

A Linguistic Relativity Study Involving
the Visual Mismatch Negativity Component and English and Vietnamese Colors

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Abstract

The Whorfian hypothesis proposes that the structure of language shapes thoughts. This hypothesis has been addressed through a diverse facet of topics, the most frequent one being color. It has been well established that color categories produce a category advantage, with better performance on a discrimination task for between- compared to within-color categories. Interestingly, this category advantage is eliminated in the presence of verbal interference, suggesting language to be the driving factor. Then the question became how and to what degree language influences color categories. Using an automatic and pre-attentive change detector, the visual mismatch negativity (vMMN), a cross-linguistic study observed that a change in luminance elicited a larger deviancy during an oddball task when different terminology for the two luminance levels were linguistically available compared to when they were not. As a follow-up, exploiting the differences between Vietnamese and English color terminology, this study looked at the deviancy effect between color pairs that were and were not linguistically differentiated. It was numerically demonstrated that having a single term for a color pair eliminated a difference perception as reflected by the vMMN. However, it is unclear whether or not this influence of language is present in the absence of attention, as attentional-like components were observed in conjunction with the vMMN in response to the deviant stimulus. These findings further supports the hypothesis that language shapes thoughts, however, they also raise concerns in regards to the degree of automaticity with which this effect occurs.

For my Daddy-

For all that you have done for me.

I can't even begin to count the ways.

Cho Ba-

Cho hết điếu ba làm cho con và da dính mình.

Bao nhiêu lần ba đã hy sinh, con không thể nào đếm được.

Chapter 1: Introduction

1.1 Overview

Language enables communication among people who share a common language. It empowers members of a society to share complex ideas and progress as a community. However, potentially more than just another tool to be wielded as necessary, the language we speak may actually influence our cognitive processes and affect our perception of the world. Cognitive categories have been shown to facilitate attention and memory, as well as influence the trajectory of thoughts since cognitive categories form concepts that are then mapped together to form thoughts. Therefore, if the structure of language contributes to the formation of cognitive categories, then language would contribute to the shaping of thoughts. Although it has been widely shown that the linguistic categories, as defined within a particular language, reflect the cognitive categories of speakers of that language, it is unclear how exactly this happens. This raises several questions: Can an individual's language affect perception on a pre-attentive and unconscious level? Are verbal codes automatically activated in perception? Is language shaping the perceptual system over time? Even though the human perceptual system is structurally universal and therefore, initially language independent, is it possible that linguistic experiences may be influencing automatic, low-level, non-conscious perceptions of the experienced world? Investigating these questions is important because if lexical and grammatical differences influence the way we think, then understanding the language features and the mechanisms through which they affect specific cognitive processes may be the key to understanding cultural differences.

1.2 The Sapir-Whorf Hypothesis

Does language shape thought? Do speakers of different languages conceptualize experiences differently? Do the differences in lexicon and grammar result in corresponding differences in thinking? Throughout history, notable scholars have made

the argument that language does indeed influence thought. For example, Herodotus, a historian, was of the opinion that the direction in which people wrote, Greeks from left to right, Egyptians from right to left, affected how they thought (Fishman, 1980), and Einstein, a physicist, concluded that there was a relationship between language and thought, the mode of concept form highly dependent on language (Einstein, 1954). But most famously, a linguist named Benjamin Lee Whorf, who studied under the anthropology linguist Edward Sapir, wrote extensively on this matter and the hypothesis that developed out of these writings is collectively coined the Sapir-Whorf, or the Whorfian hypothesis.

Sapir, commenting on cross cultural perception of physical stimuli, stated that "We see and hear and otherwise experience very largely as we do because the language habits of our community predispose certain choices of interpretation" (Sapir, 1929), implying that spoken language influences real world perception. Building up from this idea, Sapir extrapolates that social realities are constructed on a group's language habits, and therefore, "different societies live in distinct worlds, not merely the same worlds with different labels attached" (Sapir, 1929). Whorf expanded upon Sapir, ubiquitously quoted as writing, "We dissect nature along lines laid down by our native languages"(Whorf, 1940). This has been interpreted to mean that the way people perceive the world is a function of their language. There is both a strong and a weak interpretation of Whorf's hypothesis: the former, linguistic determinism, implies that language completely determines thought through the categories made available by the language; and the latter, linguistic relativity, suggests that differences among languages result in corresponding differences in the thoughts of their speakers (Pinker, 1994), potentially by influencing non-linguistic cognition.

The radical, strong determinism interpretation of the Whorfian hypothesis has been disproven. Language-imposed categories do not limit the means through which the world can be experienced. For example, the effects of language on perception discrimination can be reversed, as judgments of the distance between colors, found to be distorted by language in English participants, were reverted to conformity when the use of a naming strategy was precluded (Kay & Kempton, 1984). Therefore, although

language cannot necessarily determine thought, it can nevertheless influence it, supporting the weaker relativity hypothesis.

1.2.1 Critiques of the Sapir-Whorf Hypothesis

Although the Whorfian hypothesis has generated a substantial body of research over the past few decades, many cognitive psychologists are still skeptical of it, believing that language functions only as a means of communication (Bloom, 2000). This critique is mainly based on Pinker's presentation of Whorf's hypothesis in his denouncement of it: "The idea that thought is the same as language is an example of what can be called a conventional absurdity (Pinker, 1994)". In his argument, Pinker illogically suggests that because people do not think in language, language does not shape thought. As argued by Casasanto (2008), although the determinism interpretation of Whorf implies the relativity interpretation, it is not the case that the falseness of the determinism interpretation implies the falseness of the relativity interpretation, as the truth-value of the latter does not require the truth-value of the former. However, Pinker's erroneous reasoning has repeatedly been implemented to reject Whorf's overall.

Although not all thinking requires language, language does mediate certain types of thinking, such as the assignment of gender and gender-related qualities to nouns. This phenomenon is observed in languages with grammatically gendered nouns, and has also been found to carry over in the learning of a second language that does not have gendered nouns (Tight, 2006). Once again, does language shape thought? The key to answering Whorf's hypothesis is not an all-or-nothing approach, as his critics have presented it. Instead, it requires a re-framing of the Whorfian question, which should not be interpreted as whether or not language affects non-linguistic processes, but rather, to what extent linguistic processes are typically involved in non-linguistic tasks (Winawer et al., 2007). Many approaches have been taken to tease apart Whorf's hypothesis, one of which is the investigation of linguistic categorization on color perception.

1.3 Linguistic Influences on the Perception of Color

A color hue is represented in the visual system as a mixture of three focal colors, red, green and blue (Caelli, 1981), perceived through the corresponding cones in the retina and then processed in the visual cortex. The physiological constraints of the visual system are similar within the human specie and across speakers of various languages, resulting in similar sensory perceptions of color across individuals irrespective of language. For example, members of the Indonesian Dugum Dani tribe, while only possessing two basic color terms, are capable of remembering and recognizing colors spanning the range of the color spectrum (Heider, 1972). Additionally, the Dani have also been shown to have a cognitive organization for colors similar to that of English speakers, accurately recognizing colors with names in English more often than those without names (Brown & Lenneberge, 1954; Heider, 1972), demonstrating that the structure of color space is independent of lexical categories for colors. However, even though the color spectrum and its physical perception may be continuous, the color terms in a given language can carve the continuum into different discrete categories. As a result, the cognitive processes that interact with said sensory perceptions can potentially be influenced by language. For example, bringing it back to the Dani, while their differential memory for colors was similar to that of English speakers, their overall memory performance on the color recognition task was poorer than that of English speakers (Heider, 1972), most likely because of the lack of lexical color terms (Roberson, 2005). This same effect was observed with members of the Melanesian Berinmo tribe, for whom the relationship between color naming and color memory best explained their performance on a color task similar to that used in the study conducted with the Dani (Roberson et al., 2000). According to Sapir, "colour language can affect colour cognition" (Sapir, 1929), and indeed, a large body of research has established that language constrains the perception of color into its linguistic categories.

Color categories are formed when the physical color continuum is partitioned into qualitatively discontinuous perceptual segments. Roberson et al. (2000) was able to exploit the linguistic differences between English and Berinmo to look at the effects of linguistic color boundaries. English differentiates between blue and green, a distinction

that is absent in Berinmo, and Berinmo differentiates between 'nol' and 'wor,' a distinction that is absent in English. In an odd-man-out task that allowed decisions to be made using any criteria, all participants more consistently made judgments in line with their own color vocabulary compared to judgments relating to the color vocabulary of the other language, for which judgments incorporating color were at chance level. The linguistic color boundaries were even reflected in the performance of a language irrelevant stimulus sorting task with feedback. Furthermore, in a color recognition task, speakers of both languages demonstrated a cross-category advantage corresponding with their language. Corresponding to these differences observed between speakers of English and Berinmo, there is indubitably a discrimination advantage in cross-color-category compared to within-color-category stimuli that is consistent with how a language partitions the color spectrum. This color category advantage can be observed in that performance on color discrimination and visual search tasks is faster and more accurate when the colors are of two different color categories (between category) compared to when they are of the same category (within category) (e.g., (Bornstein & Korda, 1984). For example, due to the obligatory linguistic distinction between lighter and darker blues in Russian, "goluboy" and "siniy" respectively, Russian speakers cannot avoid distinguishing between the two in speaking. This categorical distinction between the two shades of blue provides Russian speakers a category advantage in non-linguistic color discrimination tasks. However, this advantage is eliminated by verbal interference when subjects are required to perform simultaneously a task requiring verbal processing, such as silently rehearsing a digit string, which naturally prevents them from using their normal naming strategies. In contrast, this advantage is not affected by spatial interference, which requires subjects to simultaneously maintain a spatial pattern in memory (Winawer et al., 2007). These findings suggest that linguistic categories can influence perceptual decisions on-line, but does not support the hypothesis that language physically changes perceptual processors (Goldstone, 1994) since verbal interference was enough to disable the advantage. This is supported by another study that found a verbal dual task to interfere with blue/green perceptual discrimination among English speakers whose language linguistically makes a distinction between blue and green (Witthoft et al., 2003).

