MASTER THESIS

THE EFFECTS OF COLOR ON PROCESSING OF GLOBAL AND LOCAL STIMULI IN VISUAL PERCEPTION

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Preface

This master’s thesis has been written as my graduation project of the Master of Science in “Human Factors and Engineering Psychology” at the University of Twente, Enschede in collaboration with the department of Experience and Perception Research of Philips Lighting, Eindhoven. I would like to use the preface to the thesis to thank everyone who helped me during this time to complete my project and my studies.

First, I would like to express my gratitude to the University of Twente for giving me the possibility to conduct this research. I furthermore would like to thank Philips Lighting, in particular the department of Experience and Perception Research for providing me with the possibility and the resources for conducting my research and completing my thesis.

I would like to thank Dr. Matthijs Noordzij of the University of Twente who already supervised me in my bachelor’s thesis for retaking his role as first university supervisor and providing constant feedback and help. I would also like to thank Dr. Thomas van Rompay of the University of Twente, my second supervisor, for his help and creative input on this thesis. I especially thank Dr. Jan Souman of Philips Lighting, who not only functioned as my external supervisor of the thesis on a daily basis but who also taught me a lot about working in a professional environment and without whom this project would not have been carried out.

I also would like to thank the staff at Philips in Eindhoven, especially Dr. Tobias Borra for feedback and supervision and Ruud Baselmans for constant help with the setup of my experiments. I express my gratitude to Vivian Roth and Andra Alexa for proofreading the thesis and giving me final feedback as well as Edoardo Repetti for helping me with the design of the cover letter. Furthermore, I would like to thank all participants who participated in the experiments without hesitation.

Last, but certainly not least, I want to thank my family for their support not only during the time of my graduation project but also during the whole duration of my study. None of this would have been possible without you.

Sascha Jenderny, June 2016

Abstract

Introduction: In investigating the psychological effects of light, the effects of color are a major factor. Studies have found that color can have an influence on how we recognize and process visual information in our surroundings. In the processing of visual stimuli, the global aspects are often processed earlier than their local counterparts, which may lead to interferences in the recognition of local elements, an effect known as the global precedence effect (GPE). This effect may be mediated by color, most importantly the color red. The aim of this research thesis is to investigate whether the psychological effects of color may also be obtained with colored lighting. To answer this question, a pilot study and three experiments have been carried out.

Pilot study and Experiment 1: Twelve (Pilot study) and eighteen (Experiment 1) participants were given the task to identify the global and local features of hierarchically organized stimuli on three (red, green and grey) isoluminant backgrounds. The results of the pilot and the first experiment both indicated that global features are identified faster than local features and that a global-to-local interference (GPE) took place. However, no differences in GPE across the different colors have been found.

Experiment 2: The second experiment was designed to additionally investigate the attenuating effect of a red background color on visual processing via the magnocellular pathway of the visual system. Sixteen participants were given the task to identify the orientation of either global or local features which were presented at high and low spatial frequencies on three (red, green, blue) isoluminant backgrounds. The results indicate a GPE as well as an advantage of low compared to high spatial frequencies in local tasks. No differences in GPE across the colors have been found. No consistent effects of color on different spatial frequencies have been found.

Experiment 3: In the last experiment, 16 participants carried out the same tasks as in Experiment 2. The colored backgrounds were replaced with colored ambient lighting (red, green and blue). The results indicate a GPE and an advantage of low spatial frequencies in local tasks. No differences in GPE have been found across the different colors

Conclusion: In a series of one pilot and three experiments we found further evidence for the global precedence effect in visual perception. However, we did not find an indication that the global precedence effect is mediated by background color. For this reason the effects of color on processing could also not be replicated with the use of ambient lighting. Future research should address the working mechanisms of the magnocellular pathway. Furthermore there is a strong need for a combining framework on the psychological effects of color and colored lighting.

