesia gain credence in addition to renewed interest from the scientific community in recent years.

Consistency

Synesthetes describe their experiences as being consistent over time. In the example of grapheme → color synesthetes, numbers and letters do not change dramatically (or at all) in their perceived synesthetic colors. Baron-Cohen, Wyke and Binnie (1987) developed the Test of Genuineness for word → color synesthesia, which has since been regarded as an objective diagnostic test for the presence of synesthesia. In their pioneering study, Baron-

Cohen et al. asked an auditory → color synesthete and a non-synesthete to name and describe colors for 103 words and sounds. The control participant was re-tested two weeks later and was found to be 17% consistent in her answers between the two sessions. The auditory → color synesthete showed 100% consistency when tested 10 weeks later. When tested eight months later, the synesthete was still 100% consistent.

Since the introduction of the Test of Genuineness (Baron-Cohen et al., 1987), numerous experiments have tested comparisons between synesthetes and non-synesthetes in color/language associations, asking participants to "name the color" that goes with a given letter/word/number, and then re-administering the test at a later and unannounced time. Non-synesthetes typically are less than 50% in their consistency, with synesthetes maintaining consistency of reported colors at 70% or greater (Asher, Aitken, Farooqi, Kurmani, & Baron-Cohen, 2006; Palmeri, Blake, Marois, Flanery & Whetsell, 2002; Schiltz et al., 1999). In 2006, the Revised Test of Genuineness was developed (Asher et al., 2006), which the researchers reported to be as accurate in identifying synesthesia as the original test. This revision allows synesthetes to choose color patches instead of describing the concurrent colors. They also argued that the Revised Test of Genuineness was a tool that could be used remotely and allowed identification of more subtypes of synesthesia.

Automaticity

Synesthetic experiences occur involuntarily on the part of the synesthete—that is, the experiences occur automatically. In a landmark case study, Wollen and Ruggiero (1983) demonstrated the automaticity of synesthesia by employing a modified Stroop task. The Stroop effect refers to the cognitive interference that occurs when one facet of a stimulus interferes with a person's processing of another facet of that same stimulus. In the standard presentation of the Stroop effect, participants are presented with printed words, which name colors, such as "red" or "green." The participants are then asked to name the colors in which the words are printed. Participants are slower to respond when the colors in which the words are printed do not match (for example, the word "blue" printed in green ink). Synesthetes consistently take longer to identify an incongruently-colored grapheme than a congruently-colored grapheme on reaction time tasks (Kadosh & Henik, 2006; Odgaard, Flowers, & Bradman, 1999). The difference in reaction times generally ranges from approximately 50 to 300 milliseconds in a contrived lab environment (Dixon, Smilek, Cudahy, & Merikle, 2000; Kadosh & Henik, 2006; Mills et al., 1999). In addition, many synesthetes report feelings of distress when confronted with incongruently matched graphemes.

The Stroop effect has been described as an automatic and unconscious reaction, which causes a slowing of participants' responses for words that do not match the color in which they are printed (Stroop, 1935). Wollen and Ruggiero (1983) hypothesized that a similar effect would be observed if a grapheme → color synesthete were presented letters in colors which did match (congruent) or did not match (incongruent) the synesthetic colors induced for that synesthete. They stated that if such an effect were observed, the automaticity of synesthesia would be supported. Their participant, A.N., was a grapheme → color synesthete and had stated that she could "ignore" her concurrents. An artist mixed paints to obtain four colors representing her elicited colors from the corresponding four letters. As hypothesized, A.N. named letters presented to her more slowly when those numbers were not printed in the colors elicited by her synesthesia. The authors concluded that synesthesia was indeed an automatic process, not under the voluntary control of the synesthete. Since their study, numerous studies testing synesthetes in modified Stroop tasks have followed, yielding similar findings, which support the automaticity of synesthesia (Rich & Mattingley, 2002).

Similar to Wollen and Ruggiero's (1983) study, Mills et al. (1999) hypothesized that the same effect would be observed if a grapheme → color synesthete were presented numbers (as contrasted to letters used in Wollen and Ruggiero's study) in colors which did match (congruent) or did not match (incongruent) the synesthetic colors induced for that synesthete. If such an effect were observed, they stated, the anecdotal arguments (at that time) for the automaticity of synesthesia would be supported. Their participant, G.S., was a grapheme → color synesthete and, as hypothesized, named numbers presented to her more slowly when those numbers were not printed in the colors elicited by her synesthesia. Mills et al. (1999) drew the same conclusions as Wollen and Ruggiero (1983) regarding the automaticity of synesthesia.

Similarly, Paulsen and Laeng (2006) argued that pupillometry could be employed to examine Stroop-like effects on grapheme → color synesthetes. Pupillometry is the measurement of changes in diameter of the pupil of the eye (whether pupil size increases or decreases) (Andreassi, 2000). Increased pupil diameter (size) has been linked to emotional stimuli, sexual arousal, novel stimuli, and increased information-processing load during mental tasks (Andreassi, 2000). Changes in pupil size are controlled mainly by the autonomic nervous system (ANS). Paulsen and Laeng (2006) posed that, since pupil size is controlled largely by the ANS, the pupillary response is a result of a primitive adaptive system, attuned to detect experiences that are novel. They argued that incorrectly colored graphemes for synesthetes would function as novel stimuli and would increase the information-processing load required when viewing the incongruent graphemes. Paulsen and Laeng theorized that presenting grapheme → color synesthetes with incongruently colored graphemes would increase their information-processing load, given the interference synesthetes may experience when shown a grapheme in a color not elicited by their synesthesia. Hence, pupil size would increase. Indeed, Paulsen and Laeng found that grapheme → color synesthetes' pupils dilated more when viewing incongruently colored graphemes than congruently colored ones, supporting their hypothesis and the general literature indicating automaticity of synesthesia.

Idiosyncrasy

Those with synesthetic perception experience it idiosyncratically and with great variety (Duffy, 2001). Typically, for grapheme → color synesthetes, every letter of the alphabet, and every number from 0-9 will induce a particular color. The colors reported by synesthetes are highly specific. Rather than a pure shade (such as blue or red) a synesthete will describe the shade in a very detailed manner (azure blue or crimson red). Although many synesthetes share the commonality of perceiving letters/numbers in color, they often disagree on what colors the letters/numbers should be. For one synesthete, the number 7 may be an illuminated forest green; another may report it as being a "lovely shade of dark copper."

Direction and Etiology

Synesthesia is usually reported as being unidirectional. In the previous example of the number "4," the color orange would not trigger the automatic conception of "4." Although synesthesia can result from injury or certain drug use, synesthesia in the sense that this researcher intends is present in synesthetes for as long as they can remember, typically reporting experiencing it from early childhood onward (Duffy, 2001).

Forms of Synesthesia

No one knows for sure how many forms of synesthesia there are. Those researching synesthesia have offered differing numbers of forms. Sean Day (2005) reports, through email contact with self-reported synesthetes, at least 39 forms of synesthesia, with grapheme → color synesthesia being the most common form, with a 67.3% occurrence out of 695 synesthetes. Among other forms cited are pain → color and sounds → color. Other forms also include tastes → color, as well as touch → color synesthesia. Colors are by far the most common concurrent (Day, 2004). People with one form of synesthesia often have another form as well. Day's (2004) tracking of forms of synesthesia indicates that over half of synesthetes with one form of synesthesia have other forms. Much experimental attention has examined grapheme → color synesthesia, because it is a common form. However, recently there have been more studies looking at other forms of synesthesia, such as spatial forms (Tang, Ward, & Butterworth, 2008).

An example of an unusual form of synesthesia is taste/shape synesthesia, written about by Cytowic in 1993 in his book *The Man Who Tasted Shapes.* Cytowic worked with a subject who experienced the tactile experience of shapes in response to tastes, revealing his synesthesia to Cytowic by commenting, “There aren’t enough points on the chicken” (Cytowic, 1993, p. 3). This particular synesthete had experienced shapes in response to taste for as long as he could remember, and would report various tactile sensations such as “long, smooth, glass columns” in response to the taste of peppermint, and would use his synesthetic experiences to help in his cooking (Cytowic, 1993).

On occasion, scientists have divided synesthesia into the two categories of either “associator” or “projector,” with associative (internal) synesthetes far outnumbering projectors (external synesthetes) (Dixon, Smilek, & Merikle, 2004). “Associative synesthesia” is the synesthetic experience taking place in the “mind’s eye” (Dixon et al., 2004). For example, a synesthete that pairs a particular color with the letter “t” may visualize the “t” in their minds as having a particular shade of green. External synesthetes experience their perceptions as outside their own body—in this case, the synesthete actually sees that particular color of green projected onto the piece of paper on which the “t” is printed. External synesthetes report knowing that the letters are black, and that their colored perceptions are not “real,” but they do involuntarily project the colors and see them externally. Interestingly, projector synesthetes typically report that what they see does not interfere with their understanding of what is real and what is not real. They have no trouble in making that distinction; whereas, for example, people with schizophrenia cannot distinguish between what is real and what is not real when they visualize experiences in their external environments that are not real.

Another way of distinguishing different forms of synesthesia is to categorize them as *synesthetic perception* or *synesthetic conception* (Grossenbacher & Lovelace, 2001).

Synesthetic perception means concurrents are induced by perceiving stimuli that is sensory in nature (Grossenbacher & Lovelace, 2001). An appropriate example of synesthetic perception is Cytowic's subject (1993) in which the man experienced the feeling of shapes in response to taste sensations. Another example is seeing colors in response to hearing music. *Synesthetic conception* means concurrents are induced by thinking about certain concepts (Grossenbacher & Lovelace, 2001). For example, thinking about the letter *g* (inducer) may bring about the perception of the color gray (concurrent). Similarly, periods of time such as days of the week (inducers) may have particular spatial locations (concurrents).

Prevalence of Synesthesia

At present, there is no completely agreed-upon definition of synesthesia in the academic realm, which makes accurate estimates of prevalence of synesthesia difficult. Estimates have ranged from as rare as 1:250,000 (Cytowic, 1993/1998) to the more frequently reported 1:2,000 in Baron-Cohen's newspaper survey in 1996 to 1:200 (Baron-Cohen, 1997). As the definition of synesthesia broadens, scientists will most likely find additional cases of synesthesia. Recent studies estimate the prevalence of grapheme → color synesthesia to be at least 1% of the western population, according to a large UK sample (Simner et al., 2006).

Potential Benefits of Synesthesia

In the beneficial realm, synesthesia has been implicated in enhanced memory, but as previously mentioned, recent research has questioned the degree of benefit when examining larger groups of synesthetes as compared to individual (and arguably exceptional) cases

(Rothen & Meier, 2009). One example of an individual with exceptional memory abilities is the mnemonist and synesthete Shereshevskii (Luria, 1968), who used his synesthetic shapes, textures, colors, and tastes as cues to help him recall long lists of words and numbers. He was able to recall these lists even when tested over a decade later. More recently, the savant Daniel Tammet was able to memorize pi to 22,514 digits by making use of the fact that, for him, different numbers elicit specific three-dimensional shapes, all with their own colors and textures (Tammet, 2007).