Verbal interference has been observed to affect perceptual tasks more profoundly when presented in the right visual hemifield, and therefore, the left, or language dominant hemisphere (Gilbert et al., 2006). Recently, the categorical perception of color has been investigated using brain-imaging techniques, which enable the establishment of the time course and neural correlates of this phenomenon. Using the functional magnetic resonance technique (fMRI), it was observed that the categorical advantage during a color search task was correlated with enhanced activity in regions of the visual cortex¹ and language related brain areas² in between- compared to within-category conditions (Siok et al., 2009), suggesting that color categories are registered during the early stages of chromatic processing and modulated by language. Another method of brain-imaging research that has been implemented in investigating the correlates of color categories is the event-related potential technique.

1.4 The Event-Related Potential Technique

Neuron to neuron communication in the brain is executed via neurotransmitter binding and the consequential opening and closing of ion channels. The opening and closing of ion channels result in changes to the electrical potential across cell membranes. Scalp electrodes record the summation of post-synaptic potentials from approximately 10^3 - 10^4 neurons (Kutas & Van Petten, 1994). Using electrodes placed on the scalp, we can obtain an electroencephalogram (EEG), which is a coarse measure of electrical brain activity, amplified and plotted as a function of voltage (μV) over time (ms) (Berger, 1929). Electrical activity associated with specific sensory, cognitive, and motor events can be extracted from the raw EEG data by averaging the brain activity time-locked to those specific events, and are therefore, called event-related potentials (ERPs). The recording of ERPs allows for a non-invasive online measure of stimulus processing, even in the absence of a behavioral response. Given this advantage, this methodology is ideal for answering questions regarding how different manipulations may influence certain

¹ Extrastriate visual cortex areas V2 and V3

² Left hemisphere posterior temporo-parietal region, middle temporal gyrus, and inferior prefrontal cortex

neuro-cognitive processes. However, something lacking with the ERP methodology is information pertaining to the functional significance of any given component, the specific bio-physiological event that underlies it. This is because while the ERP technique has an excellent temporal resolution of about 1ms under optimal conditions, it has, in contrast, low spatial resolution. This is because the voltage recorded from any one electrode at a given moment reflects the summed contribution of many different ERP generator sources, each of which might reflect a different neuro-cognitive process. The ERP methodology is ideal for the current study because we are not looking to find underlying neuro-cognitive processes, but rather, the earliest possible evidence of color discrimination, as evidenced by a particular ERP component (see below).

1.5 The Mismatch Negativity Component

The mismatch negativity (MMN) is a small ERP component associated with a pre-attentive change detection process. Occurring in the early stages of perceptual processing, the MMN is an automatic, non-attentional index of violation of regularity induced when infrequent (deviant) stimuli are introduced among a uniform sequence of frequent (standard) stimuli (for recent reviews see Naatanen et al., 2011; May & Tiitinen, 2010). When a deviant stimulus interrupts the monotonous repetition of the standard stimulus, an enhanced negative potential, resulting from a small negative wave superimposed on the typical stimulus-event-related-potential, is elicited. Fundamentally, the MMN is a difference wave clearly visible only through a subtraction procedure in which the average ERP response to the standard stimulus is subtracted from the average response to the deviant stimulus (**Figure 1 & Figure 2**).

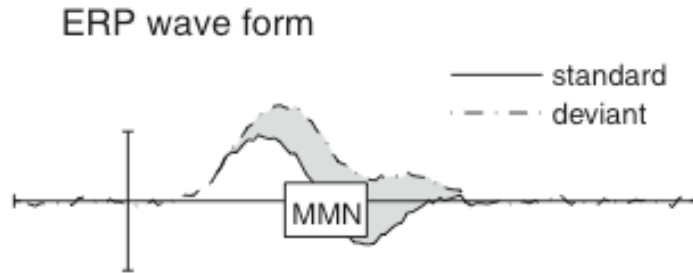


Figure 1. ERP Waveforms for Standards and Deviants

With negative plotted up in this graph, it shows the ERP component elicited by the standard stimulus and the more negative ERP component elicited by the deviant stimulus. The shaded region is their difference, which represents the MMN component. (Picture adapted from Naatanen et al. 2011)

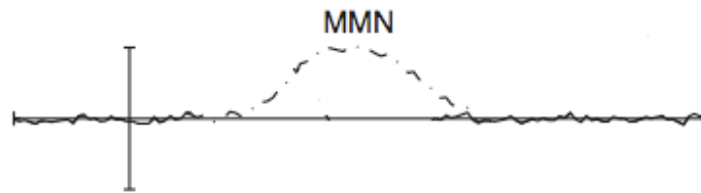


Figure 2. MMN Difference Wave

The MMN is the ERP component obtained by subtracting the ERP elicited by the standard stimulus from the ERP elicited by the deviant stimulus. (Picture adapted from Naatanen et al. 2011)

Among the stimuli within the sequence presented, physical characteristics must be held constant except for one parameter, which differs between standards and deviants. This is because any additional physical difference may significantly contribute to observed ERP differences (Heslenfeld, 1998). To be considered a MMN component, at least two criteria must be met: (1) the component must be frequency dependent, elicited by infrequent stimuli, and (2) the component must be elicited even if the relevant stimulus is unattended. The most typical manipulation used to attain the MMN component is the oddball task.

1.5.1 The Oddball Task

The oddball task has been widely used in behavioral and ERP studies to investigate the processing of task-irrelevant deviant events. The canonical version of the oddball task consists of infrequent target items presented during a series of frequent standard items (e.g., O/O/O/O/X/..., where '/' represents the inter-stimulus interval), and requires that the observer respond only to the targets, represented by the 'X'. The version of the oddball task that is more commonly used in MMN studies is the novelty oddball task. This differs from the original version in that there are two types of infrequent events: 1) novels (represented in the succeeding example by red coloring), which typically require a passive response same as the standard non-target; and 2) targets (represented in the succeeding example by 'X'), which typically require an active response, such as a button press. Altogether, there are four stimulus types (e.g., O/O/O/O/Q/O/O/O/X/O/O/O/O/X/...): 1) the frequent standard ('O'); 2) the infrequent novel counterpart to the standard ('Q'); 3) the standard target ('X'); and 4) the novel target ('X'). As in the example, the three infrequent stimuli, the infrequent novel, the standard target, and the novel target, are interspersed among the frequent stimulus, the standard non-target. In the literature, the novel is typically referred to as the 'deviant.' When the oddball task is irrelevant to the novelty deviant stimuli, the conditions established are sufficient to effectively elicit the pre-attentive MMN component.

1.5.2 The Auditory Mismatch Negativity Component

The MMN has been well established in the auditory modality where it manifests as an automatic anterior negativity elicited around 100-250ms after the onset of the deviant stimulus (Näätänen & Winkler, 1999; Picton et al., 2000). The automaticity of the auditory MMN is strongly supported in that it is evoked even during sleep (Atienza et al., 2002; Sculthorpe et al., 2009) and even with concurrent high-demand visual tasks (Müller-Gass et al., 2005; Sculthorpe et al., 2008), demonstrating that conscious attention is not required for auditory change detection as reflected in this component. Within the auditory system, the MMN effect is suggested to be a memory trace, which encodes the regularity of the most recent auditory stimuli. Therefore, the MMN is elicited when the

incoming stimulus does not match the predicted sensory information encoded in the memory trace (Grimm & Schroger, 2007; Tervaniemi et al., 1994). The encoded sensory information of preceding stimuli to be involved in the generation of an MMN usually lasts only a few seconds (Bottcher-Gandor & Ullsperger, 1992; Cooper et al., 2006), after which, a reactivation of the trace is needed (Winkler & Cowan, 2005). Prior to and without the development of a memory trace, an MMN cannot be elicited (Bendixen et al., 2007; Bendixen & Schroger, 2008).

1.5.3 The Visual Mismatch Negativity Component

In addition to the auditory MMN, there also exists a visual analog, the visual mismatch negativity (vMMN) component. The vMMN is a right hemisphere dominant (Kimura et al., 2009) negativity with a posterior scalp distribution (see **Figure 3**), appearing around 200-250ms and usually peaking between 200-400ms post stimulus onset (Kimura et al., 2009; Kimura et al., 2011) in response to a visual deviant stimulus inserted among frequent standard stimuli. This component has been observed for several visual attributes, which include location, motion, direction, orientation, spatial frequency, contrast/luminance, color, shape, and size (for summaries, see the introduction section in for Kimura et al. 2009 and Kimura et al. 2010). Due to its longer latency relative to ERP components known to originate in the primary visual cortex, the vMMN is suggested to originate from the pre-striate (aka extrastriate) visual areas (Czigler et al., 2004). In support of this theory, source localization analyses have demonstrated that the main generators of the vMMN are in the right occipital visual extrastriate areas and in the right medial pre-frontal area (Kimura et al., 2010). Additionally, with the vMMN found to be more pronounced in response to color stimuli in the lower visual field, it is suggested to reflect the visual cortex's retinotopic spatial organization (Czigler et al., 2004), which would make the source of the deviant-related activity in response to upper-visual field stimuli inaccessible to ERP recording.