Samenvatting

Introductie: In het onderzoek naar de psychologische effecten van licht spelen de effecten van kleur een belangrijke rol. Studies hebben aangetoond dat kleur invloed kan hebben op hoe wij visuele informatie in onze omgeving waarnemen en verwerken. In de verwerking van visuele stimuli worden de globale aspecten vaak sneller verwerkt dan de lokale elementen. Dit kan ertoe leiden dat de globale vormen met het identificeren van lokale elementen interfereren. Dit wordt de global precedence effect (GPE) genoemd. Dit effect kan worden gemedieerd door kleur, specifiek door de kleur rood. Het doel van deze these is om te onderzoeken of de psychologische effecten van kleur ook door gekleurd omgevingslicht kunnen worden bereikt. Om dit te beantwoorden, werden er een pilotstudie en drie experimenten uitgevoerd.

Pilotstudie en Experiment 1: Twaalf (Pilotstudie) en achttien (Experiment 1) participanten werden de taak gegeven om globale en lokale elementen van hiërarchisch georganiseerde stimuli on drie isoluminante achtergronden (rood, groen en grijs) te identificeren. De resultaten van de pilotstudie en Experiment 1 laten zien dat globale elementen sneller worden geïdentificeerd dan lokale elementen en dat een interferentie van de globale op de lokale elementen (GPE) plaats heeft gevonden. Echter waren er geen verschillen in GPE tussen de verschillen achtergrondkleuren.

Experiment 2: Het tweede experiment werd opgesteld om de verminderende effect van een rode achtergrondkleur op visueel waarnemen door de magnocellulaire pad van het visuele system te onderzoeken. Zestien participanten werden de taak gegeven om de oriëntatie van globale en lokale elementen te identificeren. De elementen werden zowel met een hoge als ook een lage spatiele frequentie (SF) op drie verschillen isoluminante achtergronden (rood, groen en blauw) aangeboden. De resultaten laten zien dat de GPE plaats heeft gevonden en dat lage spatiele frequenties in lokale taken sneller worden geïdentificeerd. Geen verschillen in GPE tussen de kleuren en geen consistente effecten van kleur op SF werden gevonden.

Experiment 3: In het laatste experiment werden 16 participanten gevraagd om dezelfde taken als in Experiment 2 uit te voeren. Echter werden de gekleurde achtergronden door gekleurd omgevingslicht (rood, groen en blauw) vervangen. De resultaten laten zowel de GPE als ook de snellere identificatie van lage spatiele frequentie op lokale taken zien. Echter worden geen verschillen in GPE tussen de kleuren gevonden.

Conclusie: In een serie van een pilotstudie en drie experimenten hebben wij aantoningen voor de GPE in visuele waarnemen gevonden. Echter kunnen wij niet ervan uitgaan dat de GPE door achtergrondkleur wordt gemedieerd. Hierdoor kunnen de effecten van kleur ook niet door

omgevingslicht worden bereikt. De focus van toekomstig onderzoek zou op de werkwijze van de magnocellulaire pad gericht zijn. Verder bestaat er behoefte aan een omvattend theoretische kader voor de psychologische effecten van kleur en gekleurd licht.

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Introduction

For a long time, light has solely been used as a synonym for its physical properties, namely the visible parts of the electromagnetic spectrum. However, in the current research on the effects of lighting and the research on lighting centered application, the need to also understand the non-physical effects of light grows (van Bommel, 2006). Concerning the biological effects, that light has on humans, research has shown that light plays a major role in the regulation of the circadian rhythm by affecting the suprachiasmatic nucleus which is mediating the production of the bodily sleep hormone melatonin (Cajochen, 2007; Pinel, 2010; Rahman et al., 2014) or by possible light transduction through the skin (Campbell & Murphy, 1998). Besides the biological effects of light, studies have shown that light may also affect cognitive functioning of human beings. Research on light and alertness has shown for instance that blue light (or blue enriched light) increases alertness on attention based tasks (Viola, James, Schlangen, & Dijk, 2008; Wahnschaffe et al., 2013) Further studies show, that light may have an effect on a vast array of cognitive processes such as attention (Chellappa, Gordijn, & Cajochen, 2011), perceived guilt (Aspinall & Dewar, 1980), mood (Kaufman & Haynes, 1981; Turner, 1995) or decision making (Kliger & Gilad, 2012; Perrons, Richards, Platts, & Singh, 2006). From a more consumer-oriented point of view, research reports that light may have profound influence on patients and consumers in terms of consumer satisfaction, stress level, health (Frasca-Beaulieu, 1999) or self-reported quality of well-being (Sörensen & Brunnström, 1995). However, other studies failed to provide evidence for the effects of light (Boray, Gifford, & Rosenblood, 1989; Veitch, 1997) and the domain of the psychological effects of light remains a field which needs to be explored. An important factor, which has to be considered when the psychological effects of lighting are discussed, is the psychological effects of color. Frasca-Beaulieu (1999) states that the effects of lighting are not to be seen as two independent mechanism but work closely together.