In a study examining groups of synesthetes, Yaro and Ward (2007) suggested that not only do synesthetes describe themselves as having "better than average" memory, they also outperform non-synesthetes on objective tests of memory. One of these objective tests was a test of verbal memory. Yaro and Ward compared 16 grapheme → color synesthetes to 16 non-synesthetes on the Rey Auditory-Verbal Learning Test (RAVLT). The synesthetes performed significantly better on the RAVLT than the non-synesthetes in this study. However, the literature has recently included cautionary reports. Radvansky, Gibson and McNerney (2011) explored inconsistencies in the existing synesthesia research and have warned against concluding that synesthetes have superior memory abilities.

At the time of the inception of this study, minimal research had been conducted to examine potential benefits of synesthesia outside the synesthetic experience and in the veridical domain. However, recent research has begun to explore this possibility. Banissy, Walsh, and Ward (2009) have suggested that synesthesia may relate to enhanced sensory perception, specific to synesthesia type. Synesthesia has also been implicated in superior cognitive capacities, including mental imagery (Brang & Ramachandran, 2010), visuospatial

(Simner, 2009) and temporal cognitive abilities (Mann, Korzenko, Carriere, & Dixon, 2009), and facility in the mathematical (Ward, Sagiv, & Butterworth, 2009) domain.

Gimmestad and Lovelace (in press) administered a standard test of color discrimination to 26 color-synesthetes, 5 no-color synesthetes, and 27 controls. Color synesthetes performed significantly better than participants without color synesthesia. The authors concluded that synesthetic experiences can indeed affect sensory experience in the veridical domain. Similar to these findings, Yaro and Ward (2007) found color synesthetes to have enhanced memory for colors after being presented with a standard color measure.

Potential Difficulties of Synesthesia

As mentioned previously, despite the benefits associated with synesthesia, difficulties have been described anecdotally both on small and larger scales. A number of grapheme → color synesthetes have relayed brief distress (negative affect) in response to viewing an incongruent grapheme, but, at the time of the inception of this study, only one research team had examined such an effect (Callejas et al., 2007).

Callejas et al. (2007) conducted a behavioral experiment upon a grapheme → color synesthete, M.A., who perceives letters, numbers, and words in color. M.A. reported negative emotions in response to incongruently-colored letters, numbers, and words. She said, "It is wrong. It's like coming into a room and finding all the chairs upside-down and everything out of place. I can't stand it. It is just wrong" (p. 100). Callejas et al. tested this reported affective reaction in four experiments, with the first comprising a modified Stroop task. Callejas et al. presented M.A. and a group of 11 control participants with a set of 72 words (neutral, positive, anxiety-related, and anger-related words) and asked them to rate their perceived valence according to the words' semantic meanings. The control participants and M.A. were presented with words in color that were congruent with M.A.'s synesthesia, incongruent with M.A.'s synesthesia, and lastly in black print. As predicted, the incongruent condition produced reduced ratings for positively-valenced words in M.A. but not in controls. Similarly, M.A. rated congruently-colored negative valence words as being less negative than controls. This finding was also statistically significant ($p < .001$). The researchers interpreted these findings as supporting the hypothesis that viewing incongruent graphemes induces an automatic negative affective state in grapheme → color synesthetes (Callejas et al., 2007).

Startle Eyeblink Modification (SEM) as a Measure of Affect

To investigate negative affect reported by grapheme → color synesthetes when viewing incongruent graphemes, affective modulation of the startle eyeblink reflex was employed in this study. Most mammals produce a rapid, involuntary startle response to a sudden, intense sensory event—interpreted as being defensive in response to the abrupt stimulus (Blumenthal et al., 2005; Cacioppo, Tassinary, & Berntson, 2007). The startle reflex is comprised of contracted skeletal and facial muscles (Braff et al., 2001; Filion et al., 1998). This reflexive response has been used to investigate emotional processes in human studies.

In studies with humans, part of the startle reflex mentioned previously includes rapid eye closure (eyeblink), which indicates a protective response to possible organ injury. Startle eyeblink is employed as a highly reliable index of the overall behavioral response that represents the startle response. The eyeblink component of the startle reflex is usually measured using electromyography (EMG) of the orbicularis oculi muscle. The amount of startle is generally measured with the amplitude of an eyeblink in response to a startling sound (Braff et al., 2001; Filion et al., 1998). Affect, attention, sensory events, and individual differences can modify the startle reflex (Blumenthal, 2001; Lang et al., 1990; Vanman, Boehmelt, Dawson, & Schell, 1996). Paradigms that have been used to demonstrate affective modulation of the start eyeblink have often included participants viewing affect-laden stimuli, such as pictures of a cute kitten (positive valence) or an injured child (negative valence). The amplitudes of startle eyeblinks have been shown to be generally greater when a participant is viewing a negative stimulus as compared to viewing a neutral of positive stimulus (Filion et al., 1998).

SEM as a Measure of Affect in Synesthetes

As people produce larger startle responses in the presence of viewing an unpleasant picture (with the picture generating negative affect), synesthetes were predicted to similarly produce a larger startle response when presented with an incongruently colored grapheme. Alternatively, persons viewing a pleasant picture produce a smaller startle response, as a grapheme → color synesthete were predicted to show decreased startle in response to a congruently colored grapheme relative to an incongruently colored one.

Sensory Overload

Since the information in our environment greatly exceeds the amount of information we can process, we need to be able to filter stimuli that are not new and do not need to be addressed (Brown & Dunn, 2002). For example, paying attention to the feeling of the chair that a person is seated in after a few minutes is probably not the most effective use of one's attention. By filtering out information we have already been presented and to which we have already adapted, we are freed up to attend to new stimuli.

Lipowski (1975) argued that every person has a limit to the sensory information they can process at a given time, influenced by individual and contextual differences, and that everyone is susceptible to sensory overload. In his review of behavioral effects of sensory and information overload, Lipowski posited that technology had provided contexts which increased the likelihood of sensory overload by rapidly increasing the amount of sensory information with which people are confronted – examples include sounds from city buses, noises from crowds in an urban setting, and radio announcements. His descriptions of sensory overload in these day-to-day scenarios included unpleasant feelings, evidence of stressful arousal, and decrements in cognitive task performance.

There is much anecdotal evidence from synesthetes indicating they may be more prone to sensory overload (National Public Radio, 2000; Thalbourne, Houran, Alias & Brugger, 2001). The synesthete Shereshevskii, whose incredible memory has been previously described (Luria, 1968), also struggled with sensory overload (Baron-Cohen & Harrison, 1997). He related trouble ignoring certain synesthetic concurrents to the point of feeling overwhelmed and confused by his synesthetic perceptions:

> …it was as though a flame with fibers protruding from his voice was advancing toward me…I couldn't follow what he was saying…What first strikes me is the colour of someone's voice. Then it fades off…for it does interfere…should another person's voice break in, blurs appear. (Baron-Cohen & Harrison, 1997, p. 103)

Synesthetic experiences are often described as an "extra" sense that provides for a greater input of overall sensory information and that, at times, this can feel overwhelming for synesthetes. Music → touch synesthete Carol Crane (CBS News, 2002) related that she found her synesthesia for the most part to be very enjoyable, but that "…I notice that every time I leave a symphony, I feel as if I've just been run over or something, like I'm just drained" (CBS News, 2002). Another example is James Wannerton, who experiences word → taste synesthesia, and described synesthesia as causing him sensory overload. In an interview with CBS News he stated, "I've had girlfriends with names I couldn't stand saying. I'll give you an example. Tracey is a very strong flavored name and it's flaky-pastry. Whenever I was in her company, that's what I thought of constantly" (CBS News, 2002). Synesthetes have been described as preferring quieter environments and being more sensitive to light than non-synesthetes as well (Crane, 2005). However, as previously stated, the possibility of synesthetes experiencing sensory overload has been anecdotal so far and is in need of objective study to help investigate whether synesthetes do truly experience more overwhelming sensory experiences than non-synesthetes.

Sensorimotor Gating

As stated previously, sensorimotor gating can be described as an automatic regulatory process in response to sensory input (Filion et al., 1998). Sensorimotor gating is an involuntary process in response to sensory input assisting in the processing of stimuli. Sensorimotor gating has been suggested to be a basic mechanism by which irrelevant sensory information is buffered or screened out (Blumenthal, 1999). Sensorimotor gating aids higher order cognitive processes by filtering out sensory input that is inessential.

When sensorimotor gating cannot effectively filter out incoming sensory input, sensory overload may arise (Braff et al., 2001; Lipowski, 1975). At times, the environment may be filled with more stimulation than an average person can handle—for example, loud music at a concert or bright lights and loud sounds in a crowded environment (Lipowski, 1975). Poor sensorimotor gating has also been implicated in psychological disorders and results in sensory flooding and cognitive confusion (Braff et al., 2001).

Prepulse inhibition as an index of sensorimotor gating. An accepted measure of sensorimotor gating is prepulse inhibition. When a loud and startling sound is preceded by a softer sound within 30 to 500 milliseconds (Blumenthal, 1999; Graham, 1975), people often have a smaller startle reaction than they would without the softer sound (Braff et al., 2001). Prepulse inhibition consists of such a reduction in amplitude of the startle reflex.

Prepulse inhibition has been posited as a simple operational index of sensorimotor gating, serving to prevent interruption of ongoing perceptual and early sensory analysis during the time required to analyze new stimuli (Corr, Tynan, & Kumari, 2002). Prepulse inhibition has been examined in both humans and animals, and, according to many authors, demonstrates the activation of a ubiquitous sensory gating process (Swerdlow, Taaid, Oostwegel, Randolph, & Geyer, 1998).

Although prepulse inhibition has been accepted as an automatic process, it has been established that it is variable in nature. Prepulse inhibition can be modulated by attentional processes (Filion et al., 1993) and potentially emotion and personality traits (Corr et al., 2002). Prepulse inhibition has also been shown to be impaired across a range of clinical conditions (Braff et al., 2001).