Figure 3. vMMN Scalp Distribution

The vMMN component elicits a posterior right hemisphere dominant scalp distribution as can be observed by the darker gradient, which reflects a more negative brain potential.

(Picture adapted from Kimura et al. 2011)

1.5.3.1 Attention and the vMMN

Characteristic of an MMN component, the vMMN is present even in the absence of top-down attention modulations. It is elicited even when participants are not spatially attentive to the stimulus sequence (e.g., Czigler et al., 2002; Pazo-Alvarez et al., 2004), and similar to the auditory MMN, the vMMN is insensitive to task difficulty, elicited even in high-demand tasks (e.g., Heslenfeld, 2003; Pazo-Alvarez et al., 2004). However, there have been some concerns about the vMMN reflecting attentional components because of the difficulty in creating a task with visually perceived but unattended stimuli. Critiques of the vMMN has been brought up in that its time course (~100-250ms) overlaps with an attention-related negativity, the N2b (onset ~200ms), which is also sensitive to mismatch detection (Folstein & Van Petten, 2008). In response, recent studies have taken to address these critiques by improving upon their manipulations and assessing for attentional components that may be present along side the vMMN component (for more details on this, please see the Discussion section). Overall, there is ample evidence showing that in the visual processing system, there does exist automatic predictive processes preceding attention and intentionality, and that these processes can be reflected through the vMMN

1.5.3.2 Factors Contributing to the vMMN Effect

In conjunction with a sensory memory trace, as explained in the auditory MMN section above, the vMMN component is also hypothesized to also respond to regularity violations (Kimura et al., 2010). The memory trace account, for example, cannot explain a vMMN elicited in response to a deviation in a regular alternating pattern (e.g., O/X/O/X/O/X/X/...) (Kimura et al., 2011), a deviation in a more complex alternating pattern of two visual stimuli (e.g., O/O/X/X/O/O/X/X/X/...) (Czigler et al., 2006), or a deviation in a regular pattern consisting of pairs of visual stimuli (e.g., O/O-X/X-X/X-O/O-O/X-..., where '-' represents an inter-trial interval) (Stefanics et al., 2011). Additionally, the vMMN effect in response to a deviant stimulus was eliminated in a patterned presentation of standards and deviants (e.g., O/O/O/O/X/O/O/O/O/X/...) (Kimura, Schroger, et al., 2010). These examples discount the memory trace hypothesis as a complete explanation of the vMMN effect, and make a claim for the inclusion of the regularity violation hypothesis. The typical deviant is actually suggested to be a result of the summation of both a memory trace and a regularity violation effect. This was arrived upon because even though a standard immediately succeeding a deviant (e.g., O/O/O/O/X/O/...) was found to also elicit a vMMN, demonstrating a regularity violation, the amplitude of the vMMN associated with it is relatively small compared to that elicited by a deviant stimulus succeeding a series of standards, and even compared to the vMMN elicited by a second deviant immediately following the first deviant (Kimura, Schroger, et al., 2010). The memory-comparison-based change detection hypothesis, collectively taking into account both the memory trace and the regularity violation hypotheses, proposes that the posterior negativity labeled as the vMMN results from the comparison of a current deviant stimulus input with the memory trace of preceding stimuli, and that it reflects the activation of change-specific neuronal populations.

1.6 ERP Data Showing Early Category Effects of Color

ERP studies implementing the oddball task have found that a deviant color presented in the context of a frequent standard color, elicits an earlier peak (or a greater

amplitude) when the standard and deviant colors are from two different color categories than when they are from the same category. This color category effect has even been found for early perceptual components, such as the P1, which is first positivity component over the parieto-occipital area, and the N1, which is the first negativity over the occipital area (Fonteneau & Davidoff, 2007; Holmes et al., 2009). However, the perceptual components assessed, and the results from these studies, cannot be separated from attention, as the experimental task has typically directly or indirectly required attending to color. The difficulty here lies in implementing a color irrelevant distracter task while simultaneously incorporating a non-attended but perceived visual color component. Therefore, the question of to what degree perceptual and post-perceptual processes, such as language, contribute to the categorical perception of color has been long outstanding. Recently, however, using spatially task-irrelevant presentations of color stimuli, Clifford et al. (2010) demonstrated that perceptual processing can exist independently of top-down attention modulations by successfully eliciting the vMMN effect in the absence of potentially conflating attentional markers. Additionally, they observed that this component, reflecting a change perception, was significantly stronger for between than within-color category deviants, suggesting that chromaticity irregularities that stretch across different color categories are automatically and implicitly perceived.

1.6.1 Cross-Linguistic ERP Color Research

While previous ERP studies have investigated the vMMN component in relation to color categories, until recently, this color category effect has only been investigated within a single language, English. Thierry et al. (2009) furthered this area of research by investigating this effect cross-linguistically. While English has only a single word for 'blue,' the Greek language has two separate words for this color category, 'ghalazio' for light blue, and 'ble' for dark blue. In accordance with previous studies on the vMMN and color categories, it was found that Greek participants elicited a greater negative electrical brain potential, which resulted in a larger vMMN, in response to a change detection between two shades of blue compared to that elicited in response to two shades of green. Importantly, the difference in luminance was comparable in both pairs. This effect

contrasted with that of English speakers, who displayed similar size vMMNs in response to the two shades of blue and the two shades of green. Additionally, while the vMMN elicited by the two shades of blue had significantly different amplitudes across groups, as expected, the two shades of green, which fell within a single color category in both languages, elicited a vMMN of similar amplitudes across participant groups. By showing that language categories can affect unconscious, automatic, and pre-attentive chromatic change detection, Thierry et al. (2009) suggests that linguistic categories may indeed influence how the brain responds to colored visual stimuli, supporting the linguistic relativity hypothesis proposed by Benjamin Whorf.

1.7 Present Study

In attempt to further knowledge in this field and contribute to the linguistic relativity debate, this study is another cross-linguistic investigation of the vMMN and the perception of color categories. In contrast to English, which linguistically differentiates between blue and green, the Vietnamese language has a shared word for blue and green, 'xanh.' However, this is not to say that the blue-green boundary does not exist in Vietnamese, as the two chromatic categories are clearly perceived as two different colors since they can be linguistically differentiated using additional modifiers (Jameson & Alvarado, 2003), similar to the way English speakers would distinguish between navy blue and turquoise blue. If the differential brain response of Greek speakers mentioned above is truly a result of their distinct language categories, then we may find parallel but opposite effects in Vietnamese speakers. That is, Vietnamese speakers' brain responses to greens and blues would be expected to show less differentiation, a smaller vMMN, than to another color-pair that is linguistically differentiated (e.g., blue and red). However, the vMMN elicited by the blue-green and blue-red color pairs should be similar in English speakers since both color pairs are linguistically differentiated, and similar to the findings in Thierry et al., (2009), it is also expected that the vMMN elicited by the blue-red color pair will be similar in magnitude across language groups, since both languages have a different word for each color.

We hypothesize that if the linguistic relativity hypothesis is true, we should find a smaller vMMN difference for Vietnamese than for English speakers when participants are presented the infrequent deviant color within a series of blue and greens. In contrast, the vMMN is expected to be of a similar magnitude across groups for the blocks with colored pairs with different names in each language.

Chapter 2: Methods

2.1 Participants

Ten self-identified monolingual native English speakers and eight native Vietnamese speakers with normal or corrected-to-normal vision were recruited through bulletin ads and word-of-mouth. Two Vietnamese participants were excluded from the final data analysis, one due to red-green colorblindness, and the other due to extreme tiredness at the time of participation, which prevented him from dutifully attending to the experimental task, resulting in a hit rate of only 82%, putting him more than two standard deviations from the average hit rate. Four monolingual English participants were also excluded, three with a low signal-to-noise ratio due to an exceedingly large amount of alpha waves, and one because of extremely noisy signals. This left a final count of six participants in each language group. A portion of the self-identified monolingual English speakers attested to having studied or been exposed to a foreign language, but did not consider themselves anywhere near proficient, which is on par with a portion of the Vietnamese speakers who have lived in the United States for a good portion of time, but do not consider themselves proficient in English. Monolingual English speakers with exposure to languages lacking a blue-green color boundary similar to Vietnamese were excluded from participation. English speakers were unselected for sex, race, or ethnic backgrounds. The Vietnamese participants were unselected for sex, but were required to be literate in Vietnamese, as instructions for this group were presented in Vietnamese to maintain a consistent Vietnamese linguistic environment. An attempt was made to match for age across groups. A summary of participant demographics and language information is provided in Table 1. All English speakers reported themselves as advance-native in English and their performance on the Peabody vocabulary measure confirms this. The Vietnamese speakers' self-report of English proficiency varied from beginner-native, and

their performance on the vocabulary measure accordingly reflects this range in age equivalence³ (3 - 22+ years).