The effects of color on human cognitive functioning have long been subject to psychological research. Starting already in 1942, Goldstein (1942) suggested that emotional experiences such as positive or negative arousal as well as certain cognitive mechanisms in human behavior may be mediated by the presence of certain colors such as red or yellow (Goldstein, 1942). Research has shown that visual search times were faster when the targets were presented in a red color compared to other colors (Buechner, Maier, Lichtenfeld, & Elliot, 2015; Lindsey et al., 2010; Tchernikov & Fallah, 2010). Furthermore, the color red has shown to have an enhancing effect on performance. In the athletic domain for example, competitors with red clothing tend to outperform those with blue clothing (Meier, Hill, Elliot, & Barton, 2015). In studies on the effects of color on academic performance, participants who first saw a red cover letter tended to perform worse on an intelligence test than participants with a grey or green cover letter (Elliot, Maier, Moller, Friedman, & Meinhardt, 2007). Although this finding has been made by several other studies (Gnambs, Appel, & Batinic, 2010; Shi, Zhang, & Jiang, 2015b; Zhang & Han, 2014), other studies show that red may also enhance cognitive performance (Kwallek & Lewis, 1990). Breitmeyer & Breier (1994) found that in a task where low spatial frequency stimuli have to be processed, participants had prolonged reaction times on identifying spot stimuli on a red background compared to a blue or green background. Similar findings have also been made concerning the processing of stimuli with a high temporal frequency where participants also performed worse (i.e. higher reaction times in an identification task) with a red background compared to other colored backgrounds (Breitmeyer & Williams, 1990a). Furthermore, the color red has shown to increase detail-oriented processing behavior. In a study on persuasive message evaluation, Mehta and Zhu (2008) showed that the participants evaluated a product as more favorable based on an advertisement on a red (compared to a blue) background when visuals on the product details were given. On the other hand, participants evaluated the product better based on the advertisement on a blue (compared to a red) background when the ad contained visuals about the overall concept and associations of the product. The effect of a red background on detail-oriented behavior has also been shown in a study on the processing of hierarchically organized stimuli. A study by Michimata Chikashi, Okubo and Mugishima (1999) found that a red background enhances detail-orientation. In a visual identification task of stimuli with global and local features, the overall shape of a stimulus interfered less with detail identification (i.e. faster reaction times) in a red background compared to a green background.

One approach to explain why a red background enhances the focus on detailed information concerns the parvocellular and magnocellular pathway of the visual system. Information processing through these pathways starts at the retina of the eye and goes through until the visual areas of the cortex. The parvocellular pathway is mainly responsible for the processing to high spatial frequency and low temporal frequency information and is known to be slower than its magnocellular counterpart through which information with high temporal frequency and low spatial frequencies are processed. Temporal frequency refers to the repetitions of a stimulus per time unit. The more often a stimulus is repeated within a specific time unit, the higher is its temporal frequency. Spatial frequency describes the level of detail in a stimulus per degree of visual angle. The more small details and sharp edges per degree of visual angle, the higher the spatial frequency of a stimulus. (Livingstone & Hubel, 1988; Livingstone & Hubel, 1987; Seymour, Clifford, Logothetis, & Bartels, 2010). The magnocellular pathway is known to contain Type IV cells which may be inhibited by red light. This is due to the fact that these cells have a receptive field with a tonic red surround mechanism. Thus, imposing a red background on stimuli may trigger this surround mechanism and suppress the working mechanism of the magnocellular pathway (Breitmeyer & Breier, 1994; Chapman et al., 2004; Chase et al., 2003; Edwards et al., 1996). If we suppose that the global features of a stimulus contain more low spatial frequency information and the detailed features contain more high spatial frequency information, we may theorize that the suppressing effect of a red background on the magnocellular pathway suppresses mostly the global features of a stimulus. Therefore the focus in visual perception shifts to the details which is how the enhancement of focus on detail on a red background may be explained.

