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Thomas Fischer *Editors*

Information Systems and Neuroscience

NeuroIS Retreat 2020

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Jan vom Brocke · Pierre-Majorique Léger ·
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Editors

Information Systems and Neuroscience

NeuroIS Retreat 2020


 Springer

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Preface

The proceedings contain papers presented at the 12th annual NeuroIS Retreat held on June 2–4, 2020. NeuroIS is a field in information systems (IS) that uses neuroscience and neurophysiological tools and knowledge to better understand the development, adoption, and impact of information and communication technologies (see <http://www.neurois.org/>).

The NeuroIS Retreat is a leading academic conference for presenting research and development projects at the nexus of IS and neurobiology. This annual conference promotes the development of the NeuroIS field with activities primarily delivered by and for academics, though works often have a professional orientation.

In 2009, the inaugural NeuroIS Retreat was held in Gmunden, Austria. Since then, the NeuroIS community has grown steadily, with subsequent annual Retreats in Gmunden from 2010–2017. Beginning in 2018, the conference is taking place in Vienna, Austria. Due to the Corona crisis, the organizers decided to host a virtual NeuroIS Retreat in 2020.

The NeuroIS Retreat provides a platform for scholars to discuss their studies and exchange ideas. A major goal is to provide feedback for scholars to advance their research papers toward high-quality journal publications. The organizing committee welcomes not only completed research, but also work in progress. The NeuroIS Retreat is known for its informal and constructive workshop atmosphere. Many NeuroIS presentations have evolved into publications in highly regarded academic journals.

This year is the sixth time that we publish the proceedings in the form of an edited volume. A total of 41 research papers are published in this volume, and we observe diversity in topics, theories, methods, and tools of the contributions in this book. The 2020 keynote presentation entitled “NeuroIS as Qualitative Research: Solving the Reverse Inference Problem” was given by Alan R. Dennis, current president of the Association for Information Systems (AIS) and Professor of Information Systems and John T. Chambers Chair of Internet Systems in the Kelley School of Business at Indiana University, USA. Moreover, Aaron Newman, Professor and Chair of the Department of Psychology and Neuroscience at

Dalhousie University, Canada, gave a hot topic talk entitled “A Critical View of Neuroimaging.”

Altogether, we are happy to see the ongoing progress in the NeuroIS field. Also, we can report that the NeuroIS Society, established in 2018 as a non-profit organization, has been developing well. We foresee a prosperous development of NeuroIS.

June 2020

Fred D. Davis
René Riedl
Jan vom Brocke
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Keynote Talks

NeuroIS as Qualitative Research: Solving the Reverse Inference Problem (Keynote)

Alan R. Dennis

NeuroIS research is commonly quantitative, driven by large amounts data and p-values. My own research using EEG, specifically event-related spectral perturbation (ERSP), is a good example. Yet, I have come to realize that research using ERSP (and other forms of NeuroIS) has much more in common with the style of qualitative research popularized by Allen Lee (former EIC of MIS Quarterly) than it does with quantitative research. A researcher may hypothesize that a treatment will lead to differences in activation in some brain regions but ERSP is a hypothesis-free analysis that examines activity across the entire surface area of the brain, so ERSP commonly finds activation in regions the researcher did not hypothesize about. Some neuroscientists have called this the “reverse inference problem” as it is impossible to use deductive reasoning to determine the cause because the regions are often associated with several functions. Neuroscientists who see this as a “problem” lack qualitative research training. For centuries, qualitative researchers have used abductive reasoning to draw conclusions in situations such as this, so for them, reverse inference is a valid, well-used, and well-understood research method, not “problem.” The irony is that the same neuroscientists who label this as a problem use abductive reasoning when they build their hypotheses to test using other methods. So, it is not a question of whether or not to use abductive reasoning; it is a question of when—before or after building hypotheses. Like many issues in science, the answer is that both approaches are useful and valid.