	English Speakers	Vietnamese Speakers
# of Individuals Included in Final Analysis	6	6
Age Range	19 - 44	21 - 53
Mean Age	28.2 ± 12.30	31.2 ± 13.63
Mean Age of First Exposure to English	0 ± 0.00	13.6 ± 11.25
Range of Duration in the US in Years	19 - 44	2 - 23
Mean Duration in the US n Years	28.2 ± 12.30	13.49 ± 9.41
Self Reported Proficiency in English	Advance - Native	Beginner - Native
Range of Peabody Picture Vocabulary Score	170 - 200	46 - 189
Range of Age Equivalent Vocabulary Score	18.58 - 22+	3.66 - 22+

Table 1. A Comparison of Participants Between Groups

The information provided is based on that solicited from participants included in the final analysis. Of the English speakers, two were 44, and the rest were between 19-22. Of the Vietnamese speakers, one was 43, one was 53, and the rest were between 20-27.

2.2 Materials

2.2.1 Novelty Oddball Task Stimuli

Solid filled circles and squares subtending 2° of visual angle were presented against a black background on a standard flat screen monitor. An initial group of pilot participants (n=8) completed a heterochromatic flicker test to determine the RGB⁴ values of colors to be used for all participants that would allow for the presentation of stimuli that would on average, be perceived at equal luminance. The values of the three colors used were: blue (R: 0, G: 0, B: 255); red (R: 170, G: 0, B: 0); and green (R: 0, G: 100, B: 0).

³ Age equivalence is the age in years and month for which a particular raw score on the Peabody Picture Vocabulary Measure is the median.

⁴ An additive color model in which each color is made up of varying intensities of red, blue, and green. Intensity is defined on a scale from 0-255, which corresponds to the scale from dark-light.

2.2.2 Language Background Questionnaire

A language questionnaire was adapted from an established Language Experience and Proficiency Questionnaire (LEAP-Q) (Marian et al., 2007) in order to measure the amount of exposure to, immersion in, and self-reported proficiency of English, Vietnamese, and any other language of each participant. These key inquiries were intermixed among other tangentially relevant language-related questions. This questionnaire was administered to all participants in their native language.

2.2.3 Color Similarity Questionnaire

This questionnaire was meant to verify that the stimuli used were exemplary of the colors blue, red, and green as intended, and to confirm that the Vietnamese speakers were indeed using the same base word for blue and green, and a different word for red. Participants were asked to write the name of the color of each critical color square (blue, red, and green) presented one at a time. The language questionnaire was also meant to assess whether language priming altered color similarity judgments, which may explain differences between groups in their response to deviants across the two color-pair conditions. In order to assess this, participants were asked to rate the similarity of the colors of seven pairs of squares on a 1-9 Likert scale. The colored squares were randomly presented two at a time, horizontally adjacent to one another. Crucially, two of the color pairs were the experimental pairs blue-green and red-blue.

2.2.4 English Proficiency Measure

The Peabody Picture Vocabulary Test, 3rd Edition (Dunn & Dunn, 1997), was used to assess English proficiency for all subjects, since the level of second language proficiency may shift non-linguistic judgments (Panos Athanasopoulos, 2006, 2007). Participants were shown 4 pictures at a time and asked to point to the picture corresponding to an English word spoken by the experimenter. In order to reduce any stress or discouragement that may be induced by the English vocabulary measure, for Vietnamese speakers who rated their English proficiency at the beginner-intermediate

level, the test was started at a middle range set meant for ages 6-7. Additionally, participants were reminded that their scores on this vocabulary measure would not be linked to their name, and that their scores would bear no consequences to them. The suggested Peabody protocol of regularly reinforcing participants by telling him/her that he/she is "doing well" was also implemented.

2.3 Procedures

Prior to starting the oddball task, during the set-up of the EEG cap, participants were engaged in small talk in the relevant language with a bilingual Vietnamese-English experimenter in an attempt to prime for, and induce a specific "language mode" (Grosjean, 1998). Experimental instructions were also provided in the native language of each participant. Before starting the EEG recording, participants first performed a short practice session of the oddball shape detection task (see description below). After confirming comprehension, participants performed this task while their brain activity was measured (see ERP section below). Half way through the oddball task series, participants were asked to complete the language questionnaire in their respective native language. After the remainder of the oddball task series was completed, participants were given the color similarity questionnaire and then administered the Peabody Picture Vocabulary Test, 3rd Edition.

2.3.1 Novelty Oddball Task

Participants were presented eight blocks of stimuli (4 blue/green and 4 red/blue), each block made up of 3 sets of trials, with 180 stimuli in each set. In each and every block, one color was the standard, occurring frequently (86.67%), while the other color was the deviant, occurring infrequently (13.33%). However, considering *both* shape and color, one stimulus was frequent (standard color circle, 80%) and three stimuli were infrequent (20%): deviant color circle (6.67%), standard color square (target, 6.67%), and deviant color square (target, 6.67%). Additionally, infrequent stimuli were always preceded by three, four, or five presentations of the standard non-target stimulus in order

to maintain an established standard. Each stimulus duration was 200ms. In order to eliminate neuronal habituation that may result from a fixed inter-stimulus interval, and to avoid overlapping ERPs from previous and subsequent stimuli, a random inter-stimulus interval jitter between 500 and 600ms was used. A small white fixation cross was visible in the center of the screen throughout each set of trials. Participants were instructed, both verbally and through printed text in their native language, to fixate on the cross in the center of the screen, to refrain from eye, head, neck, and body movements, to refrain from eye blinking as much as possible, and to detect any squares (independent of color) by pressing the spacebar of a standard keyboard. No special mention was made about the circles or colors the colors. Four blocks were presented before the midpoint break, when the questionnaire was administered, followed by the other four blocks. Block order was randomized for each participant using Excel random number generator equations. Within a block and between sets, participants were given self-paced short breaks, approximately every two minutes, and a longer break between blocks, approximately every 9 minutes. During these longer breaks, the participant's alertness and overall well-being was informally assessed, and the participant was allowed to hydrate and consume nourishments in the form of candy.

By Colors	Standard (Frequent) Color	86.67%
	Deviant (Infrequent) Color	13.33%
By Shapes	Non-Target Circle	86.67%
	Target Square	13.33%
By Color and Shapes	Standard Color Non-Target Circle	80%
	Standard Color Target Square	6.67%
	Deviant Color Non-Target Circle	6.67%
	Deviant Color Target Square	6.67%

Table 2. Oddball Task Stimulus Percentages

Above is a summary of the breakdown of the percentage of each stimulus type. Overall, the frequent stimulus, the standard non-target circle, was presented at 80% while the infrequent stimuli were collectively presented at 20%.

2.4 Event Related Potential Recording and Analysis

Electrophysiological data were recorded at a sampling rate of 500Hz from 28 electrodes embedded in an electrode cap according to the 10-20 International System (**Figure 4**) and from 5 free Ag/AgCl electrodes placed on the head/face (one on each side of the eyes, one below the left eye, and one on the mastoid bones behind each ear). Impedances were kept below 5 k Ω . EEG activity was filtered online with a band pass of 1.592 Hz and 100 Hz, and re-filtered off-line at 20 Hz and with a notch filter targeting 60 Hz. Eye blinks, vertical eye movements, and epochs exceeding 200 μ V at any electrode cap site were automatically discarded. Due to design demands of the novelty oddball task, we had a higher count of standards compared to deviants. Therefore, we used only the ERPs elicited by standards immediately preceding a deviant, in order to equate the amount of ERPs contributing to each experimental condition.

The vMMN has been found to be maximal over parieto-occipital areas and detected mostly in electrodes IZ, O1, O2, OZ, PO7, PO8, PO9, and PO10 (Thierry et al., 2009); therefore, these electrodes were chosen for recording. In addition, we also recorded VeOG, HeOGL, HeOGR, FP1, FP2, F7, F3, Fz, F4, F8, LT, C3, Cz, C4, RT, LTP, RTP, LP, P3, Pz, P4, RP, POz, and A2 (**see Figure 4**). The left mastoid (A1) was used as the online reference for all electrodes. However, the electrode placed on to the side of the left eye (HeOGL) was re-referenced offline to the one placed on the side of the right eye (HeOGR) in order to capture maximal horizontal eye movement artifacts. All scalp electrodes were re-referenced off-line back to A2. Analysis of brain activity was conducted on individual averages for ERPs elicited by deviant circles and the standard circles immediately preceding them (see section 3.3). Difference waves were obtained by subtracting the ERP elicited by standard circles from those elicited by deviant circles.