Variance among populations in prepulse inhibition/sensorimotor gating ability. Although sensorimotor gating is robust, sensorimotor gating does vary among adults with (Braff et al., 2001) and without psychological disorders (Bitsios, Giakoumaki, & Frangou, 2005). Dispositional traits such as neuroticism and anxiety have been found to affect sensorimotor gating abilities such that reduced prepulse inhibition is thought to reflect difficulty with gating out irrelevant information (Corr et al., 2002). Such deficits in sensorimotor gating have also been linked to psychological disorders, most notably schizophrenia (Dawson et al., 2000). People without schizophrenia generally show the marked decrease in their startle reflex in response to a stimulus when preceded by a non-startling prepulse. Conversely, people with schizophrenia have been shown to demonstrate impaired prepulse inhibition (Keller, Hicks, & Miller, 2000). In one study, patients with greater numbers of Positive Symptoms (e.g., unusual thought content, conceptual disorganization) demonstrated greater impairments in sensorimotor gating (Keller et al., 2000). Impaired prepulse inhibition has also been found in psychiatric disorders such as Bipolar Disorder and in cases of Major Depression (Keller et al., 2000) Symptoms of sensory overload (e.g., confusion, trouble with goal-directed behavior, distress, difficulty gating out irrelevant stimuli) are reported symptoms of each of the psychological disorders mentioned above (Keller et al., 2000).

Prepulse inhibition as a measure of sensorimotor gating in synesthetes. Summarily, sensorimotor gating impairments have been linked to conditions in which sensory overload has been reported. Sensory overload occasionally happens in everyone (Lipowski, 1975), may be more likely with respect to dispositional factors such as anxiety and neuroticism (Corr et al., 2002), and has been linked to sensorimotor gating impairments in various populations (Braff et al., 2001).

Given the large body of anecdotal reports of sensory overload in synesthetes, sensorimotor gating may be different in synesthetes as compared to non-synesthetes. Prepulse inhibition offers an objective measure to investigate these—until now—anecdotal reports of sensory overload. As stated earlier, however, I do not wish to pathologize synesthesia. Rather, I wished to investigate a possible physiological marker for these reports by synesthetes describing occasional difficulty with feeling overwhelmed by sensory stimuli. Synesthetes' reports of sensory overload are not comparable to the interference with daily life that a person with schizophrenia may experience, and I did not expect to observe comparable impairments in sensorimotor gating as measured by prepulse inhibition.

Summary of Literature and Study

Synesthesia research has focused mainly on investigating the perceptual nature of the phenomena that constitute synesthesia, as well as its neural basis. Thus far, there has been a lack of research on how synesthesia may affect an individual's life beyond the synesthesia. Limited research has explored practical benefits of synesthesia (Gimmestad & Lovelace, 2011; Yaro & Ward, 2007). Similarly, anecdotal reports have been described regarding both small and large difficulties that can co-occur with synesthesia. In particular, grapheme → synesthetes have described distress when viewing incongruent graphemes. However, only one case study has explored this reported distress. Many synesthetes have also reported sensory overload, although no research to date has investigated these reports.

By employing startle eyeblink modification, I proposed to objectively measure the potential negative affect (distress) in synesthetes when presented with incongruent versus congruent graphemes specific to their synesthetic responses. I predicted that briefly viewing an incongruent grapheme would produce a transient negative affective state, which would then temporarily increase the magnitude of startle reflex as measured by eyeblinks among grapheme → color synesthetes. By examining prepulse inhibition as a measure of sensorimotor gating in synesthetes, I examined whether they are more prone to sensory overload.

The purpose of this dissertation was to objectively investigate how synesthesia may influence affect and sensorimotor gating in synesthetes. Overall, this dissertation provided an original and objective approach to examining subjective experiences reported by synesthetes. This dissertation aimed to contribute to the literature by investigating, in an objective manner, reported negative affect in the presence of an incongruently-colored grapheme and also by investigating whether synesthetes are more prone to sensory overload.

I hypothesized that the participants would show increased startle eyeblink magnitude and support negative affect in response to incongruently-colored graphemes, and that such results would be the first empirical demonstration to date of the negative affect that synesthetes experience when viewing incongruently-colored graphemes. In addition, I also hypothesized that synesthetes would be found to be different in their sensorimotor gating abilities such that they would have decreased prepulse inhibition as compared to non-synesthetes, and that these results would also represent the first empirical study of sensory overload in synesthetes. Increased understanding in this domain could yield further insights into sensory processing in people both with and without synesthesia.

CHAPTER 3

METHODOLOGY

Participants

I recruited participants from undergraduate psychology courses at the University of Missouri-Kansas City with the permission of the instructors. In addition, I recruited participants from the community via flyers. I also contacted participants from previous studies who were known, through the use of the NIMH Synesthesia Screen, to experience synesthesia and had previously agreed to being contacted again for future studies. Fifty-seven participants were recruited for this study. Twenty-seven synesthetes (5 males, 22 females, mean age = 36.07 years, *SD* = 14.42) and 29 non-synesthetes (7 males, 22 females) mean age = 26.24 years, *SD* = 10.64) participated in all aspects of the study except for the startle portion. Each participant answered all questions contained in the written measures. Fifteen synesthetes (2 males, 13 females, mean age = 27.8 years, *SD* = 9.22) and 17 non-synesthetes (3 males, 13 females, mean age = 22.12 years, *SD* = 3.46) participated in all of the study, including the startle portion.

All eligible participants had self-reported normal or corrected-to-normal vision, hearing, and touch. After being interviewed, participants were assigned to one of three groups: Synesthetes with grapheme → color synesthesia, synesthetes without grapheme → color synesthesia, and non-synesthetes.

Self-report Measures

Presence or Absence of Synesthesia

The NIMH-Naropa Synesthesia Screening Interview (Synesthesia Screen) is used for detecting synesthetic experiences and assessing strength of concurrents (Grossenbacher, 2004a). Participants were asked a series of questions by the researcher, with the researcher writing down the participants' responses.

There are two forms of the Synesthesia Screen: Research and Clinical. This study utilized the lengthier but more thorough research version, and the descriptions that follow pertain to this version. Four sections of primary screening questions were included: Synesthetic Perception, Synesthetic Conception, Synattribution, and Knowledge of Synesthesia. Synesthetic Perception consists of ten questions about conscious experiences of sensory phenomena triggered by sensory stimulation. Synesthetic Conception consists of five questions about conscious experiences of sensory phenomena triggered by conceptual thought or affective feeling. Synattribution consists of six questions about conscious experience of non-sensory phenomena that are triggered by something not otherwise described in the other primary screening sections. Knowledge of Synesthesia is intended to gauge the participants' understanding of and familiarity with the term synesthesia. The four sections all begin with primary questions, or questions that ask for a "yes" or "no" response to whether the participant has ever had the experience described in the primary question. If the participant answered "yes," then probe questions were asked. The researcher then asked for at least two specific examples from the participant in which the participant may have been describing inducers and concurrents indicative of synesthesia. If the researcher determined that the examples were indicative of synesthesia, a series of additional parametric questions were asked. The parametric questions involved how early the participant could remember having had such experiences, when the most recent time was that they had the experience, and so on. An example of a parametric question is, "What is the youngest age at which you were pretty sure that letters had colors?" Parametric questions also ask about frequency, vividness of the experiences over time in the participant's life, and potential influences on synesthetic experiences.

The Synesthesia Screen Manual (Grossenbacher, 2004b) delineates the criteria for a positive diagnosis of synesthesia. A "yes" response to a primary question may be indicative of a form of synesthesia. However, to be classified as "genuine" synesthesia, the following criteria must be met:

1. There must be more than one item in the inducer set (e.g., more than one number invokes an experience of color).

2. Each item in the inducer set must induce a distinct concurrent (e g., a particular color).

3. Concurrent attributes did not cohere—that is, the two concurrents (say, colors) are not the same for the two distinct inducers (such as the numbers "6" and "3")

4. The inducer-concurrent mapping was not something commonly experienced, such as feeling blue or shuddering in the response to the sound of fingernails on a chalkboard.

Meeting the criteria just described is sufficient to provide a positive diagnosis for synesthesia. If the form of synesthesia involved concurrents perceived for grapheme inducers, the synesthete was categorized as having grapheme → color synesthesia.

Sensory Sensitivity

Two self-report measures were used to assess sensory sensitivity: The Adult Sensory Profile, for established validity; the SCNL Sensory Overload Questionnaire for face validity. The Adult Sensory Profile (Brown, Tollefson, Dunn, Cromwell, & Filion, 2001) assesses an individual's preferences for sensory processing and was administered for exploratory purposes.

The Adult Sensory has a total of 60 questions which asks individuals to indicate how they generally respond to everyday sensations. The questionnaire typically takes ten to fifteen minutes for completion. Individuals completing the questionnaire were asked to choose their answers for the items, with the possible choices including the frequency of such responses to the sensory experiences, ranging from *Almost Never, Seldom, Occasionally, Frequently*, to *Almost Always*. The questions are in accordance with the sensory processing categories of Taste/Smell, Movement, Visual, Touch, Activity Level, and Auditory. An example of an Auditory Processing item is, "I am distracted if there is a lot of noise around." Items from the questionnaire also aim to provide information to place an individual's preferences in four quadrants: Low Registration, Sensation Seeking, Sensory Sensitivity, and Sensation Avoiding – that is, measuring slowed responses, enjoyment and seeking of sensory stimuli, distractibility and discomfort, and efforts to reduce sensory stimuli, respectively. An example of a question from the Adult Sensory Profile for a Sensation Avoiding item is "When others get too close, I move away."

Previous research on the Adult Sensory Profile has indicated that it is a valid and reliable measure of sensory preferences (Brown et al., 2001). Using the internal consistency method, the Cronbach's alpha values for various age groups and quadrant scores have ranged from .64 to .78 (Brown et al., 2001). In a study conducted by Chess and Thomas (1998) to demonstrate convergent and discriminant validity of the Adult Sensory Profile, 207 adult participants completed both the Adult Sensory Profile and the NYLS Adult Temperament Questionnaire. Significant moderate correlations were found between the subscales of the Adult Sensory Profile and the NYLS Adult Temperament Questionnaires.

The SCNL Sensory Overload Questionnaire is intended to assess an individual's potential for feeling overwhelmed by incoming sensory stimuli and was used for exploratory purposes. The SCNL Sensory Overload Questionnaire contains six questions. The first question, "Have you ever experienced sensory overload?" which participants could answer "Yes" or "No," determined whether the remaining questions would be asked. If an individual reported having had such an experience, they were then asked to report how often they had felt sensory overload on a 5-point Likert scale with *a* meaning *Once*, *b* meaning *A few times*, *c* meaning *A few times per year*, *d* meaning *A few times a month*, and *e* meaning *More frequently*. They were also asked about the first time, most recent time, and frequency and nature of such experiences. Participants were then asked to rate how intense the feeling of being overwhelmed was the last time they experienced it on a 5-point Likert scale, with *a* meaning that they had *Barely noticed it* and *e* meaning that the experience was *Disabling*. Participants were then asked to use the same scale to describe the most intense time they had ever had feelings of being overwhelmed by sensory stimuli.