A Critical View of Neuroimaging (Hot Topic Talk)

Aaron Newman

Neuroimaging has opened new doors for understanding the brain and, ultimately, using this knowledge to improve quality of life. The increasing availability of neuroimaging tools is accelerating this process, through an explosion of available data. This has also exposed the limitations of these relatively coarse physiological measurements—and the need for big data, data sharing, and meta-analytic techniques, as well as an emphasis on reproducibility. NeuroIS holds great potential as an applied discipline, but must always reflect critically on the limitations of the available techniques. I will outline challenges and opportunities for NeuroIS that can be learned from the evolution of cognitive neuroscience.

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Why We Love Blue Hues on Websites: A fNIRS Investigation of Color and Its Impact on the Neural Processing of Ecommerce Websites

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Abstract. Blue of all colors seems to be generally preferred by humans and animals. Consequently, the use of this color in ecommerce context has several positive effects such as increased trustworthiness and aesthetic ratings. These effects are, in this study, hypothesized to be caused by specific neural processes in the prefrontal cortex of human decision makers. Consequently, this study tackles the research question whether there is a distinct neural activation pattern for blue websites that helps to explain why blue is often most favored. To investigate this, one website is designed and manipulated in color to which user reactions are measured by employing functional near-infrared spectroscopy (fNIRS). The results of this study show that blue colored websites seem to require generally less processing power related to cognitive processing while revealing increases in brain structures related to processing pleasant and aesthetic stimuli.

Keywords: Color · Aesthetics · Websites · fNIRS · Decision making · Neural measurements

1 Introduction

Out of the blue, the true blue, being blue or feeling blue – blue has several associations and is consistently rated as the most famous color even across different cultures [1, 2]. Further, this trend does not only occur for humans, but seems to count for animals, too [3]. Consequently, it is not surprising that websites are often designed in decent blue hues (i.e. Facebook, Twitter, PayPal) [4]. One reason for blue's popularity might be its association (among others) with space, openness, and faithfulness [1] while there is no negative association with this color. Next to these associations, colors can also influence our emotions and therefore impact heavily the first impressions and evaluations of products and websites [5, 6]. It was found that the first impression which is influenced by the color scheme of websites dominates 67% of the purchase process [7]. Consequently, it is suggested, that blue colors raise the likelihood of purchase decisions on websites [8]. Further, for (physical) products 62–90% of the evaluations made about them stem from

the color of their packaging [9], which makes the study of color inevitable for design and marketing. While blue seems to be the preferred color scheme for websites as it is consistently rated as more favorable and more trustworthy [10–13], we are wondering whether there is an impact of blue observable in the emotional and cognitive processing of ecommerce websites. So far, general neuroscientific studies that deal with color vision and perception primarily focus on what is processed in the visual cortex which is directly related to vision, and not what is processed in the prefrontal cortex (PFC) in which higher cognitive and emotional processing happens [14, 15]. However, as there have also been studies revealing the emotional and cognitive impact of color on humans, an investigation of the PFC in which such processes take place might be reasonable. Especially, when the context of the study is in online shopping and website perception. Consequently, in this work in progress, we are questioning if changes in the PFC are observable for blue designed ecommerce websites when they are compared to the same website, albeit in a different color scheme. Thus, we tackle the research question *how are blue colored ecommerce websites processed in the prefrontal cortex?* To give answers to this question, the remainder of the paper is structured as follows. First, related literature dealing with color theory and human color vision in general, as well as the effects of blue color in particular are reviewed. From the latter, two working hypotheses are derived which are further investigated in this study. After that, the method functional near-infrared spectroscopy (fNIRS) is described, as well as the study design and procedure. Finally, results are presented and discussed, and conclusions are drawn.