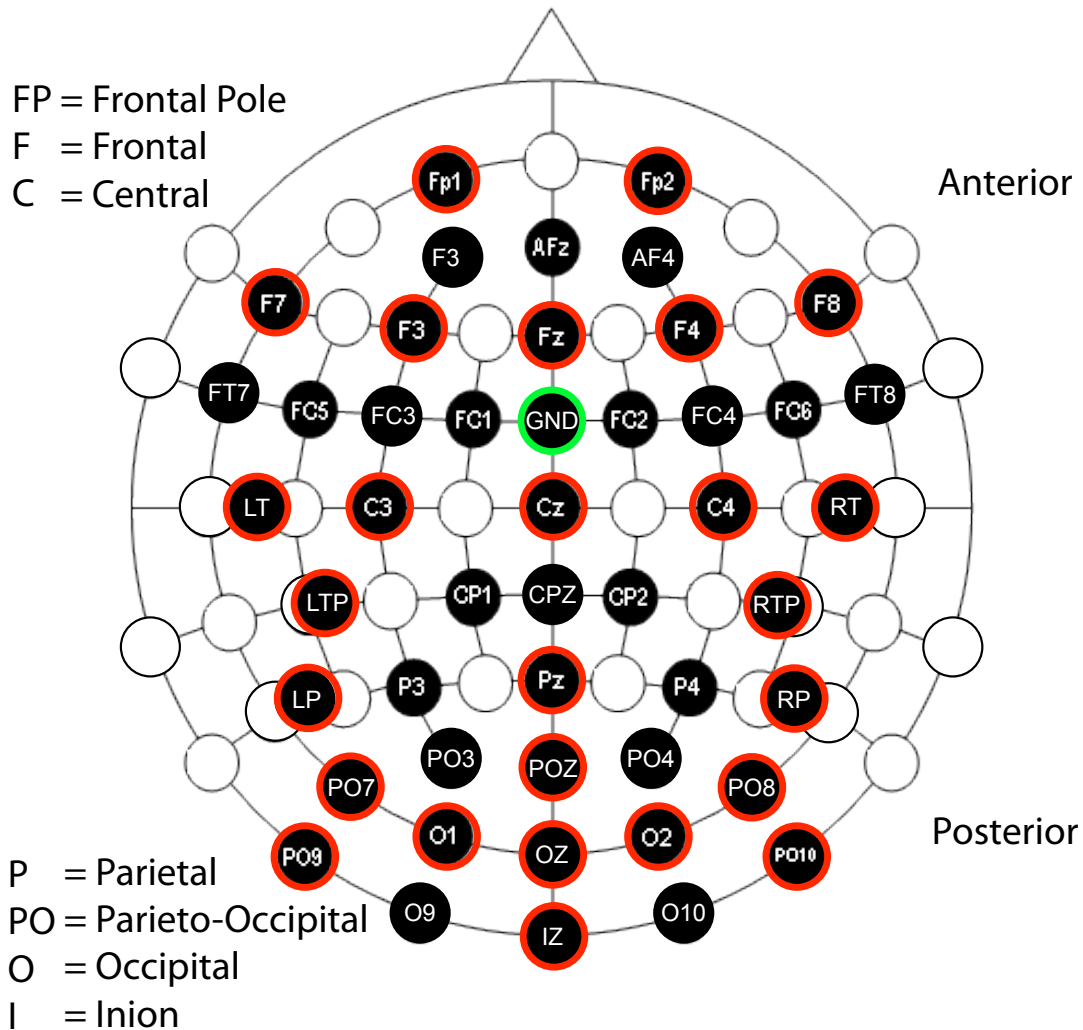


Figure 4. EEG Electrode Cap Scalp Distribution

Above is an example of an electrode cap with coordinates in conjunction with the 10-20 international system. The electrodes circled in red are the ones that were used in this study. The electrode circled in green represents the ground electrode. Not represented are the vertical eye (VeOG), horizontal (HeOGL), horizontal (HeOGR), right mastoid (A2) and left mastoid (A1 - Reference).

Chapter 3: Results

3.1 Behavioral Performance

A response to a target (square) was considered a hit if it occurred within 700ms post stimulus onset. Incorrect and late responses were excluded from the final count. Excluding outliers, the hit rate was $95.32\% \pm 3.99\%$ for English speakers, $97.56\% \pm 2.66\%$ for Vietnamese speakers, and $96.44\% \pm 3.44\%$ across all participants. A two-tail two-sample equal variance t-test found no significant difference between groups ($p > 05$). This confirmed that all participants whose data was subjected to final data analysis attended to the target in the oddball task.

3.2 Color Similarity

English participants judged the similarity of the blue and green used in the study to be 2.17 ± 1.33 , and that of blue and red to be 1 ± 0.00 (both on a scale from 1-9, with 1 = lowest similarity). Vietnamese participants judged the similarity of blue and green to be 2 ± 1.55 , and that of blue and red to be 1 ± 0.00 . Two-tailed two-sample equal variance t-tests showed that the similarity ratings for these two pairs of colors did not differ significantly within group ($p = .06$ and $p = .14$, respectively), and that overall, the similarity ratings did not differ across groups ($p = .86$). This shows that speakers of the two languages have a similar organization of color space.

3.3 ERPs

After excluding participants for reasons previously described, each condition had only a small number of participants remaining ($n = 6$), which resulted in a reduced signal-to-noise ratio. **Figure 5** shows the ERPs elicited in response to circles in each condition and for each group. From these ERPs we calculated the difference waves by subtracting

the ERPs elicited by standard stimuli from those elicited by deviant stimuli (see **Figure 6**); therefore, the closer to zero, the more similar the ERPs are across conditions. Due to the presence of early fluctuations, most likely related to the low signal-to-noise ratio (especially in the group of English speakers), our results should be considered preliminary.

A visual analysis of the difference waves (deviant - standard) revealed a posterior negativity (the vMMN) between 220-270ms, peaking at approximately 260ms (**Figure 6**). However, it is unclear where exactly the vMMN ends because this posterior negativity appears to partially overlap in time with another more central negative component. This can be seen in the topographical maps, observed most clearly in the Vietnamese blue-red condition over 250-280ms (**Figure 7**). Even though the vMMN component peaking at approximately 260ms may carry on beyond 270ms, the analysis was cut off there because of the potential overlap with a later effect of an anterior negativity component peaking at 300ms⁵.

In addition to the component reflecting the vMMN, differences in ERP responses to deviants and standards, as reflected in the difference wave, were observed in other time windows. However, only those found to be significant are reported: 1) an early central positivity at approximately 145-230ms, peaking at approximately 190ms; 2) a frontal-central negativity at approximately 260-350ms, peaking at approximately 300ms; and 3) a later occipital negativity at approximately 310-380ms, peaking at approximately 345ms. The time windows selected for analysis were mostly based on the difference waves of the Vietnamese group since they had a relatively bigger signal-to-noise ratio compared to the English-speaking group. In what follows, the vMMN component is addressed first, and then each of these other components one by one. Note: In order to facilitate final comparisons with previous studies, all ERP figures from this point on will be plotted with negativity down.

⁵ A repeated measures ANOVA conducted over 250-280ms on central (LT, C3, Cz, C4, RT, LTP, RTP) and occipital electrodes (PO7, PO8, O1, Oz, O2, PO9, PO10) did not find a main effect of scalp area ($F[1, 10] = .099, p = .76$), confirming the ambiguity of which component is more clearly expressed at this time window.

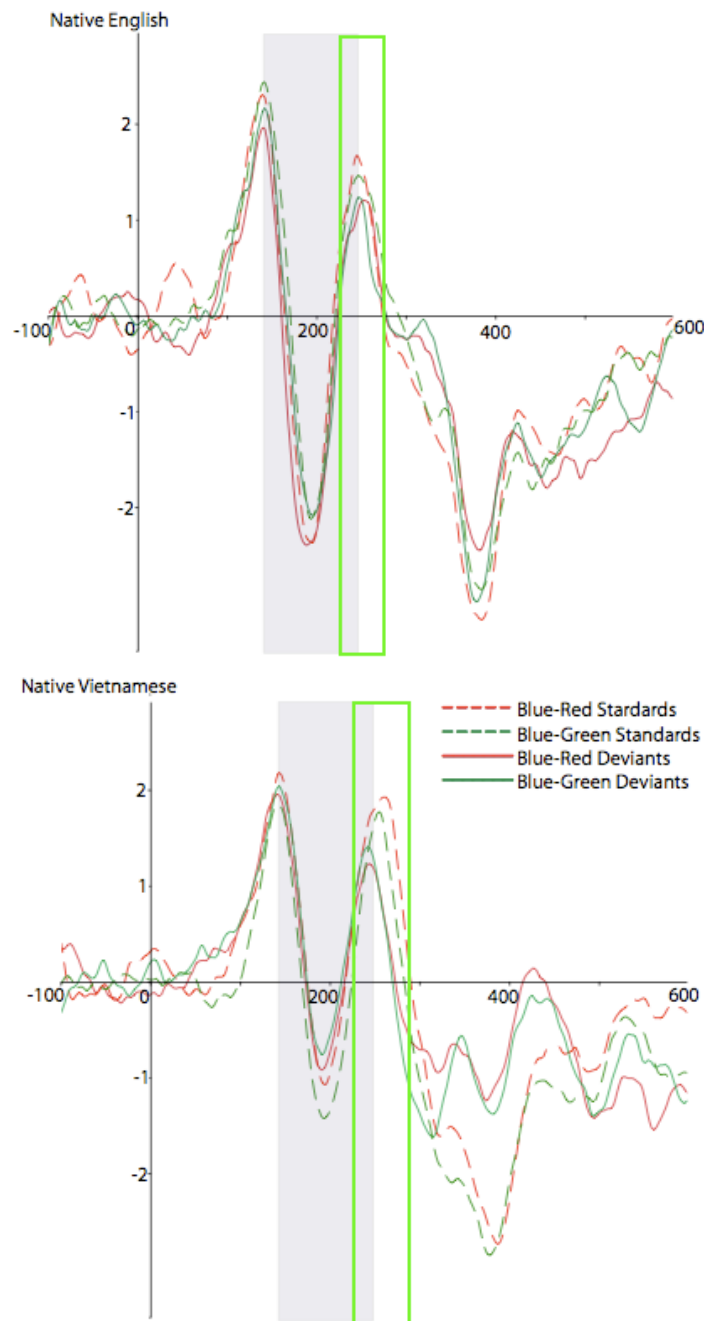


Figure 5. ERP Waveforms Over Parieto-Occipital Electrodes Pooled

Grand average mean amplitude of ERPs elicited by circle stimuli for each language group over parieto-occipital electrodes. This figure shows the effect at PO7, PO8, O1, Oz, O2, PO9, Iz, and PO10 pooled together. The negative potential evoked by the stimuli (indicated by the shaded area) is most prominent between 150-250ms. The more negative waveform in response to deviants relative to standards (boxed in green), from which the vMMN is derived, is most prominent between 220-270ms. The high level of noise can also be observed at baseline (<100ms).