The questionnaire is designed to assess the experience of sensory overload independent of whether a person has synesthesia. This measure is notably shorter than the

Adult Sensory Profile. However, the SCNL Sensory Overload Questionnaire has significant correlations with the Sensory Sensitivity and Sensation Avoiding subscales of the Adult Sensory Profile, and does appear to accurately measure sensory overload. A point-biserial correlation between item 1 from the SCNL Sensory Overload Questionnaire and the subscales Sensory Sensitivity and Sensation Avoiding of the Adult Sensory Profile revealed corrected item-total correlations of .21 ($p < .10$), and .32 ($p < .01$), respectively.

Eysenck Personality Questionnaire-Revised

This measure was included for exploratory purposes. Previous research on the Eysenck Personality Inventory has indicated that it is a valid and reliable measure (Sato, 2005; Zuckerman, Kuhlman, Joireman, Teta, & Kraft, 1993). In their comparison of three structural models of personality, Zuckerman et al. found convergent validity of .76, .80 and .90 for the Extraversion, Neuroticism and Psychoticism scales with the Big Five and Alternate Big Five personality measures. Average internal consistency ratings for the Eysenck Personality Inventory range from .76 to .87 (Eysenck, Eysenck & Barret, 1985; Sato, 2005; Zuckerman et al., 1993).

Startle Measures

The participants were presented with sounds and pictures as their eyeblinks were recorded in a sound and light-attenuating room. They were asked to keep their head still and their eyes pointed at the center of the monitor at all times. Participants were observed by video during this portion of the study; if communication was necessary, an intercom was used. Stimuli were presented in two sets of trials, with each set lasting approximately 14 minutes and containing 40 trials with a rest break in between the two trials. Twenty of the

40 trials per set had prepulses, and twenty were controls (no prepulse) in pseudorandom order. Forty images and white noise bursts were presented for each set; however, white noise bursts occurred in the absence of an image (No Picture), and presence of an image (Congruent, Incongruent) pseudorandomly. There was an interval of 16 to 26 seconds between each startle stimulus. While the participants were hearing the sounds, they were viewing images on the computer screen, with each image lasting for 6 seconds. The sounds used to elicit startle reflex were loud, brief (105 dB SPL(A), 50 millisecond) white noise bursts (<1ms rise/fall). Precisely 120 ms prior to half of the startle stimuli there was a softer sound (a 20 ms, 70 dB SPL(A)), 1 kHz tone which was the prepulse (5 ms rise/fall).

The EMG data were digitized at 1kHz using the Biopac M-150 system with a gain of 1000 and filter passband of 10-500 Hz. Raw data were stored and analyzed offline using in-house software. Before analysis, the EMG waveforms were filtered using 4^{th}-order Butterworth filters with -3 dB cutoff frequencies at 30 and 400 Hz. Response onset and peak latency were measured according to stimulus onset and peak amplitude relative to the 50 ms pre-stimulus baseline.

Stimuli

At the beginning of each startle session, each participant was asked to select, using a computer "color picker" the appropriate color for each letter of the alphabet and single-digit number. For the grapheme → color synesthetes, these were the colors they associated with the graphemes chosen. The non-synesthetes were simply asked to select a color that "goes with" each grapheme. After selecting colors for graphemes, participants were asked to rate, on a scale from 1 to 7, how close the color they had chosen matched the color they had intended to pick. During startle eyeblink recording, participants saw a subset of the graphemes for which they selected colors. The subset of graphemes were the ten graphemes with the highest ratings of similarity to what the participants had intended to choose as colors for particular graphemes. Half of the subset of these characters were presented in the color the participant selected, and half were presented in a different color (a color which the participants had rated as highly similar to another grapheme). I hypothesized that, for only the grapheme → color synesthetes, the incongruently colored graphemes would generate a negative affective response, amplifying the magnitude of their startle response. I also hypothesized that synesthetes would exhibit reduced prepulse inhibition compared to non-synesthetes.

Procedure

All testing was done in the Sensory and Cognitive Neuroscience Laboratory in the Department of Psychology at the University of Missouri-Kansas City. As they arrived, the researcher asked each participant to read and sign an informed consent form. The researcher explained the study and answered any general questions at that time. The participants were given a short survey requesting demographic information such as sex, age, and handedness (see Appendix A). Upon completion of the informed consent form and demographics survey, the researcher then administered the Synesthesia Screen (see Appendix B) to the participant as previously described (unless the participant had already been administered the Synesthesia Screen in a prior study), the SCNL Sensory Overload Questionnaire (see Appendix C), the Adult Sensory Profile, and the EPQ-R.

For the startle eyeblink portion of the study, rubbing alcohol was used to clean the skin just beneath the left eye and the left temple, and a pair of small (4 mm contactor area) recording electrodes were adhered to the skin just below the left eye with double-sided adhesive collars. These were attached far enough below the lower lid so as not to interfere with eyeblinks. A third (grounding) electrode was attached to the left temple. The participants were then led into the light and sound-attenuating chamber and seated in front of a computer, where they were asked to select colors for graphemes. Once they were finished with this task, participants were then asked to wear circumaural Sennheiser HD590 headphones. The electrodes on the participant were then attached to a Biopac MP150 data acquisition system, used to amplify the electrical signals from the infraorbital electrodes. These amplified signals were transmitted to a computer for data storage and analysis. At the end of the startle portion study, the electrodes were removed.

Each testing session lasted approximately two hours. At the end of testing, each participant was debriefed, including another summary of the study's purpose, an explanation of the measures, and a brief description of the hypotheses being tested. Participants who enrolled in psychology classes earned course credit for their participation at the discretion of their instructors.

Data Analysis

Startle data from two non-synesthete and six synesthete participants were excluded from the startle portion of the study, one due to the individual being a non-responder to startle stimuli. In this study, non-responders were defined as those participants who did not respond to more than 75% of the trials. The five remaining participants who were excluded from the startle portion of the study had startle responses that could not be properly filtered for analysis of their data for the majority of the startle conditions. Dependent measures I examined included startle magnitude, onset latency, peak latency, percent prepulse inhibition of startle magnitude, and percent facilitation of onset latency and peak latency. I calculated Percent PPI and latency facilitation by the following formula:

$$\frac{\text{(mean of pulse alone trials – mean of prepulse trials)}}{\text{(mean of pulse alone trials)}} * 100$$

All statistical tests were conducted using SPSS, with the alpha value for significance set at .05. When conducting ANOVAs, if significant differences were found, post hoc testing was conducted to ascertain the source(s) of the differences. Bonferroni tests were used to control for the effects of experiment-wise error rates, (Tabachnick & Fidell, 2001, p. 349).

CHAPTER 4

RESULTS

Main Analyses

Hypothesis 1: Incongruent Graphemes and Transient Negative Affect

Hypothesis 1 predicted that grapheme → color synesthetes would experience greater negative affect in response to incongruently-colored graphemes, as compared to non-synesthetes. Specifically, I expected that grapheme → color synesthetes would display greater eyeblink magnitudes in the incongruent condition than in the no picture or congruent conditions, and that for non-synesthetes eyeblink magnitude would not vary significantly across these conditions. A 3 (Picture Condition: Congruent, Incongruent, No Picture) x 2 (Run: 1, 2) x 2 (Presence of Synesthesia: Synesthete, Non-synesthete) mixed-design ANOVA with Presence of Synesthesia entered as between-groups factor was performed. The analysis did not support an interaction effect involving Presence of Synesthesia and Picture Condition, $F(2, 23) = 1.35$, $p > .05$. Overall means (collapsed across runs) for grapheme → color synesthetes in the conditions of No Picture, Incongruent, and Congruent in microvolts were 125.76 (SD = 102.47), 140.32 (SD = 112.87), and 135.44 (SD = 107.79), respectively. Overall means for non-synesthetes in the conditions of No Picture, Incongruent, and Congruent, in microvolts were 80.98 (SD = 62.70), 78.52 (SD = 65.99), and 77.49 (SD = 67.47) (see Figure 1).

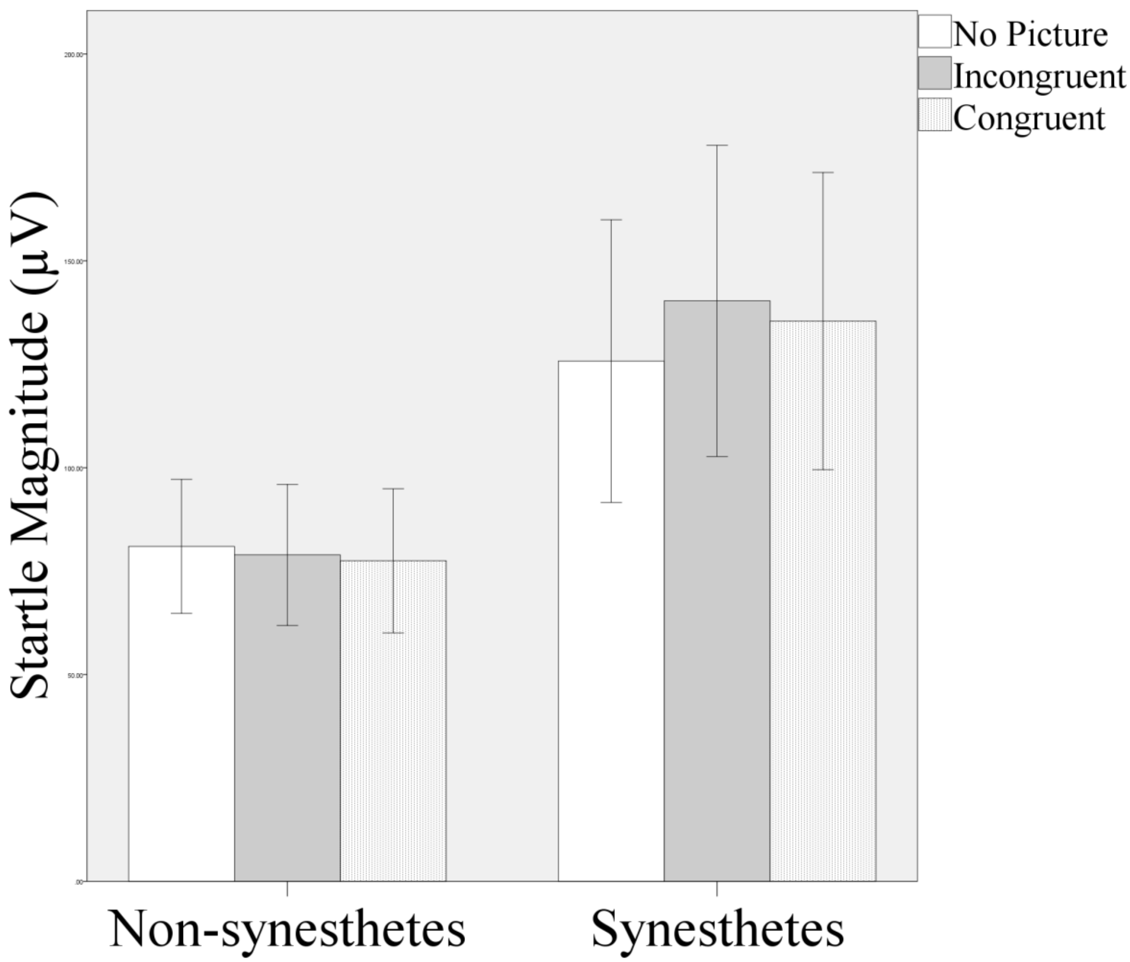

Figure 1. Mean Startle Response (+ SE) for non-synesthetes (n = 15) and synesthetes (n = 9) in the No Picture, Incongruent, and Congruent conditions

Hypothesis 2: Sensory Overload and Prepulse Inhibition

Hypothesis 2 predicted that synesthetes would show reduced ability to filter incoming sensory information as compared to non-synesthetes. This hypothesis was examined by comparing prepulse inhibition (PPI) between these two groups. Collapsing across runs and computed across picture conditions, a single group t-test determined the presence of PPI for onset latency, peak latency, amplitude, and magnitude, which was significant for all indices ($p < .05$).