2 Related Literature

Color Theory and Human Color Vision

Colors have been in focus of several studies reaching from physics to artists to finally, computer engineers. Apparently, these investigations resulted in several different approaches of how to group and mix primary colors into further tones. Generally, it can be differentiated between additive and reductive color mixing. The former is used i.e. in the RGB color model (=red, green, blue). This model was derived from the ideas coming from the trichromatic theory of color vision [16] and the Grassman's Laws of mixing colored light [17]. This is also in accordance with how humans perceive colors with their eyes. That is, we physically perceive colors as light sent at different wavelengths that leads to a sensation in the eye and consequently, in the brain. The peaks of each of the three colors can be defined in nanometers (nm) – for instance, the blue color peaks 440 nm which is a short-wavelength, the color green peaks at 540 nm, which is a medium-wavelength, and red peaks at 580 nm, which is a long-wavelength in the color spectrum [18]. The different wavelengths of the light are perceived through cones in the human eye for which a different amount of cones is available for each of the three colors [19]. The number of cones determines the sensitivity we have for a specific color – as there are about 40-times more cones for red than for blue, the human eye is more sensitive to perceiving the color red than the color blue [18, 19].

Reductive color mixing resulted in what is now known as the CMY(K) color model (cyan, magenta, yellow, black value for printers). Subtracting primary colors was originally called RYB (red, yellow, blue) and was derived by taking the opposing and complementary hues from afterimages of the primary color. From this, several theories of colors were derived with one result of this being the color wheel originally invented by Isaac Newton [20]. Based on the color wheel, different harmonies according to the color's hue can be mixed. Early approaches to color harmonies and their psychological effects reach back to the 19th century [21, 22]. Another approach is to distinguish colors due to contrasts on three dimensions being 1) **value** (meaning light vs. Dark), 2) **chroma** (or saturation, intensity or purity), and 3) **hue** (that means color family, i.e. blue, green, red...) [10]. These dimensions have resulted in several color atlases that can also be understood by lay people such as the Munsell color system [23] which is also frequently applied in literature focusing on color [24–26].

In website design, however, the RGB model either in form of dedicated RGB values or via HEX codes is most frequently used. Studies that focus on color use on websites, have shown that the color scheme can influence emotions and the mood of customers which might further impact their decision making in ecommerce environments [27]. Additionally, color also impacts beauty evaluations of the website and thus, they are one major impact factor on the aesthetic attribution of websites [10, 28–30]. In some studies, it has been shown that for instance blue colors positively influence customers' mood while red colors negatively impact this [31]. Furthermore, another study revealed that blue also positively influences user performance while red negatively impacts it [32]. However, all these studies have primarily used behavioral measurements and did not employ psychophysiological measures. Although the perception and processing of color might also be culture-dependent, the favor of blue seems to be consistent even across different cultures [1, 2]. As both prior described cognitive and emotional responses are processed in the prefrontal cortex (PFC) of the human brain, we further regard it as reasonable to investigate this with a neuroimaging method.

The Perception and Effects of Blue Color

As stated, the human eye possesses cones which can be identified and related to different primary colors. When considering both cones and neural pathways through the visual cortex, it can be differentiated between a blue-yellow and red-green pathway – with the human eye being less sensible to blue, than to red and green [33, 34]. Consequently, blue colored stimuli might lead to specific, unique effects which also unconsciously influence users' perceptions of ecommerce websites. The main identified effects of blue color are that it can positively impact human health [35], which might be due to its relaxation effect [24]. Consequently, blue is suggested to increase performance in creative tasks and decrease it in tasks requiring high detail [36]. With special focus on color impact on attention, red seems to evoke a larger and earlier response in the brain in attention-related tasks [37], which further supports the relaxing effect of blue. In the context of ecommerce and websites, this effect can also be of advantage as studies have shown that blue positively signals approach behavior [36], and thus, it leads to higher pleasure and lower arousal ratings [38]. In general economic contexts, blue is suggested to signal brand competence when used in a company logo [39], and thus, it might lead to higher purchase rates [8]. However, it is also perceived as more trustworthy and more favorable

when used on ecommerce websites [10–13]. Finally, and also of special interest for online environments, blue websites tend to be perceived to download faster than i.e. orange websites although their actual download times do not differ [24].