From an evolutionary perspective the association of a certain color to a certain nature of the situation can be explained by research which has been conducted in non-human animals. In nature, dominance in a species is often presented by the color red which may be caused by an increased blood flow which reddens parts of the skin as a signal (Bishop & Robinson, 2000; Böddeker & Stemmler, 2000; Hill & Barton, 2005). For other animals, this skin reddening may be associated with dominance and aggressiveness which influences their behavior. Color theorists believe that also in humans color influences cognition and behavior through learned associations (Kwallek & Lewis, 1990). The concept that color serves as a cue for the nature of the situation was used and elaborated by Elliot and Maier in 2012 when they published the color-in-context theory (Elliot & Maier, 2012). The theory states that color elicits certain behavior by association but always has to be seen in the context in which the color is presented. A prime example for the importance of the context on the color association is the color red. On the one hand, researchers have found out that viewing the color red increases the appraisal of dominance in a more competitive context such as a football match or another competitive sport (Feltman & Elliot, 2011; Greenlees, Leyland, Thelwell, & Filby, 2008; Little & Hill, 2007) or induce a more cautious behavior in an academic context such as an intelligence test (Elliot et al., 2007; Mehta & Zhu, 2008; Rutchick, Slepian, & Ferris, 2010). Both behaviors can be seen as caused by a typical avoidance motivation. On the other hand, red has also shown to increase approach-motivated behavior. For example, females wearing red are often rated as more attractive by heterosexual male participants in a romantic context (Elliot & Niesta, 2008; Schwarz & Singer, 2013; Wen, Zuo, Wu, Sun, & Liu, 2014). Scientists believe that the avoidance motivation which is triggered by perceiving the color red makes people more vigilant and risk-averse (Förster, Friedman, Özelsel, & Denzler, 2006; Friedman & Förster, 2000) and that threatening situations drive people to a more careful and detail oriented behavior (Ronald S. Friedman & Förster, 2002). Based on these two premises, we may theorize that red enhances the focus on detail through associations with danger or threat.

A paradigm to investigate how people process overall features and small details has been proposed by Navon (1977) with a task that required the identification of hierarchically organized stimuli, i.e. an overall (global) shape which is constructed by the accumulation of several smaller (local) shapes. If the smaller shapes are the same as the overall shape, the stimuli are congruent (local and global shape match). If the shapes differ, the stimuli are called incongruent (mismatch between global and local shape). Navon (1977) found that identifying global shapes takes less time than identifying their local counterparts, also known as the global-to-local-advantage. Furthermore, he found that reaction times in identifying local stimuli are slower if the global appearance of the stimuli does not match the local appearance (i.e. the global form is not equal to the local form). This effect, which is also called the global-to-local interference, does take place in the identification of local stimuli with incongruent global stimuli, but takes place far less with global identification with incongruent local stimuli. Based on this, Navon (1977) named this effect the *global precedence effect*, meaning that the global features are identified earlier than their local counterparts, leading to an interference in the case of incongruent stimuli when local features have to be identified. Since then, the existence of the global precedence effect has been shown in several other studies (Bouvet, Rousset, Valdois, & Donnadieu, 2011; Goto, Wills, & Lea, 2004; Kimchi, 1992) including studies, that found evidence for the effect on a physiological level (Han, Yund, & Woods, 2003; Proverbio, Minniti, & Zani, 1998). Research furthermore has shown that the perception of global and local features of a stimulus can be affected by several factors such as size of the stimulus, viewing angle or spatial frequency (Baker & Braddick, 1982; Eagle & Rogers, 1997; Kimchi, 1992). Michimata et al. (1999) reported that the global precedence effect can also be mediated by changing the background color of the stimuli. The researchers found, that while global-to-local interference took place normally when stimuli where presented on a green background, it was decreased when presented on a red background. This led to the theory that the color red has an attenuating effect on the interference of conflicting global features on the identification of local elements in hierarchically organized stimuli.