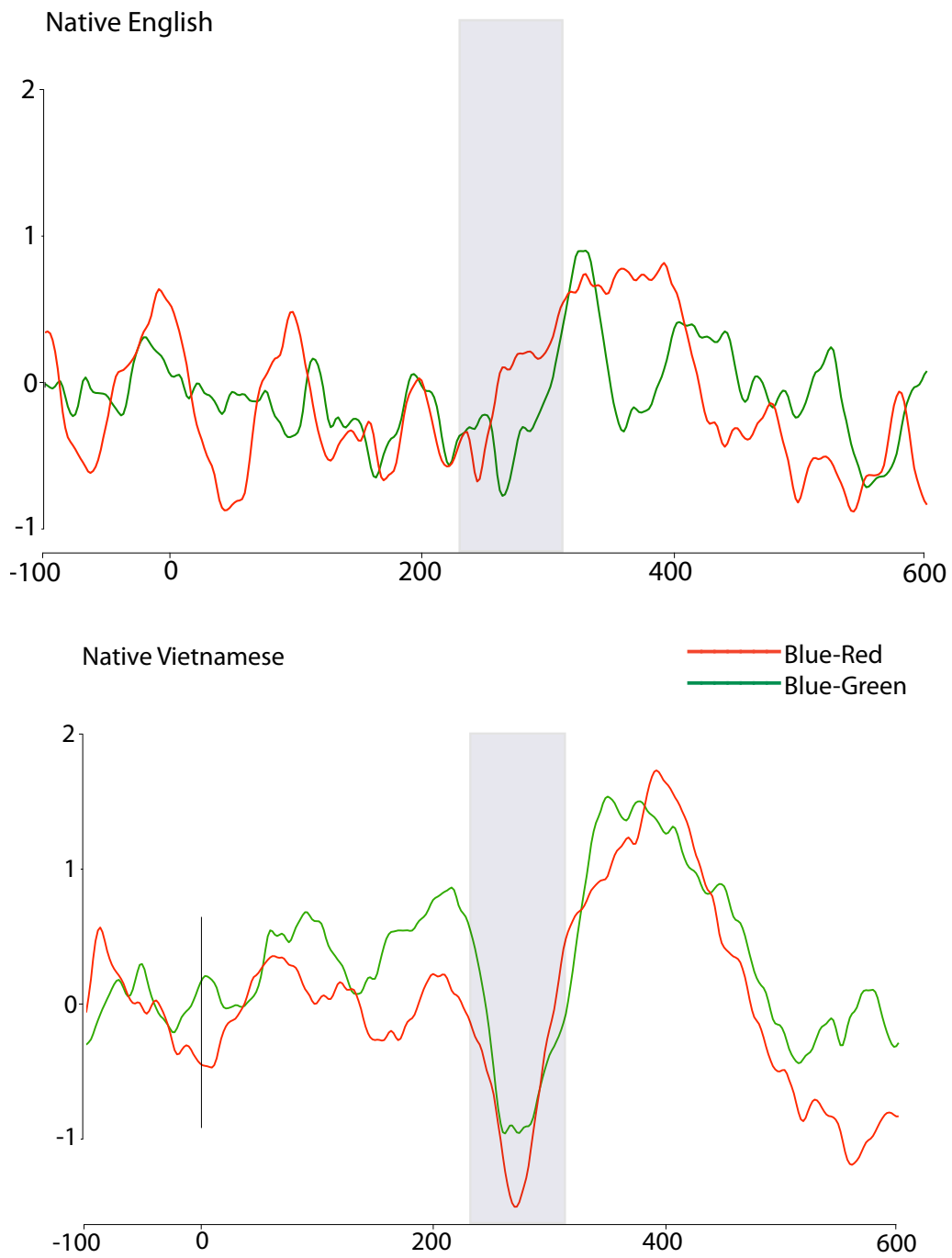


Figure 6. Difference Waves Over Parieto-Occipital Electrodes Pooled

Difference waves (deviant - standard) for each color pair and language group over parieto-occipital electrodes. This figure shows the effect at PO7, PO8, O1, Oz, O2, PO9, Iz, and PO10 pooled together. The vMMN (indicated by the shaded area) is most prominent between 220-230ms.

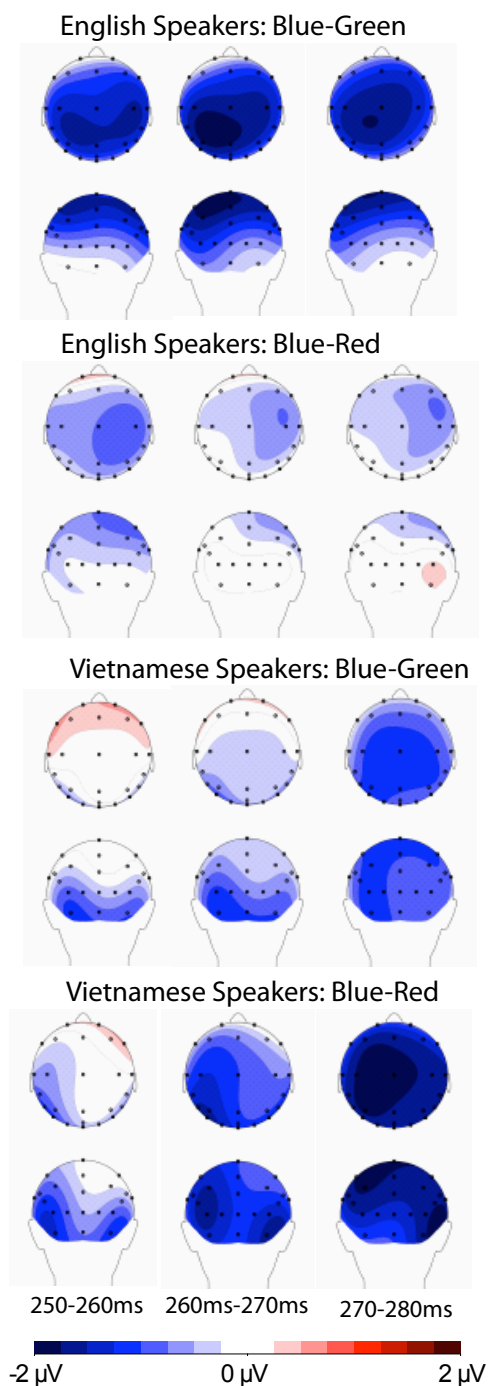


Figure 7. Topographical Mapping of the Difference Wave Between 260-280ms

The higher the amplitude, the more intense the color. Blue indicates a negativity, while red indicates a positivity. The vMMN is localized in the occipital region and peaks at approximately 260ms. However, at 260ms, an anterior component also appears to start; this component then dominates the original posterior component in effect. This can be observed most clearly in the Vietnamese blue-red condition.

3.3.1 vMMN Posterior Negativity (220-270ms)

We calculated the mean amplitude of ERP waveforms in the time interval between 220 and 270ms for all individual averages. We submitted these mean amplitudes to a 2 (group: English vs. Vietnamese) x 2 (deviancy: deviant vs. standard) x 2 (color pair: blue-green vs. blue-red) x 10 (electrode: LP, RP, PO7, PO8, O1, Oz, O2, PO9, Iz, and PO10)⁶ repeated measures ANOVA. We found a significant main effect of deviancy ($F(1, 10) = 7.62, p < .05$), with deviants eliciting a less positive waveform than standards. Although a deviancy by color by language interaction was not significant ($p > .05$), a plot of this interaction shows the deviancy effect for English speakers in response to blue-green and blue-red, and that of Vietnamese speakers in response to blue-red, to all have a positive slope, while that of Vietnamese speakers in response to blue-green has a slope of approximately zero (**Figure 8**). Additionally, there was an interaction of electrode by deviancy by language ($F(9, 90) = 2.68, p < .01$), the difference between deviants and standards more pronounced in more anterior electrodes in English speakers, and more wide spread in Vietnamese speakers. Looking only at Vietnamese speakers, no significant effects of English proficiency ($p > .05$) or immersion ($p > .05$) were observed.