When summarizing these effects on a more abstract level, they might be differentiated in (a) *emotional processes* which include approach behavior, higher pleasure, less arousal, brand competence and trustworthiness, and in (b) *cognitive processes* such as relaxation, attention, user performance, and probably also trust. Cognitive and emotional processing in terms of the here named constructs is further observable in the prefrontal cortex of humans. Thus, blue colored websites might in fact be relatable to distinct cognitive and emotional processes reflected in the human brain. This leads us to the following two working hypotheses:

H1: Blue websites will reveal significant neural activity changes in PFC areas related to processing pleasant stimuli.

H2: Blue websites will reveal significant neural activity changes in PFC areas related to reduced cognitive processing.

Given that the PFC is primarily responsible for processing such higher, more complex (attribution to) stimuli, this study further uses one website which is manipulated in color and observes whether significant patterns can be observed in the PFC for the blue colored website. These patterns are further analyzed for blue in comparison to (1) no color at all, and blue in comparison to (2) green and orange, which both lie on the red-green pathway.

3 fNIRS Study for Neural Color Processing

Method

The visual appeal of the websites was measured using three scales from the Visual Aesthetics of Website Inventory (VisAWI) developed by Moshagen and Thielsch [40, 41]. In their questionnaire, they include the aspects of colorfulness, simplicity, and diversity which are each represented by 4–5 items, including reversed items. Simplicity (SIM) mainly comprises whether the content is easy to grasp and whether the overall layout appears harmonic. Diversity (DIV) describes the prior described visual complexity and variety which represent the originality of a website. Further, colorfulness (COL) considers whether the color scheme seems appealing and attractive or not. In addition to this, we wanted to assess whether the change in color has a significant impact on purchase intentions (PUI) and consequently, PUI was added as construct.

To complement the questionnaire data, we use fNIRS as second method to assess **neural activity** in the prefrontal cortex (PFC) of participants to receive deeper insights into cognitive and emotional appraisal processes for the blue colored website. The method fNIRS has been applied in the field of neuroscience, as well as cognate disciplines [42, 43]. Furthermore, in the context of human-computer interaction and interaction design, fNIRS has been shown to be a feasible method for measuring usability and user experiences of graphical user interfaces [44, 45]. fNIRS offers a lightweight and portable

method which can be applied in real-life contexts, while measuring the same biological processes as fMRI. Further, when compared to electroencephalography (EEG), fNIRS tends to be more user-friendly and most importantly, more robust to movement artefacts of the whole body and facial expressions when participants for instance talk during recordings [43, 45, 46]. In earlier studies, fNIRS data was found to highly correlate with the more mature fMRI signal [47, 48]. fNIRS operates with near-infrared light sent by sources that is absorbed, reflected or scattered by the human brain tissue, or more precisely by hemoglobin, and received by detectors. As a consequence, fNIRS takes advantage of this characteristic as the amount of oxygenated and deoxygenated hemoglobin (HbO and HbR, respectively) for a given brain region can be calculated with the received light by the detectors [49, 50]. This measurement therefore is an indirect parameter of neural cortical brain activity. Consequently, fNIRS yields potential for IS research, as it is a portable and lightweight technology that appears to be mostly robust to (movement) artefacts and can therefore be applied in practice-relevant scenarios [51, 52]. However, fNIRS has also some shortcomings that might be relevant for IS research. Most predominately, fNIRS has a limited spatial resolution, allowing to penetrate the human brain only on cortical structures [49, 53]. This, however, is sufficient to capture neural responses related to cognitive and emotional processing and decision making on blue ecommerce websites.

Sample and Study Design

Overall a **sample** size of $N = 24$ participants was recruited from the local university with 75% being male, 25% being female. From the sample, 87.5% were right-handed, 12.5% were left-handed. All participants had normal or corrected to normal sight, except one that had a red-green color blindness. Average age of the participants was $M = 26.33$ ($SD = 3.985$).