Although synesthetes, as measured by the SCNL Sensory Overload Questionnaire and Adult Sensory Profile, reported more frequent and intense sensory overload experiences, analysis revealed no significant differences between synesthetes and non-synesthetes on PPI scores. In the reverse direction of the hypothesis, synesthetes exhibited more PPI for the magnitude of startle (*M* = 37.50, *SD* = 30.00) in the first run than non-synesthetes (*M* = 16.13, *SD* = 24.92). Independent samples t-tests revealed that these differences were not significant. The PPI values for magnitude of startle in the second run of the synesthetes (*M* = 29.16, *SD* = 28.17) and non-synesthetes (*M* = 28.14, *SD* = 20.86) were comparable, with no significant differences. To assess for habituation across runs, a paired samples t-test was conducted for the magnitude of PPI, yielding insignificant results.

These analyses were repeated with data from the two synesthetes who did not report experiencing sensory overload and data from non-synesthetes reporting sensory overload excluded, but the results were similar and remained insignificant.

Analyses were also conducted to examine the startle differences between synesthetes and non-synesthetes on trials with no prepulse (Control) and trials with a prepulse (Prepulse). A 2 (Condition: Control, Prepulse) x 2 (Run: 1, 2) x 2 (Presence of Synesthesia: Synesthete, Non-synesthete) mixed-design ANOVA with Presence of Synesthesia entered as between-groups factor was performed for magnitude of startle. Results were insignificant, [$F(1, 22) = 2.80$, $p > .05$].

Given the non-significant findings regarding presence of synesthesia and PPI, a correlational analysis was run between the methods chosen to assess for presence of sensory overload and PPI indices in this study. All correlations were small in size and statistically insignificant. Interestingly, self-report measures supported the hypothesis of synesthetes being more prone to sensory overload.

When comparing all participants on the subscales Sensory Sensitivity and Sensation Avoiding of the Adult Sensory Profile, with item 1 from the SCNL Sensory Overload Questionnaire as the between-subjects factor, a significant difference was found for Sensation Avoiding, $t(54) = -3.02$, $p < .01$. The mean Sensation Avoiding score for participants endorsing sensory overload was 41.11 ($SD = 11.14$); the mean Sensation Avoiding score for participants who did not endorse sensory overload was 34.37 ($SD = 5.53$). A trend was found for Sensory Sensitivity and Sensation Avoiding, $t(54) = -1.57$, $p = .09$. The mean Sensory Sensitivity score for participants endorsing sensory overload was 40.14 ($SD = 10.46$); mean Sensory Sensitivity score for participants who did not endorse sensory overload was 35.89 ($SD = 7.48$).

A Pearson's correlation was performed between the "How often have you felt this?," "How intense was this experience the last time it happened?," "How intense was this experience most of the time it happens?" and the Sensory Sensitivity and Sensation avoiding subscales. All subscales had significant correlations among them (see Table 1).

Consistent with a main hypothesis of synesthetes reporting and displaying greater Sensory Sensitivity compared to non-synesthetes, I expected that synesthetes would have higher overall and sub-scaled scores on the SCNL Sensory Overload Questionnaire. An answer of "No" to the first SCNL Sensory Overload Questionnaire item "Have you ever experienced sensory overload" excluded those participants from the remaining analyses. Of

Table 1

Intercorrelations between Subscales of SCNL Sensory Overload Questionnaire and Adult Sensory Profile

	Sensory Sensitivity	Sensation Avoiding
How often have you felt this ?	$r = .36, p < .01$	$r = .43, p = .001$
How intense was this experience the last time it happened?	$r = .35, p < .01$	$r = .46, p < .001$
How intense is this experience most of the time it happens?	$r = .45, p = .001$	$r = .48, p < .001$

the 27 synesthetes, three (11.11%) answered "No" to having experienced sensory overload, and 16 of the 29 non-synesthetes (55.17%) answered "No," a significant difference, Pearson's X^2 (1, N = 56) = 12.11, $p < .05$

For the purposes of this study, I created a SCNL Total score, which sums participants' answers to the three quantitative questions asked after a participant endorses experiencing sensory overload. The minimum possible score for SCNL Total (for participants who answer "yes" to experiencing sensory overload) is 3, and the maximum possible score is 15. Of the 37 participants who answered "Yes" to ever having experienced sensory overload, the synesthetes reported higher overall frequency of sensory overload than non-synesthetes. Analyses revealed significant differences between synesthetes and non-synesthetes on total scores of the subscales, $t(35) = -2.20$, $p < .05$ (see Table 2).

Table 2

Mean SCNL Sensory Overload Questionnaire Subscale Scores by Synesthetes and Non-synesthetes

	Frequency	Intensity(a)	Intensity(b)	SCNL Total
	M(SD)	*M(SD)*	*M(SD)*	*M(SD)*
Synesthetes (*n* = 24)	3.33(1.01)	3.73(.77)	3.48(1.08)	10.58(2.19)
Non-synesthetes (*n* = 13)	2.69(1.11)	3.15(1.07)	3.0(1.08)	8.85(2.48)

I predicted that synesthetes, overall, would score higher on the Sensory Sensitivity and Sensation Avoiding scales of the Adult Sensory Profile than non-synesthetes, and they did: $t(54) = -2.05$, $p < .05$ and $t(34) = -2.82$, $p < .01$. The overall means for Sensory Sensitivity and Sensation Avoiding for synesthetes were 41.37 (*SD* = 10.23) and 42.59 (*SD* = 11.74), respectively. Non-synesthetes' overall means for Sensory Sensitivity and Sensation Avoiding were 36.21 (*SD* = 8.62) and 35.31 (*SD* = 6.72), respectively.

Exploratory Analyses

People with synesthesia demonstrate variability in the nature and intensity of their synesthetic perceptions. For example, in one study, synesthetes with external concurrents had significantly fewer errors on the Farnsworth-Munsell 100 Hue test than synesthetes with internal concurrents (Gimmestad & Lovelace, in press). Given that synesthetes with external concurrents (who are called *external synesthetes)* perceive their concurrents projected onto their environment (or onto letters/numbers, as is the case with grapheme →

color synesthesia) as contrasted with synesthetes with *internal concurrents* (those who perceive concurrents in their mind's eye), I hypothesized that external synesthetes would experience more instances of sensory overload than internal synesthetes, with greater intensity. I also predicted external synesthetes' scores on the SCNL Sensory Overload Questionnaire and on the Adults Sensory Profile would reflect these more frequent and intense instances of sensory overload.

Of the synesthetes who answered "Yes" to ever having experienced sensory overload, External synesthetes had slightly higher total and sub-scale scores than internal synesthetes. However, these differences were not significant (see Table 3).

Table 3

SCNL Sensory Overload Questionnaire Scores of Participants with External Synesthesia and

Internal Synesthesia

	Frequency	Intensity(a)	Intensity(b)	SCNL Total
	M(SD)	*M(SD)*	*M(SD)*	*M(SD)*
External synesthetes (*n* = 7)	3.71(1.25)	3.76(.81)	3.64(.85)	11.29(2.81)
Internal synesthetes (*n* = 20)	3.18(.88)	3.71(.77)	3.41(1.18)	10.29(1.90)

Non-parametric test were conducted with Synesthesia Type (non-synesthete, external synesthesia, internal synesthesia) as the between-groups factor for all scales of the Adult Sensory Profile. Results revealed significant differences for the groups on Sensory

Sensitivity, $F(2, 53) = 3.24$, $p < .05$, and Sensation Avoiding scales, $F(2, 53) = 8.38$, $p = .001$. Follow up t-tests revealed that external synesthetes had significantly higher Sensory Sensitivity scores than internal synesthetes, $t(25) = -2.63$, $p = .01$. External synesthetes also had significantly higher Sensation Avoiding scores than internal synesthetes, $t(25) = -2.25$, $p < .05$ and non-synesthetes, $t(34) = -3.27$, $p < .05$ (see Table 4 for scores by group).

Table 4

Mean Scores on Sensory Sensitivity and Sensation Avoiding Subscales by Participants with External Synesthesia, Internal Synesthesia, and Participants without Synesthesia

	Total (*n*)	Sensory Sensitivity Score *M(SD)*	Sensation Avoiding Score M*(SD)*
External synesthetes	7	45.86(9.19)	50.57(11.89)
Internal synesthetes	20	39.80(10.32)	39.8(10.60)
Non-synesthetes	29	36.21(8.62)	35.31(6.72)

It was expected that, on the Eysenck Personality Questionnaire-Revised (EPQ-R), synesthetes would have lower scores on the Extraversion subscale than non-synesthetes. The rationale was that synesthetes, with greater overall Sensory Sensitivity as measured by the SCNL Sensory Overload Questionnaire and Adult Sensory Profile, would endorse fewer items on the Extraversion scale of the EPQ-R, such as “Do you like plenty of bustle and excitement around you?”

Synesthetes had significantly lower Extraversion scores overall, $t(54) = 2.05$, $p < .05$ (see Table 5). However, both age and gender are known to affect scores on the EPQ-R in normative samples. As age of participants increases, scores on the Extraversion Scale decrease; women also generally score higher on the Extraversion Scale than men (Eysenck et al., 1985). In this sample, gender was not significantly different between the two groups, Pearson's X^2 (1, $N = 56$) = 18.29, $p > .05$. However, age was significantly different, $t(54) = -2.92$, $p < .01$. An ANCOVA revealed that, when controlling for age, the difference in Extraversion scores between groups was no longer significant, $F(2,53) = 1.48$, $p = .23$. Presence of synesthesia was not found to have a significant effect upon the remaining three scales of the EPQ-R, $F(1,55)$, $p > .05$.