⁶ A visual inspection suggested no hemisphere-deviancy interaction, which was confirmed by a 2 (hemisphere) x 2 (group) x 2 (color pair) x 4 (electrode pair: LP/RP, PO7/PO8, O1/O2, and PO9/PO10) repeated measures ANOVA ($p > .05$).

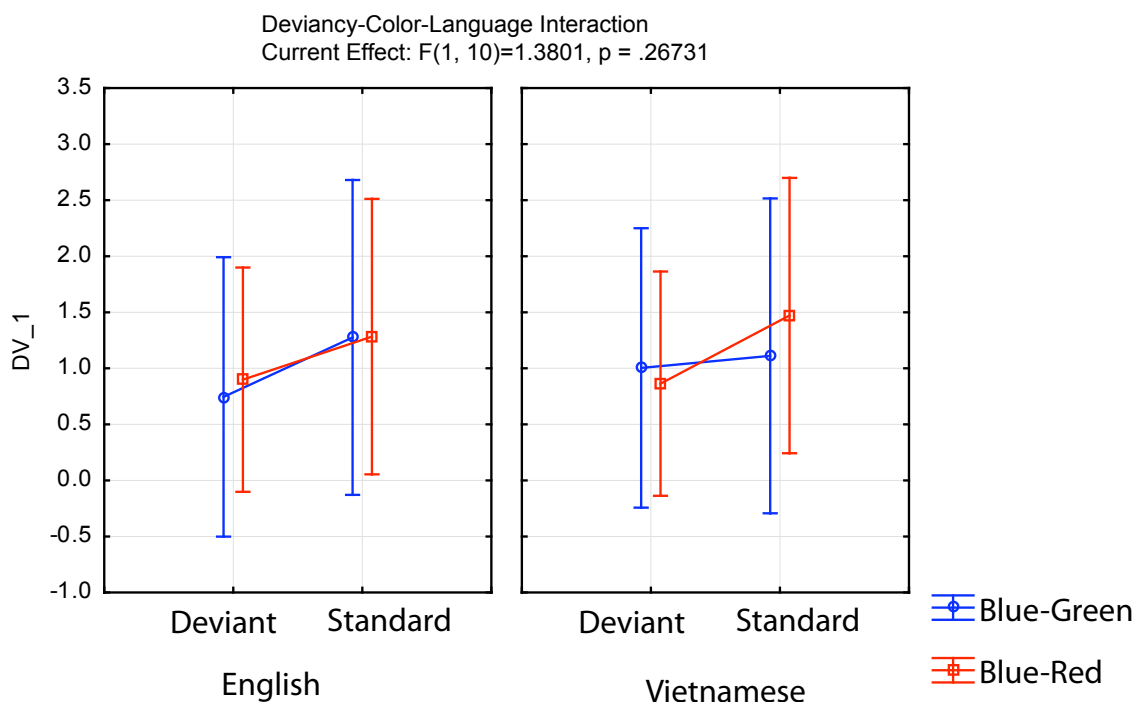


Figure 8. Deviancy-Color-Language Interaction Derived from the vMMN Analysis

In spite of an insignificant interaction, it can be seen that English speakers displayed a similar deviancy effect across color pair, and that this was also similar to the effect observed for Vietnamese speakers in the blue-red condition. In contrast, the deviancy effect is practically zero in Vietnamese speakers in the blue-green condition. Note: Vertical bars reflect a 95% confidence interval.

3.3.2 Early Central Positivity (145-230ms)⁷

We calculated the mean amplitude of ERP waveforms in the time interval between 145 and 230ms for all individual averages. We submitted these mean amplitudes to a 2 (group: English vs. Vietnamese) x 2 (deviancy: deviant vs. standard) x 2 (color pair: blue-green vs. blue-red) x 7 (electrode: LT, C3, Cz, C4, RT, LTP, and RTP) repeated measures ANOVA. There was a deviancy main effect ($F(1, 10) = 5.45, p < .05$),

⁷ Derived from a transition from a negative to a positive potential in the ERP waveform.

with deviants eliciting a more positive waveform than the standards.⁸ There was also a deviancy by language interaction ($F(1, 10) = 7.15, p < .05$), indicating that English speakers show little difference between deviants and standards, while in Vietnamese speakers showed a more prominent deviancy effect.

3.3.4 Frontal-Central Negativity (260-350ms)⁹

We calculated the mean amplitude of ERP waveforms in the time interval between 260 and 350 ms for all individual averages. Visually observing a hemispherical effect, we submitted these mean amplitudes to a 2 (hemisphere: left vs. right) x 2 (group: English vs. Vietnamese) x 2 (deviancy: standard vs deviant) x 2 (color pair: blue-red vs. blue-green) x 5 (electrode pair: F7/F8, F3/F4, LT/RT, C3/C4, and LTP/RTP) to a repeated measures ANOVA. We found a significant main effect of deviancy ($F(1, 10) = 28.42, p < .001$), deviants eliciting a larger negativity than standards. A significant hemisphere by deviancy interaction was also observed ($F(1, 10) = 9.26, p < .05$), indicating the difference between deviants and standards to be more pronounced in the right hemisphere. And additionally, a significant hemisphere by electrode by deviancy interaction ($F(4, 40) = 4.42, p < .01$) confirmed a larger deviancy effect on the right compared to the left hemisphere, and in more the anterior frontal electrodes. We also found a deviancy by language interaction ($F(1, 10) = 6.38, p < .05$), Vietnamese speakers showing a greater difference between deviants and standards compared to English speakers.

3.3.5 Later Occipital Positivity (310-380ms)¹⁰

We calculated the mean amplitude of ERP waveforms in the time interval between 220 and 270 ms for all individual averages. We submitted these mean

⁸ A visual inspection suggested no hemisphere-deviancy interaction, which was confirmed by a 2 (hemisphere) x 2 (group) x 2 (color pair) x 3 (electrode pair: LT/RT, C3/C4, and LTP/RTP) repeated measures ANOVA ($p > .05$).

⁹ Derived from a negative potential in the ERP waveform.

¹⁰ Derived from a negative potential in the ERP waveform.

amplitudes to a 2 (group: English vs. Vietnamese) x 2 (deviancy: standard vs deviant) x 2 (color pair: blue-red vs. blue-green) X 8 (electrode: PO7, PO8, O1, Oz, O2, PO9, Iz, and PO10) to a repeated measures ANOVA. We found a significant main effect of deviancy ($F(1, 10) = 6.50, p < .05$), deviants eliciting a more positive waveform than standards.¹¹

¹¹ A visual inspection suggested no hemisphere-deviancy interaction, which was confirmed by a 2 (hemisphere) x 2 (group) x 2 (color pair) x 3 (electrode pair: PO7/PO8, O1/O2, and PO9/PO10) repeated measures ANOVA ($p > .05$).

Chapter 4: Discussion

4.1 Overview

Exploiting a difference in linguistic color categories between two languages, Vietnamese and English, this study investigated the potential effects of color terminology on early stages of visual perception using the vMMN, an index of deviancy detection. The primary hypothesis predicted that the vMMN would be elicited in response to deviant stimuli presented among a series of standard stimuli for all participants, and that vMMNs for Vietnamese speakers would be smaller than that of English speakers for a pair of colors that were linguistically differentiated in English, but not in Vietnamese (blue-green). It was also predicted that the vMMN would be similar in magnitude across groups for a pair of colors that were linguistically differentiated in both languages (blue-red). The results from this study found an overall main effect of deviancy, but the particular language by deviancy by color interaction predicted by our hypothesis failed to reach significance at this time interval. However, the numeric tendencies observed were in line with our hypothesis. Additionally, significant effects were also found in three other time windows.

4.2 Identifying the vMMN

As mentioned before, the vMMN is found to be maximal in posterior electrodes and is the difference between the ERPs elicited by standards and deviants, resulting from an enhanced negativity in response to a deviant stimulus among a series of standards. Similar to previous studies, in the present study, the ERPs elicited by the circles consistently produced an early posterior negativity between 150-250ms (**Figure 5**) (e.g., Thierry et al., 2009; Clifford et al., 2010). However, at this negative potential, deviants are more positive than standards, and the enhanced negativity in response to the deviant stimulus is not observed until 220-260ms (**Figure 5**). Although delayed relative to the

negative potential that it is derived from, the vMMN is still occurring in the expected time window (200-250ms onset; 200-400ms peak) (**Figure 6**) (Kimura et al., 2009; Kimura et al., 2011). Additionally, a component is defined by the neuro-anatomical relationship that produces it and the cognitive function that it reflects (Luck, 2005), rather than by the superficial features like latency, polarity, and scalp distribution, which may indicate it.

Over the parieto-occipital area, in addition to the noise clearly present at baseline, it can be observed in Vietnamese speakers that the responses elicited by deviants are initially more positive than those elicited by standards (**see Figure 5**), potentially contributing to the early large positivities of the difference wave, such as between 50-150ms and 150-250ms (**see Figure 6**). In English speakers, the large ERP amplitudes at baseline (< 0ms) similarly reduce the signal-to-noise ratio (**see Figure 5**), and this noise is consequently reflected in the difference wave (**see Figure 6**). This noise, resulting from the small number of participants, obscures the information reflected in the derived difference wave. Despite these technicalities, the expected deviant negativity relative to standards can be seen going into the succeeding positive potential, as the vMMN has been shown to extend in an attenuated form up to 350ms post stimulus onset (e.g., Clifford et al., 2010). It is the difference at this point that is inferred to reflect the vMMN component.