For the **study design**, four different color manipulated websites (blue, green, orange, black) are used as stimuli (Fig. 1) in connection with the short scales of the VisAWI [40, 41] and a purchase intention question. The questions and websites are then shown randomized in an experimental paradigm which showed the question first for 2s, then the website for 4s, then came the question again with a rating 5-point Likert scale and finally came a jitter with a fixation cross for the mean of 2s. Before the experiment started, participants were informed about their privacy and data protection rights, as well as the operating principle of fNIRS both in verbal and written form. After participants signed the informed consent, the mobile fNIRS headband was placed on the participants' head while taking the craniometric point of the nasion as reference to ensure comparability. To avoid data biases due to experiment equipment interference, several variables were controlled which can produce noise in the fNIRS signal [54–56]. The headband was calibrated for every individual participant through which data quality was assured. Having finished the calibration procedure, participants were instructed to start with the study. After participants finished the study, they were freed of the fNIRS headband and had to fill out a closing questionnaire including demographic questions.

Data Acquisition and Pre-processing

Physiological data was acquired using a continuous-wave NIRSport device developed by NIRx with a headband montage holding 8 sources, 7 long-distance detectors (average

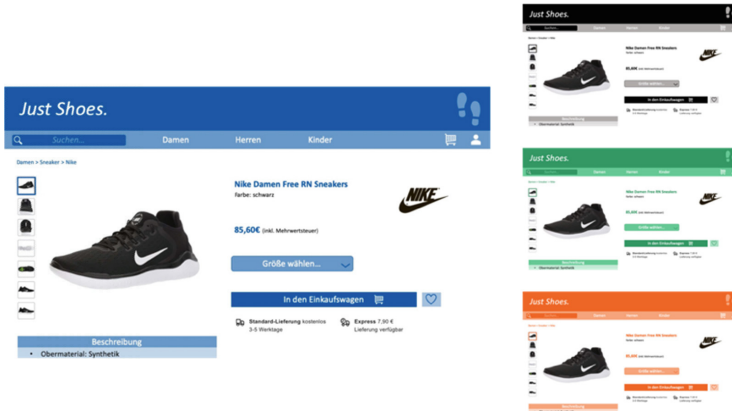


Fig. 1. Employed stimuli

distance 30 mm), and 8 short-distance detectors (average distance 8 mm). As commonly suggested by literature, short-distance measurements are crucial to filter out noise caused by extracerebral blood flow [57, 58] for which 8 mm provide an accurate distance [59, 60]. The wavelengths of the infrared light are 760 nm and 850 nm, the sampling frequency was 7.81 Hz which was resampled to 7 Hz in the pre-processing procedure. The raw fNIRS data was **processed** using the NIRS AnalyzIR toolbox [61]. At first, optical density was calculated, after which the data was bandpass filtered with a high cut-off frequency of 0.2 Hz and a low-cutoff frequency of 0.01 Hz which filters out artefacts due to heart rate and respiration [62, 63]. Further, short separation channel regression was applied as next pre-processing step by using the Linear Minimum Mean Square Estimations (LMMSE) [53, 64], which also heavily improves the hemodynamic response including when Mayer waves are present in the signal [65]. This is followed by calculating hemoglobin values by using the modified Beer-Lambert Law [66, 67]. Canonical hemodynamic response function (hrf) was used as baseline function for the general linear model (GLM). The questionnaire data was analyzed using an ANOVA with Tukey-HSD post-hoc tests. A threshold of $p < .05$ (Bonferroni corrected) was applied for the conducted group comparisons.

Results

The self-reported questionnaire results reflect what has been found in literature before. The ANOVA results were: $F_{\text{Simplicity}}(3, 188) = 3.045$ ($p < .03$), $F_{\text{Diversity}}(3, 188) = 3.916$ ($p < .01$), $F_{\text{Colorfulness}}(3, 188) = 3.730$ ($p < .012$), and $F_{\text{Purchase}}(3, 188) = 3.630$ ($p < .053$) which show statistical significance for all constructs except for purchase intention. For the other three constructs significant differences were found between the orange and the blue website with Bonferroni corrected p-values of $p = .018$ for simplicity, $p = .036$ for diversity, and most significantly $p = .006$ for colorfulness. As blue is in focus of this study, it provides the basis for the fNIRS group analysis in which it is compared to (1) an uncolored, black and white website, and (2) to both a green and an orange colored website. With this, the further focus on the data analysis and discussion are the prior named contrasts being (1) blue vs. non-colors and (2) blue versus other colors. For