Table 5

EPQ-R Total Scores for Synesthetes and Non-synesthetes

	Extraversion	Psychoticism	Neuroticism	Lie
	M(SD)	*M(SD)*	*M(SD)*	*M(SD)*
Synesthetes ($n = 27$)	6.15(3.96)	2.16(1.80)	5.00(3.39)	5.27(3.62)
Non-synesthetes ($n = 29$)	8.17(3.43)	3.24(1.90)	4.48(3.19)	5.07(3.71)

A Pearson's correlation found significant correlations between the Adult Sensory Profile subscales, SCNL Total score (from the 37 participants who endorsed sensory overload), and EPQ-R subscales. Sensation Seeking correlated significantly and positively with Extraversion, Sensory Sensitivity correlated significantly and positively with

Neuroticism and with SCNL Total. Sensation Avoiding correlated significantly negatively with Extraversion, and significantly and positively with SCNL Total (see Table 6).

Table 6

Intercorrelations between Subscales for Adult Sensory Profile, SCNL Sensory Overload Questionnaire and EPQ-R

	Sensation Seeking	Sensory Sensitivity	Sensation Avoiding
Extraversion	r = .58, p < .001	r = .05, p = .74	r = -.30, p < .05
Neuroticism	r = .05, p = .73	r = .32, p < .001	r = .24, p = .08
SCNL Total	r = -.11, p = .52	r = .50, p < .01	r = .58, p < .001

When comparing synesthetes who reported sensory overload (n = 13) on the SCNL Sensory Overload Questionnaire to non-synesthetes who did not report sensory overload , (n = 10) EPQ-R Extraversion subscale scores were significantly lower, t(21) = 2.76, p = .01. The mean Extraversion score for synesthetes with sensory overload was 6.15 (SD = 4.0), and, for non-synesthetes without sensory overload, was 9.70 (SD = 2.06). The two groups were significantly different in both age [t(21) = -2.47, p < .05] but not gender [Pearson's X^2 (1, N = 23) = 9.78, p = .39.]. However, an ANCOVA revealed that, when controlling for age [F(1, 19) = .002, p > .05], Extraversion scores between groups remained significant, F(3,19) = 3.65, p < .05. Analyses were repeated for females (n = 19) separately. Female synesthetes reporting sensory overload (n = 10) had significantly lower Extraversion scores

(M = 6.90, SD = 3.87) than female non-synesthetes not reporting sensory overload (M = 10.11, SD = 1.69), $t(12.59) = 2.38$, $p <. 05$. An ANCOVA revealed that age [$F(1,16) = .37$, $p > .50$] did not affect the results.

Interestingly, when comparing all participants on Extraversion scores with item 1 from the SCNL Sensory Overload Questionnaire, significant differences in the Extraversion subscale scores were found, $t(54) = 2.51$, $p < .05$. The mean Extraversion score for participants endorsing sensory overload was 6.32 (SD = 3.76); the mean Extraversion score for participants who did not endorse sensory overload was 8.89 (SD = 3.35). The two groups were significantly different in both age [$t(54) = -4.46$, $p < .001$] and gender [Pearson's X^2 (1, N = 56) = 18.29, $p < .001$]. However, an ANCOVA revealed that age did not affect Extraversion scores [$F(1,53) = 1.32$, $p > .05$] and that the differences between these two groups remained significant, $F(3,19) = 3.65$, $p < .05$. Analyses were repeated for females (n = 44) and males (n = 12) separately. Females reporting sensory overload (n = 30) had significantly lower Extraversion scores (M = 6.60, SD = 3.70) than females not reporting sensory overload (n = 14; M = 9.21, SD = 2.69), $t(42) = 2.36$, $p <. 05$. An ANCOVA revealed that age [$F(1,41) = 3.39$, $p > .05$] did not affect the results. Males reporting sensory overload (n = 7) had lower Extraversion scores (M = 5.14, SD = 4.10) than males not reporting sensory overload (M = 8.00, SD = 5.05), although these differences were not statistically significant.

When comparing participants who endorsed sensory overload and those who did not on the subscales Sensory Sensitivity and Sensation Avoiding of the Adult Sensory Profile, an association was found for Sensory Sensitivity, $t(54) = -1.75$, $p = .09$; the mean score on

Sensory Sensitivity for participants endorsing sensory overload was 40.14 (*SD* = 10.46); the mean score for participants who did not endorse sensory overload was 35.89 (*SD* = 7.48). A significant difference was found for Sensation Avoiding $t(54) = -3.02$, $p < .01$. The mean score on Sensation Avoiding for participants endorsing sensory overload was 41.11 (*SD* = 11.14); the mean score for participants who did not endorse sensory overload was 34.37 (*SD* = 5.53).

CHAPTER 5

DISCUSSION

The purpose of this research was twofold. The first was to investigate whether synesthetes, when presented with incongruently colored graphemes, would display transient negative affect, as indexed by startle eyeblink modification. The second was to examine potential differences in sensorimotor gating, hence potential for sensory overload, in people with synesthesia compared to people without, as indexed by prepulse inhibition differences. The main goal of this research was to contribute to the existing literature by empirically investigating sensory and affective experiences described by synesthetes that, to my knowledge, until now had support only from case studies and anecdotal reports.

The first hypothesis, that grapheme → color synesthetes would display greater eyeblink magnitudes in the incongruent condition than in no picture or congruent conditions, and that for non-synesthetes eyeblink magnitude would not vary significantly across these conditions, was not supported. Although magnitude of startle was greater for grapheme → synesthetes than when viewing an incongruent grapheme compared to viewing a congruent grapheme or in the baseline (no picture) condition, these results were not statistically significant. Anecdotally, all synesthetes who underwent the startle paradigm portion of this study described feelings ranging from "uncomfortable" to "intolerable" when viewing the incongruent graphemes, and described difficulty in keeping their eyes upon the incongruently-colored grapheme. Although related research is scarce, the pattern of these results falls in line with research conducted by Callejas et al. (2007), Paulsen and Laeng (2006), and more recently Hochel et al. (2009).

Callejas et al. (2007) conducted a behavioral experiment upon a grapheme → color synesthete M.A., who reported negative emotions in response to incongruently-colored graphemes. In contrast to non-synesthetes, M.A. reported reduced rating for positively-valenced words when presented as incongruent graphemes. Similarly, M.A. rated congruently-colored negative valence words as being less negative than controls. The researchers interpreted these findings as supporting the hypothesis that viewing incongruent graphemes induces an automatic negative affective state in grapheme → color synesthetes (Callejas et al., 2007).

Paulsen and Laeng (2006) employed pupillometry to examine Stroop-like effects on grapheme → color synesthetes. As stated previously, increased pupil diameter (size) has been linked to emotional and novel stimuli, and increased information-processing load during mental tasks (Andreassi, 2000). Paulsen and Laeng hypothesized that showing grapheme → color synesthetes incongruently colored graphemes would ultimately result in increased pupil size. Indeed, grapheme → color synesthetes' pupils dilated more when viewing incongruently colored graphemes than congruent. A limitation to this study is that control participants were not included.

Recent research on R., a grapheme → color synesthete who reported affective reactions for colors, lends support to the idea of distress for synesthetes when their environment is incongruent with their automatic synesthetic concurrents (Hochel et al., 2009). Interestingly, R. related to researchers that, to him, not only did congruence between color and grapheme matter, but the emotional coherence between stimulus and corresponding photism mattered just as much to him, if not more. R. told researchers that he also experienced colored photisms in response to emotional stimuli. For example, he described attractive faces as red (having described red as having positive valence) and unattractive faces as being green (with the color green incited under repulsive or ugly conditions). Researchers presented R with graphemes presented congruently and incongruently colored, and asked him to rate them in terms of valence and arousal. Similar to this study and to that of Callejas et al. (2007) , researchers found that R. gave significantly more negative valence and higher arousal ratings when presented with incongruently-colored graphemes compared to when viewing congruently-colored graphemes.

Interestingly, when researchers framed the graphemes with a color that was either congruent or incongruent in emotional significance (say, a positive red frame around the number 5, which elicits the positively-valenced color blue or red for R.), a significant interaction occurred in that when the frames did not match, R. rated otherwise congruently-colored graphemes with more negative valence scores, and incongruently-colored graphemes with more positive valence scores. When researchers repeated presentation of the stimuli above to R. and presented him with the decision task of deciding as fast as possible whether the number was even or odd, R.'s performance was significantly less accurate in the incongruent conditions (whether it was an incongruent grapheme or frame) than in the congruent conditions (Hochel et al., 2009).

Taken together, the studies described above provide support for the negative affect reported by grapheme → color synesthetes when viewing graphemes incongruent with their synesthesia. The common cause for the negative affect in synesthetes among these studies is the *incongruency* between the presented stimulus and the synesthete's true concurrent for an inducer. Although these studies have explored the affective influence of incongruency regarding grapheme → color synesthesia, it would be interesting to explore incongruency in other types of synesthesia. For example, a researcher could have music → color synesthetes select musical note → color pairings and then present them with no picture, congruent, or incongruent colors displayed on a color screen as they listened to individual musical tones. Another idea would be to have time → location synesthetes map out their locations for certain inducers (days of the week, for example) in three-dimensional space and then take physiological measures from participants in addition to self-reported valence ratings for incongruent and congruent conditions.

Overall, it appears that the effects in this study and in others result from the underlying incongruency experienced by the synesthetes, specific to their synesthesia. It is strongly likely that these effects can and will be found in a number of differently manifested ways for different types of synesthesia and inducer → concurrent pairings.

The second hypothesis, that synesthetes reporting greater sensory overload would show reduced ability to filter incoming sensory information than non-synesthetes, as reflected by prepulse inhibition differences, hence showing greater potential for sensory overload, was partially supported. Although synesthetes did not display reduced PPI, significantly more synesthetes than non-synesthetes reported experiencing sensory overload and significantly higher levels of sensory sensitivity and sensation avoiding. Indeed, in this study there were no correlations found between PPI indices and items from questionnaires designed to examine sensory sensitivity and sensation avoiding.

Although PPI is often regarded as a stable physiological marker of sensorimotor gating, and is trait-related (Braff et al., 2001), there is some dispute as to the extent to which it measures sensory overload, and exactly what methodology most accurately captures prepulse inhibition differences. Agreement is lacking in the literature, but recent research has argued that, when taking into account baseline startle reactivity, differences in prepulse inhibition between groups such as extraverts and introverts diminish to the point of insignificance (Csomor, Yee, Vollenweider et al., 2008). In addition, some studies have suggested that prepulse inhibition differences are best detected with prepulses administered at approximately 60 milliseconds (this study delivered prepulses 120 milliseconds prior to a white noise startle stimulus) (Csomor, Yee, Feldon et al., 2008).