To this moment, there is a vast theoretical framework on the psychological effects of color on human beings. In particular, the color red has been given a lot of attention. The effects of colored lighting on the other hand need further elaboration. Given the current developments in the areas on surround and ambient lighting, there is a strong need to understand how these lights may influence human functioning and behavior. Based on the theoretical framework, there is reason to claim that the color red enhances the focus on detail and enforces thorough processing of information. These effects may prove to be beneficial in a vast variety of lighting applications such as the quick assessment of detailed information on computer screen in traffic control, high-pressure, high-risk environments such as an airplane cockpit, power plant control stations or defusing explosives. Red-induced detail orientation may aid the controllers in resolving emergency situations. On the other hand, red lighting may also be beneficial in academic tasks, which require detail-orientation such as complex mathematics exercises. Lastly, as already mentioned in the theoretical framework, the color of the light may influence how we perceive and elaborate advertisement. In this case the colored light could be used to set the focus on certain products of features of the advertisement.

However, until now there is no evidence that the effects of color may also be achieved by colored ambient lighting. By using the paradigm of hierarchically organized stimuli by Navon (1977), the aim of this master thesis is to investigate whether the effects of background color on visual processing of hierarchically organized stimuli may also be obtained by ambient lighting. To find an answer to this research question, we started on conducting research on the effects of color on the global precedence effect in the processing of hierarchically organized stimuli. In a pilot study, which was based on the study by Michimata et al. (1999), we investigated the effects of three different background colors on the GPE. Since the pilot did not yield the expected results, the first experiment was conducted as an exact replication of the study by Michimata et al. (1999). We continued with a second experiment on the effects of colored backgrounds on the global precedence effect. Furthermore, we investigated the effects of red background lighting on the magnocellular pathway of the visual system. Lastly, a third experiment was carried out in which the color manipulation was achieved with colored ambient lighting to investigate the effects of ambient lighting on visual processing.

Pilot study - Introduction

The first research question that arises in this master thesis is to find evidence for the effects of a red background color on the global precedence effect in the identification of hierarchically organized stimuli. For this purpose a pilot study was conducted which aimed to replicate the results made by Michmimata et al. (1999). To investigate these effects we chose to conduct a visual identification task of hierarchically organized stimuli on different colored backgrounds. The stimuli used on this study were based on the stimuli used by Michimata et al. (1999). By letting the participants identify shapes with a global feature (square or diamond) and local features (square or diamond) we aimed to investigate whether the global precedence effect can be attenuated in a red background.

We chose to conduct the tasks on three different backgrounds. A red and a green background were used to investigate the effects of color as suggested by Michimata et al. (1999). Furthermore, we chose to add a grey background as a baseline condition. Every participant completed the same tasks on all backgrounds. By comparing reaction times and error rates in the identification of the stimuli, we aimed to find evidence that the global precedence effect appears less strong in the red background condition compared to the other conditions. Contrary to the original study, we presented the stimuli on much brighter displays in the hope that this would increase the effects of the background color on visual processing. We furthermore presented the stimulus on a random point on the screen to avoid anticipatory effects.

We expected that in the identification of the stimuli, we would find evidence for a global-to-local interference in the identification of local features in incongruent stimuli (i.e. higher reaction times on incongruent local stimuli compared to congruent local stimuli). We furthermore expected this interference to be less present in the red background compared to the other backgrounds.

Pilot study - Method

Participants

Twelve Participants (5 female, 7 male) took part in the study. The age of the participants ranged from 23 to 31 years with a mean age of 25.75 years. Ten of the participants were right-handed, one was left-handed and one participant indicated that he was both-handed. All participants were recruited via non-probability convenience sampling and were employed by Philips at the moment of the study.

Materials

Computers

The experiment was presented on a computer with a Windows 7 operating system with a NVIDIA Quadro K620 graphics card. The task was conducted using the program psychopy2 (Peirce, 2007). Assessment of the reaction time was done by using a keyboard which was connected to the computer via USB.