Oxygenated Hemoglobin:

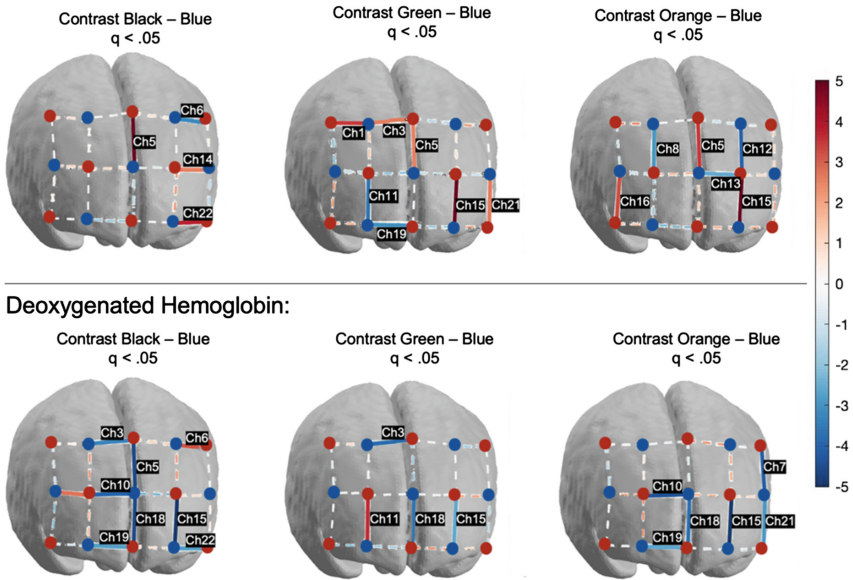


Fig. 2. T-statistic contrasts between blue and other colored websites (continuous and flagged lines represent significant channels).

each comparison, we applied paired t-tests with a false discovery rate (FDR) corrected threshold of $q < .05$ [68]. Figure 2 shows the t-statistic results of the contrasts between the blue and the other websites for HbO and HbR with the continuous lines representing significant channels (Ch) (with $q < .05$). When being compared to the uncolored website, decreased neural activity in the *left vmPFC* (Ch 22), and *right dmPFC* and *vmPFC* (Ch 3, 5, 10, 15, 18, 19) could be identified for the blue website. Further, this comparison also leads to significantly increased activity in the *left dIPFC* (Ch 6). When compared to both other colors (in this case orange and green), significant decreases on the blue website could be identified in the *dmPFC* (Ch 5) and the *left vmPFC* (Ch 15), as well as increases in the *right vmPFC* (Ch 11, 18, 19).

4 Discussion

In order to interpret our results and further analyze, whether the working hypotheses are supported by neural activity, we followingly present typical functions of the identified PFC regions which are related to decision making, together with the here found activity in these structures (Table 1). Firstly, and following our hypothesis H1, the left dIPFC seems to be related to processing pleasant stimuli which was identified increased for the blue website. Further, areas related to processing negative emotional stimuli such as the dmPFC and vmPFC were found to be decreased for the blue website which further supports our H1 which stated that blue websites will show significant differences in neural structures related to processing pleasant stimuli. Solely the vmPFC partly rejects

this hypothesis, as it only showed increases on the right hemisphere, albeit not on the left. Given its role in processing pleasurable experiences, this hemisphere-specific activation seems contradicting. However, as increases in this region are also observed when confronted with the favorite brand of a product, activations in this region seem plausible for the blue website which was rated highest in the aesthetic scales. Consequently, H1 is regarded as supported.