Despite the possible problems measuring prepulse inhibition as described above, a potential explanation for the lack of prepulse inhibition differences between synesthetes and non-synesthetes in this study is that, indeed, there is no difference in the general population between these groups for this measure. Although the population of synesthetes in this study did score higher on measures of sensory sensitivity and sensation avoiding, the underlying reasons for these higher scores are likely very different from, for example, those of people with schizophrenia who have scored higher on sensation avoiding (Brown et al., 2002). Whereas people with schizophrenia have reported distress related to sensory overload, this has often been attributed to more generalized difficulties with sensory processing (deficits in PPI) (Brown et al., 2002). In contrast, much of the anecdotal evidence presented for sensory overload in people with synesthesia has centered around the types of synesthesia experienced by individuals (as in the example of a synesthete with sound → touch synesthesia being overwhelmed by attending a symphony) with the overload specific to a synesthetic inducer. I would argue that further research on the fine shades of what people with synesthesia mean when they describe being "sensitive" or having "sensory overload" —and how these experiences relate to their synesthesia—would help to further elucidate the synesthetic experience, hopefully across many different forms.

Another potential explanation for the lack of prepulse inhibition differences in this study is that, whereas the clinical disorders associated with decreased prepulse inhibition are disorders that cause significant distress and interfere with daily life, synesthesia does not fall into the category of disorder. Even in the case of schizophrenia, self-reports of sensory overload have not corresponded to deficits in sensory gating as measured by psychophysiological methods (Light & Braff, 2000). Jin et al. (1998) conducted an innovative study in which 16 patients diagnosed with schizophrenia who reported sensory inundation due to perceptual anomalies were compared to 16 patients with schizophrenia who did not report perceptual anomalies, and 16 normal subjects. Surprisingly, results revealed that the P50 patterns of patients reporting perceptual anomalies did not differ from normal subjects. However, patients not reporting perceptual anomalies exhibited the abnormal P50 ratios previously linked with schizophrenia. The authors concluded that their study did not support a significant relationship between self-reported feelings of being overwhelmed by sensory stimuli and abnormal P50 patterns (Jin et, al., 1998).

Interestingly, synesthetes also had higher overall amplitudes and magnitudes of startle. These differences were statistically significant. In addition, the peak latencies were significantly shorter in synesthetes than non-synesthetes, which is not surprising, given the overall greater startle amplitudes and magnitudes of the synesthetes and general reactivity, both psycho-physiological and self-reported. In addition, synesthetes had lower overall Extraversion scores than non-synesthetes. Although these differences were not significant once age was taken into account, Introversion, as measured by the EPQ-R, has been linked to greater general startle reactivity, including greater startle magnitudes and shorter latencies (Blumenthal, 2001).

Blumenthal (2001) examined presence of extraversion or introversion as a between-subjects factor in a startle study. He administered the Eysenck Personality Inventory to approximately 800 college students. He then took the upper quartile (n = 24) "extraverts" and the lower quartile (n = 23) "introverts" and enrolled them in his startle study. Blumenthal asked participants to direct their attention to a startle-eyeblink-eliciting acoustic noise pulse (90 or 105 dB) or to animal drawings, or to ignore all stimuli, while measuring their eyeblink reflex to the noise pulse. Regardless of instructions to attend or not attend to visual or acoustic stimuli, and independent of stimulus intensity, he found introverts to generally be more reactive (have greater magnitudes and amplitudes of startle eyeblink). Similar to the present study, he found that introverts showed more variation, across conditions, in their startle responses than extraverts. Blumenthal also posited that he and other researchers had conducted similar examinations of extraverts and introverts before, but significant differences were not found if introverts and extraverts were selected based upon a median split. Rather, he argued that differences in magnitudes and amplitudes of startle eyeblinks are not great enough to yield statistically significant findings when not comparing more extreme groups in terms of extraversion levels. It is tempting to postulate that with a larger sample size, this study could have replicated Blumenthal's method and yielded similar results.

The standard deviations for the sensory sensitivity and sensation avoiding scores for the synesthesia group were almost twice that of the non-synesthetes group. This would suggest that some persons with synesthesia reported very high scores, compared to others who reported very low scores. Although the comparison between external and internal synesthetes did not produce statistically significant findings, the trends in the data are interesting and could be further explored with greater sample sizes in the future to increase the power of the study. Individuals with external synesthesia had higher mean scores on the sensory sensitivity and sensory avoiding subscales than individuals with internal synesthesia, suggesting that subtypes of synesthesia could have contributed to the variability observed in this study.

Regarding the variance in scores among synesthetes in this study, I have posed potential explanations such as location of the concurrent, and type of synesthesia. As synesthesia has been implicated in enhanced sensory perception and also increased sensitivity, future research would benefit from further exploring the sources of differing perception(s) and sensitivity. For example, when interviewing synesthetes, I have typically found that people with synesthesia do not possess just one form. Although this study focused upon grapheme → synesthesia, the majority of synesthetes reported other forms. Other forms included forms that I had never heard of before, such as geometric shapes → colors. It would be interesting to examine if the number of different forms of synesthesia influences the degree of sensitivity a person reports as well.

The existing literature has provided mixed opinions on how synesthesia influences a person's daily life. For example, Daniel Tammet, who memorized pi to 22,514 digits, wrote in his autobiography (2007) that his synesthesia was the reason for his prodigious mathematical and memorization abilities. In contrast, there have also been reports about synesthesia disrupting an individual's efforts in math (Green & Goswami, 2008). In my conversations with synesthetes over the course of this research project, I have heard varying reports, with synesthesia described as being helpful or detrimental (sometimes both from the same individual) in academic pursuits. Hence, there may be no definitive answers as to how synesthesia affects one's life in the veridical domain. Rather, research may help to bring awareness about factors that are likely to influence the daily sensory and conceptual experiences of synesthetes.

In conclusion, this study provided, to my knowledge, the first empirical examination (aside from two case studies) of reports of distress reported by synesthetes when viewing graphemes incongruent with their synesthesia, in addition to examining synesthetes for increased potential for sensory overload. However, additional research is needed to further explore the extent to which synesthetes experience transient negative affect and sensory overload. Future research would benefit from clinical measures of type and number of forms of synesthesia, the location of the synesthetic concurrents, and whether these concurrents are conceptual and or perceptual. All of these mentioned variables have the potential to explain some of the variability in responses to self-report measures and in psycho-physiological testing in this study.

APPENDIX A

SCNL Demographic Form

University of Missouri - Kansas City, Dept. of Psychology
Sensory and Cognitive Neuroscience Laboratory

subj-screen.doc
rev. 7/23/04

SCNL Health Screening Form

Subject ID#: ___________

Interviewer name: ____________________________

Date: _________________

I just need to ask you a few questions.

How old are you? ___________ yrs. What is your date of birth? (mo/da/yr) _______________

IF UNDER 18 YRS.: I'm sorry, but we're only looking for people 18 years of age or older. [end here]

Sex: MALE FEMALE [ask if not sure]

Do you wear eyeglasses or contact lenses? GLASSES CONTACTS NEITHER

If GLASSES/CONTACTS, is your vision good while wearing these? YES NO

If NO, explain: ____

____

If NEITHER: do you have any problems seeing? YES NO

If YES, explain: ____

____

[If they can't clearly see the computer monitor, end here.]

Do you have any problems hearing? YES NO

If YES, explain: ____

____

[If they can't hear sounds at about the level of normal speech, end here.]

Are you left-handed, ambidextrous, or right-handed? LEFT AMBI. RIGHT

Edinburgh score: _______________ [do before first session]

Do you have sensitivity issues with your sense of touch? YES NO

If YES, explain: ____

Is English your first language? YES NO

If NO, how old were you when you learned to speak English? ____________________

[What is your impression of this person's ability to speak and understand English?]

EXCELLENT GOOD FAIR POOR NOT AT ALL

APPENDIX B

NIMH-NAROPA SYNESTHESIA SCREEN INTERVIEW (RESEARCH VERSION)
Naropa University Consciousness Laboratory (© 2004 Peter Grossenbacher)

Screen Session Logged: ________ Data Entered: ________

Staff Inits: _________ Today's Date (m/d/y): ____/____/__________

Start Time: _________ End Time: _________ MinutesTotal: _________

First: ___________________________ Last: ______________________________

Participant ID#: ____

Participant Age: ______ Participant Sex: __________

Interview Medium: telephone in-person (circle one)

Section I: Synesthetic Perception

Sometimes, something experienced in *one* of the five senses triggers extra sensations in *another* sense. Here is an example to give you an idea of how this could work. Suppose when you touch something hard like concrete, you get the smell of **vanilla**, or when you touch something soft like cotton, you get the taste of **salt**.

To find out if you've had any such experience ever in your life, I'm going to go through a series of Yes-or-No questions. Say "Yes" if it seems clear to you that you have had the experience in question, otherwise say "No." If nothing comes to mind within a few seconds, we will go on to the next question. If you are unsure how to answer any question, please say so.

If at any time something comes up in response to an earlier question, then tell me right away. Also, let me know if you don't understand something.

I will be taking notes, and may pause from time to time as my writing catches up. Do you have any questions, or shall we get started?

S1. Has any sense other than your sense of hearing ever produced an experience of **hearing** anything?	Yes No

Details Noted

S2.	Has any sense other than your sense of sight ever produced an experience of **seeing** anything?	Yes No
S3.	Has any sense other than your sense of smell ever produced an experience of **smelling** anything?	Yes No
S4.	Has any sense other than your sense of touch ever produced an experience of **touching** anything or feeling a skin sensation?	Yes No
S5.	Has any sense other than your sense of bodily position ever produced an experience of feeling a particular **body position or movement**, such as arms out or waist bending, even if you are **not** in that posture or movement?	Yes No
S6.	Has any sense other than your sense of taste ever produced an experience of **tasting** anything?	Yes No
S7.	Has **being startled** ever had location, shape, color, texture, movement, weight, sound, smell, taste, or any other sensation?	Yes No
S8.	Have shapes, shades of gray, colors, or anything that you **see** ever had location, shape, color, texture, movement, or any other sensation other than how they're printed?	Yes No
S9.	Have **numbers** that you see or hear ever had location, shape, color, texture, movement, weight, sound, smell, taste, or any other sensation other than how they're printed?	Yes No
S10.	Have **letters** of the alphabet or **words** that you see or hear ever had location, shape, color, texture, movement, weight, sound, smell, taste, or any other sensation other than how they're printed?	Yes No
S11.	Have you ever experienced **anything similar** to what we have been talking about so far that has not been mentioned yet?	Yes No

TimeCheck:__________ MinutesElapsedDuringSynestheticPerception:_____

Section II: Synesthetic Conception

Sometimes, an idea or concept triggers a sensory experience, or sensation. The thought and the sensation go together, so when you have the thought, the sensation happens with it. Sensations may include location, shape, color, texture, movement, weight, sound, smell, taste, etc.

Here is an example to give you an idea of how this could work. Suppose you hear a **high-pitched sound** whenever you think about wealth, or thinking about infinity produces a **skin sensation on your left ankle**.