4.2.1 Concerns Regarding Scalp Distribution

A posterior distribution is characteristic of the vMMN and sets it apart from an anterior attentional component with an overlapping time course, and also found to be sensitive to mismatch detections, the N2b (~200ms post stimulus onset) (Folstein & Van Petten, 2008). A visual inspection of our data clearly shows our deviancy effect having a posterior distribution, and sets it apart from a succeeding anterior negativity. The vMMN is also typically found to be right hemisphere dominant (Cammann, 1990). Although the present study found no hemispheric effect, this may be due to the small number of participants overall ($n = 12$), and the large amount of noise present in the recordings of some participants kept in the final analysis in order to obtain a somewhat substantial number of participants.

4.2.2 Concerns Regarding the Refractory Hypothesis

In the past, there have been some concerns as to whether the posterior negativity produced in response to deviant stimuli reflected the memory-comparison-based change detection characteristic of an MMN component, or if it instead reflected a simplistic refractory effect. The refractory hypothesis is that the greater activation potential in response to deviants among a series of standards is a result of neuronal adaptation to particular features of the standard stimulus. Kimura et al. (2009) has demonstrated that the refractory effect is reflected in an early difference negativity (~100-150ms) and is separate from the later difference negativity that is the memory-based vMMN. Although not observed to reach significance, the present study found a deviance-related negativity occurring in the difference wave prior to the vMMN in the posterior electrodes (see **Figure 6**). This first effect could potentially be attributed to the refractory effect, leaving the later effect as the vMMN component.

4.2.3 Concerns Regarding Attention

To be considered an MMN component, the vMMN needs to be present even in the absence of top-down attention modulations. As previously mentioned, there are concerns that the negativity inferred to be the vMMN is sometimes actually the attentional N2b component, the second negative peak in the averaged ERP, maximal at frontal-central locations (200-350ms), also found to be sensitive to mismatch detection (see Folstein & Van Petten, 2008, for a review). The frontal-central negativity (260-350ms) observed in this study, found to have a main effect of deviancy, can very possibly be the N2b. However, the N2b does not have a hemispheric dominance, while the observed component had a right hemisphere dominance, which is actually stereotypical of the vMMN. Since it is unclear where the vMMN ends due to the overlap with this later component, it is within reason that the vMMN component is still enduring at the time interval of the frontal-central negativity and shows up in this later negativity as the right hemisphere dominance. If this is the case, then the vMMN may be followed by an attention component in this study. However, part the N2b/P3a complex, the N2b is also accompanied by the P3a, an anterior difference positivity (350-600ms) linked to the

explicit switching of attention towards unexpected or physically alerting stimuli (see Polich, 2007, for a review). Given that a P3a component was not observed in this study, in addition to the right hemisphere dominance, it is suggested that the central negativity observed is not an attentional N2b; however, it is not inconceivable. It may just be that the P3a did not reach significance given the analysis limitations of this current study due to participant number and noise. However, if the frontal-central negativity (260-350ms) is the N2b, it is unclear why the difference between deviants and standards would be of a larger magnitude for Vietnamese than English speakers. Despite the true identity of the central negativity, however, the observed vMMN is not itself an N2b. Although its co-existence with the N2b would draw attention to the question of whether or not the effects observed are occurring in the absence of attention.

Additionally, there also exists the P3b component, a posterior positivity (350-600ms), proposed to be a consciously maintained working memory trace, is indicative of explicit attention (see Polich, 2007). For example, in the standard oddball task, a larger P3b is elicited in response to rare visual targets (e.g., Ritter et al., 1983; Ritter et al., 1982). However, the deviancy examined in this study was in response to task-irrelevant stimuli, not the target stimuli. But given the time course during which the P3b typically occurs, its polarity, and its scalp distribution, the later posterior positivity observed in this study can very well be the P3b, especially since it was found to have a main effect of deviancy. Taking this into account, it is possible that attention to the non-target circle stimuli may have triggered attentional processes despite their task-irrelevant nature. Even though the vMMN must be elicited even when the relevant stimulus is unattended, it may still be elicited in observation of attention. These findings do not so much cast doubt on whether the occipital difference negativity occurring between 220 and 270ms, but rather, cause us to question whether the oddball task used in Thierry et al. (2009) and adapted in this study actually elicits a pre-attentive vMMN.

4.3 Summary and Interpretation of vMMN Results

Analysis of posterior electrodes at 220-270ms found the vMMN component for both group and color pairs. However, the relevant interaction that would have supported

the hypothesis was not observed. The lack of interactions is most likely due to the small signal-to-noise ratio of the ERPs resulting from the small number of participants in each condition. The finding of a vMMN across groups and colors shows that this task can successfully elicit a vMMN in response to deviants, and although not significant, the vMMN elicited in conditions in which there were linguistic differentiations (Vietnamese blue-red, English blue-green, English blue-red) were numerically similar to one other, but different from the vMMN elicited in the condition lacking a linguistic differentiation (Vietnamese blue-green), where the vMMN was almost non-existent. These findings suggest that an interaction among deviancy, group, and color may be found with more participants.

4.3.1 English Proficiency and Immersion Effects

A previous study observed immersion to reflect the effect of color terminology on vMMN. Speakers were found to show an effect resembling that of their second language with long immersions (Athanasopoulos et al., 2010). In the present study, no significant effects were observed for either proficiency or immersion in Vietnamese participants. It is likely that significance was not reached due to the small number of participants in each of those subgroups (low proficiency and short immersion, $n = 2$; high proficiency and long immersion, $n = 4$). Separate numeric comparisons among posterior electrodes showed, in general, more positive ERPs in the vMMN time window for the low proficiency and the long immersion Vietnamese groups compared to their counterparts. However, these numeric observations, in addition to not being significant, are potentially conflated, given that both of the Vietnamese speakers with low English proficiency were also in the long immersion group. Additionally, the cognitive shift resulting from immersion has been observed as early as three years (Frenck-Mestre, 1993), and the short immersion Vietnamese participants in this study had 2 and 3.66 years of immersion in English. These results, therefore, are highly inconclusive.

4.4 Other Significant Findings

In addition to the vMMN, a significant main effect of deviancy was observed in three other time windows. The central positivity (260-350ms) and the later occipital positivity (310ms-380ms) have already been discussed as potentially being the attentional N2b and the conscious working memory trace P3b, but the identity of the early central difference positivity (145-230ms) is unclear. It is not reflecting the P1 component as observed by Thierry et al. (2009) since the visually elicited P1 occurs over parieto-occipital areas, unlike the centrally localized component observed in this study. This component's central distribution also precludes it from reflecting the visually evoked N1, another parieto-occipital component. Altogether, although exhibiting a significant deviancy effect and found to be more prominent in Vietnamese than English speakers, this early central positivity remains ambiguous.

Conclusion

It is unclear how language contributes to color category effects in the early processing of chromaticity. The top-down modulation from language related brain areas is an unlikely proposal since a vMMN color deviancy effect can be elicited using task-irrelevant, non-attentional colored stimuli (e.g., (Clifford et al., 2010)). And the hypothesis that language physically warps perceptual processors over time has been discredited by studies showing verbal interference to disable color category advantage (Winawer et al., 2007; Witthoft et al., 2003). However, it is possible that verbal codes for color are activated unconsciously and automatically. For example, the rapid presentation of color stimuli have been shown to activate lexical codes for color (Tan et al., 2008), but it is unclear whether this activation would persist in a non-attentional, color-irrelevant task.

A previous cross-linguistic study has shown that the color terminology of a native language affects automatic, pre-attentive early visual processing (Thierry et al., 2009). In their study, since a vMMN was successfully elicited in response to deviants that were task irrelevant, the argument was made for an automatic effect of language on the categorization of colors, suggesting that language does indeed shape thoughts. Using a novelty oddball task adapted from the one used by Thierry et al. (2009), the present cross-linguistic study successfully elicited a vMMN effect in response to deviants presented in a series of standards. And although it did not reach significance, the numeric assessment of the interaction of deviancy by language by color pair suggested an effect of linguistic differentiation on early visual processing. Conditions with different lexemes for a color pair were found to show a perception of difference between the two colors, as reflected by the vMMN, while the condition with only a single lexeme for the color pair did not. This is especially interesting because speakers of the two languages were found to have a similar organization of color space, yet despite color space similarity, color perception seems to be skewed by language. These findings support the hypothesis that language influences categorization, and in turn, thoughts. However, the

automaticity of this influence is still unclear. In the present study, although the critical color stimuli are task irrelevant, participants were still attending to them, and consequently, the vMMN was observed in conjunction with what appear to be attentional components. Additionally, the study by Thierry et al. (2009) has been critiqued for not addressing the presence of an attentional P3 component in their results (Clifford et al., 2010). The findings of this study supports the observed cross-linguistic vMMN effect, however, it questions whether this effect truly occurs in the absence of attention. Therefore, it is suggested that a better manipulation of unattended color change needs to be implemented in a cross-linguistic study in order to further the investigation of how language influences thoughts, and in particular, color perception.

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