Table 1. Identified activations in this study and typical functions of corresponding areas in the PFC (*italic points are used for discussion*)

Area	Typical functions	Ref.
(left) dlPFC (blue > non-color)	<ul style="list-style-type: none"> • performance monitoring • behavioral adjustment & error detection • reward evaluation & <i>linking sensory information to decision and action</i> • decreased when confronted with favorite brand • <i>left dlPFC increased for beautiful or pleasing stimuli</i> 	[15, 42, 69–80]
dmPFC (blue < non-color & other-color)	<ul style="list-style-type: none"> • performance monitoring & adjusting behavior • forming and <i>processing first impressions</i> • <i>increased in attributing negative valence to stimuli</i> • emotion processing and <i>regulation</i> • activated in color discrimination and categorization 	[69, 70, 73, 77, 81–85]
vmPFC (<i>left</i> : blue < non-color & other-color; <i>right</i> : blue > other color)	<ul style="list-style-type: none"> • increased for purchase intentions • <i>working memory</i> • necessary for rational decision making • <i>cognitive control of emotional processes</i> • <i>active when facing anticipation and uncertainty</i> • activated when facing one's first choice brand • increased for beautiful and pleasant stimuli 	[15, 80, 86–94]
(left) vlPFC (blue < non-color)	<ul style="list-style-type: none"> • related to semantic processing and categorization processes • receives emotional and motivational information to process for decisions • controls hand and eye movements • <i>activated for facing negative, or unpleasant images</i> 	[15, 83, 95–100]

Further, as already mentioned, the left vmPFC was decreased on the blue website compared to all three other websites. Therefore, in the given context this deactivation might reflect a lower impact of working memory on blue websites which would be in line with our second hypothesis H2. Cognitive deactivations were also observable in the dmPFC and vlPFC for the blue website, which both point to decreased effort to process the first impression, behavioral adjustments, and semantic processing – all of which can be regarded as more cognitive than emotional functions and thus, these findings support H2. However, the dlPFC which also incorporates cognitive processing through its role in performance monitoring, error detection, and behavior adjustment does not support this hypothesis. Given that this structure was only identified on the left hemisphere, and not bilaterally might support our assumption that this activation is more related to the emotional processing and not to the cognitive.

5 Conclusion

To conclude the findings of this work in progress, prior hypotheses which were derived from literature regarding the effects of the blue color on human perception and behavior were found to be supported in the neural activity in the prefrontal cortex. That is, blue websites seem to be characterized by a decrease in cognitive processing which becomes evident in areas of the vlPFC, vmPFC, and dmPFC. Further, blue websites also elicit activation patterns typically related to processing beautiful and thus, pleasant stimuli which further represents emotional processing and attribution of blue websites when compared to other colors. These findings and conclusions further reveal the need to pursue **further research** in this direction in order to shed more light onto the role of the prefrontal cortex in website processing. Additionally, as mainly areas for decision making and processing emotional stimuli were activated, both processes seem to be tightly connected on ecommerce websites. Future research could therefore focus on how personality traits, gender-related color processing, or the impact of culture, as well as the use context, and website design influence these processes both on a behavioral and neural level and therefore, conduct between-group analyses. That is, the favorite color of a person might for instance influence their perception of the color use on a website, or specific meanings attached to color which are culture-dependent might impact its perception. Further, this study could also be reconducted with other methods such as eye tracking or EEG to better assess the visual pathways of users as well as get more timely neural information which may be crucial for decision making and color processing [101]. Although this paper provides a start into this research domain, it also comes with **limitations**. Among others, its major limitation is that participants only viewed screenshots of the colored websites and did not interact with them. The findings of this study thus are limited in their external validity and need to be further validated in real-life contexts where users actually interact with the websites – maybe even for longer time spans or repetitively. Further, the employed sample size included 75% males which might result in gender-related biased results, as men and women tend to process information differently [102, 103]. Finally, the analysis and data interpretation solely focused on the blue website and did not focus on the other included colors and their unique neural patterns. Consequently, follow-up studies can further use these results and investigate

different colors on websites and their impact on neural processing and consequently, on beauty perceptions and purchase intentions.

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