To find out if you've had any such experience ever in your life, I'm going to go through a series of Yes-or-No questions. Say "Yes" if it seems clear to you that you have had the experience in question, otherwise say "No." If nothing comes to mind within a few seconds, we will go on to the next question. If you are unsure how to answer any question, please say so.

If at any time something comes up in response to an earlier question, then tell me right away. Also, let me know if you don't understand something. OK?

Details Noted

C1.	When thinking about **numbers** in any context, have they ever had location, shape, color, texture, movement, weight, sound, smell, taste, or any other sensation?	Yes No
C2.	When you have felt **any emotion**, has that ever had location, shape, color, texture, movement, weight, sound, smell, taste, or any other sensation?	Yes No
C3.	When thinking about any **periods of time**, such as minutes, hours, days, weeks, months, seasons, years, or periods of history, etc., have they ever had location, shape, color, texture, movement, weight, sound, smell, taste, or any other sensation?	Yes No
C4.	When thinking about **places or geographic locations**, have they ever had shape, color, texture, movement, weight, sound, smell, taste, or any other sensation?	Yes No
C5.	Have you ever experienced **anything similar** to what we have been talking about that has not been mentioned yet?	Yes No

TimeCheck:__________ MinutesElapsedDuringSynestheticConception:_____

Section III: Synattribution

Sometimes, an experience includes a sensed quality. The experience and the sensed quality go together, so when you have the experience, the sensed quality happens with it. Sensed qualities may include personality, gender, age, evenness or oddness, atmosphere, et cetera.

Here is an example to give you an idea of how this could work. Suppose you experience the number 5 as mean, or the color red produces a sense of evenness.

To find out if you've had any such experience ever in your life, I'm going to go through a series of Yes-or-No questions. Say "Yes" if it seems clear to you that you have had the experience in question, otherwise say "No." If nothing comes to mind within a few seconds, we will go on to the next question. If you are unsure how to answer any question, please say so.

If at any time something comes up in response to an earlier question, then tell me right away. Also, let me know if you don't understand something. OK?

Details Noted

N1.	Have you ever experienced a **personality** characteristic or attitude as part of something other than a person or other being?	Yes No
N2.	Have you ever experienced **gender**, such as male or female, as part of something other than a person or other being?	Yes No
N3.	Have you ever experienced **evenness or oddness** as part of something other than a number or numeric quantity?	Yes No
N4.	Have you ever experienced youth, elderliness, or any **age** as part of something other than someone or some thing that actually has age?	Yes No
N5.	Have you ever experienced **mood or emotion** as part of something that does not actually have mood or emotion?	Yes No
N6.	Have you ever experienced anything similar to what we have been talking about that **has not** been mentioned yet?	Yes No

TimeCheck:_________ MinutesElapsedDuringSynattribution:_____

Section IV: Knowledge

Verbal Response

K1. Have you ever heard of "synesthesia?" "Yes" **"**No"

{If has heard:} K2. Do you know what synesthesia is? "Yes" **"**No"

{If does know:} K3. In your own words, what is synesthesia?

{If does know:} K4. Have you ever experienced synesthesia? "Yes" **"**No" Unsure

{If Yes or Unsure, that is, possibly has experienced synesthesia:}

K5. What kinds of synesthesia have you experienced?

{If mentions any form not already discussed: Ask secondary questions.}

K6. It is important that we have not missed anything or gotten something wrong. So is there anything you'd like to go over again? "Yes" **"**No"

End Time: _________

Secondary Questions: Examples, Inducers, and Concurrent Attributes

{Example 1:} Please give me an example. {Example 2:} Please give me another example.

{>> If has mentioned only a partial subset of a known inducer set, ask until answer is no: }

{Inducers:} Have any [known inducers] other than [mentioned inducers] had [concurrent]?

{>> Ask until answer is no: }

{More Concurrent Attributes:} Have [inducers] ever had anything besides [concurrent]?

Parametric Questions

A. {Locus:} With [inducers] having [concurrent attribute], where have you experienced the [concurrent attribute]?

B. {Age:} How old were you when [inducers] first had [concurrent]?

C. {Cause:} Do you know of any event that may have caused [inducers] to have [concurrent]?

{if Yes:} D*. *What may have caused [inducers] to have [concurrent]?*

E. {Recent:} How long ago was the most recent time that [inducers] had [concurrent]?

F. {Condition (Med & Spec):} With [inducers] having [concurrent], has that happened ***only*** in specific circumstances, such as having taken a drug or medication, or while in any particular state of mind?

{if Yes:} G*. *What are the specific circumstances?*

H. {Count:} How many times in your life have [inducers] had [concurrent]?

{if count > 2 & < 5:} I*. *How old were you each time [inducers] had [concurrent]?*

{if count > 4:} J. {Stop:} Have [inducers] ever stopped having [concurrent] {condition}?

{if Yes:} K. {stopAge:} How old were you when [inducers] first no longer had [concurrent] {condition}?

{if Yes:} L. {stopDur:} For how long had [inducers] stopped having [concurrent] {condition}?

{if Yes:} M. {stopWhy:} Do you have any idea why [inducers] stopped having [concurrent]?

{if count > 4:} N. {absFreq:} During your most recent experiences of [inducers] having [concurrent], ***how many times*** per day or month or other time period was there [concurrent]?

{if count > 4:} O. {relFreq:} During your most recent experiences of [inducers] having [concurrent], in those instances of [perceiving] [inducers] {condition}, what percent of the time was there [concurrent]?

{if count > 4:} P. {MoreFreq:} Was there ever a time in your life when, for those occasions that you [perceived] [inducers] {condition}, they had [concurrent] ***more*** than during your most recent experiences of [inducers] having [concurrent]?

{if Yes:} Q. {+age:} How old were you when, for those occasions that you [perceived] [inducers] {condition}, they had [concurrent] the ***most***?

{if Yes:} R. {+freq:} Back then, when you [perceived] [inducers] {condition}, what percent of the time was there [concurrent]?

{if count > 4 & never stopped:} S. {less:} Was there ever a time in your life when, for those occasions that you [perceived] [inducers], they had [concurrent] ***less*** than during your most recent experiences of [inducers] having [concurrent]?

{if Yes:} T. {-age:} How old were you when, for those occasions that you [perceived] [inducers], they had [concurrent] {condition} the ***least***?

{if Yes:} U. {-freq:} Back then, when you [perceived] [inducers], what percent of the time was there [concurrent]?

V. {Vivid:} During your most recent experiences of [inducers] having [concurrent], ***how vivid*** was the ***most vivid*** [concurrent] you experienced? Use a scale from 1 to 7, 1 is no [concurrent] sensation at all, you only have the ***idea*** of it. 7 is [concurrent] as distinct and clear as you have ever experienced in any circumstance.

W. {MoreVivid:} Was there ever a time in your life when [inducers] had [concurrent] ***more vivid*** than during your most recent experiences of [inducers] having [concurrent]?

{if Yes:} X. {+age:} How old were you when [inducers] had the ***most*** vivid [concurrent]?

{if Yes:} Y. {+viv:} Back then, when you [perceived] [inducers], **how vivid** was the ***most* vivid** [concurrent] you experienced? Use a scale from 1 to 7, 1 is no [concurrent] sensation at all, you only have the ***idea*** of it. 7 is [concurrent] as distinct and clear as you have ever experienced in any circumstance.

Z. {Purpose:} With [inducers] having [concurrent], has that happened ***only*** on purpose? Or did you ever not mean for [inducers] to have [concurrent] but they did anyway?

AA. {Prefer:} On a scale of 1 to 7, would you prefer that [inducers] have [concurrent], or not? 1 is strongly preferring that [inducers] **not** have [concurrent], 7 is strongly preferring that [inducers] **do** have [concurrent], 4 is no preference either way.

{>> Ask until answer is no: }
AB. {Other:} Is there anything else important about [inducers] having [concurrent] that has not been mentioned yet?

APPENDIX C

SCNL Sensory Overload Questionnaire

The intent of the SCNL Sensory Overload Questionnaire is to ascertain whether a person has experienced something akin to what synesthetes describe as “sensory overload.” While this term receives frequent use in the autism literature, we here specifically refer to the experiences described by synesthetes. However, this measure is meant to ascertain the presence or absence of this experience in a synesthesia-independent way. The questions should be answerable by both synesthetes and non-synesthetes.

INSTRUCTIONS
Start by reading the Introduction to the participant. Then read each question to the participant and write their answers in the space provided.

INTRODUCTION
Some people report, experiencing at one time or another, what could be called "sensory overload." These are occasions when they find it difficult to deal with all of the incoming sensory information (lights, sounds, smells, touches, etc.). I’d like to find out whether you have ever had an experience like this

1. Have you ever felt this? YES NO

If YES, continue…

2. How often have you felt this?
    a) Once
    b) A few times
    c) A few times per year
    d) A few times a month
    e) More frequently

3. When was the first time you felt this? ______________________________

____

____

4. (If more than once to #2 →) When was the last time you felt this?

____

5. I'd like to get an idea of how intense this experience may be. How intense was this experience the last time it happened?
   a) Barely noticed it
   b) Slightly annoying
   c) Fairly annoying
   d) Very annoying
   e) Disabling

6. How intense is this experience most of the time it happens?
   a) Barely noticed it
   b) Slightly annoying
   c) Fairly annoying
   d) Very annoying
   e) Disabling

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VITA

Katherine Dawn Gimmestad was born in Boulder, Colorado. She was raised in the Upper Peninsula of Michigan and graduated from Houghton High School in 1994.
Ms. Gimmestad attended Alma College for two years before transferring to the University of Michigan and graduating with a Bachelor’s in Science in Biological Psychology in 1998. She obtained her Master’s in Arts from the University of Missouri-Kansas City in 2010.

After completing her undergraduate education, Ms. Gimmestad worked for a business corporation for three years before returning to academia. In addition to her graduate coursework, she has had varied experiences in clinical practice, including in settings such as public hospitals and outpatient clinics. Ms. Gimmestad completed her pre-doctoral internship at the Center for Behavioral Medicine in Kansas City, Missouri.

Ms. Gimmestad has been a Research and Teaching Assistant at the University of Missouri-Kansas City during her graduate studies. She was twice awarded funds by the Women’s Council of the University of Missouri-Kansas City to support her research on synesthesia. One of these awards was with outstanding merit, allowing her to travel and present her findings at the University of Oxford. In addition to research and teaching, During graduate school, Ms. Gimmestad has enjoyed tutoring individual students, primarily high school students, in math and science.

Ms. Gimmestad recently accepted a postdoctoral fellowship in Advanced Clinical Psychology Training (emphasis in Smoking Cessation) at Edith Nourse Rogers Memorial Veterans Administration in Bedford, Massachusetts. Ms. Gimmestad will begin her advanced training with this site in September 2011.