Screen and background colors

The stimuli were presented on a high - resolution 27" MultiSync PA272W-BK screen with a 60 hz refresh rate. Three different background screen colors were used. The indicated *x* and *y* values refer to the CIE 1931 color space (CIE, 1931), which can be found in the attachments (Appendix A). The three colors ([x], [y]) used were: Red ([0.6428], [0.3248]), Green ([0.2309], [0.6801]) and Grey ([0.3213], [0.3284]). Luminance was assessed with a photospectrometer (JETI Specbos 1211, JETI Technische Instrumente, Jena, Germany) prior to the experiment. All backgrounds were isoluminant with a luminance of 44 cd/m^2. The screen had a diameter of 56.48 x 32.02 degrees of visual angle (58 x 31 cm), with a resolution of 2560 x 1440 pixels. A chin rest was placed 54 cm in front of the screen.

Stimuli

The stimuli in this study were large figures, which were composed of eight smaller figures. The figures differed on two levels: The large shape (global) of the stimuli, which could be either a square or a diamond and the smaller shapes (local), which could be either squares or diamonds. This led to four possible combinations (see

). The stimuli could be either *congruent* (small and large shape were the same) and *incongruent* (small and large shapes differed). The smaller shapes had a diameter of 0.85 x 0.85 degrees of visual angle. The large shapes had a diameter of 4.24 x 4.24 degrees of visual angle. The stimuli were colored black (*x* [0.2642], *y* [0.2463]) had a luminance of 0,23 cd/m^2.

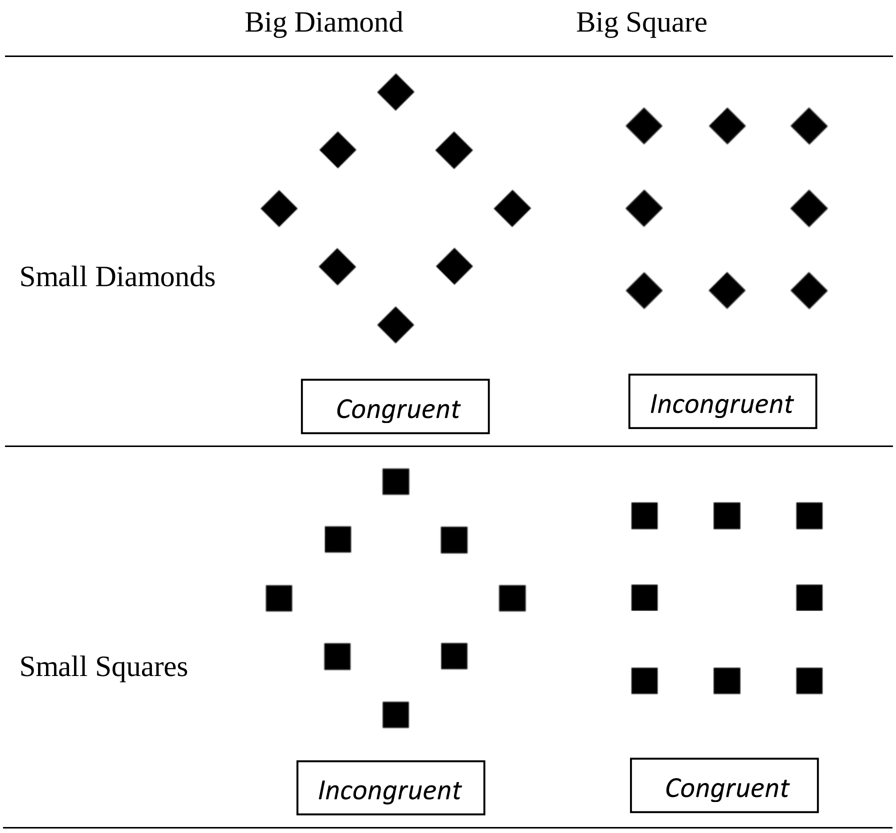

Figure 1. Overview of the different stimuli of the pilot study. The stimuli could either differ on a global level (big square or big diamond, columns) or on a local level (small squares or small diamonds, rows). The table shows all four possible combinations.

Procedure

The researcher explained the experiment to the participants by showing them the different figures and explaining the organization, duration and tasks of the experiment. Prior to the experiment the participants filled in an informed consent (Appendix B) and a demographic questionnaire (Appendix C).

The participants were instructed to sit down in front of the screen and place their head on the chin rest. Besides the screen, there was no other source of lighting in the room. The entire experiment consisted of 576 trials. 24 trials were given to each of the 24 conditions, defined by an orthogonal combination of background color (red/green/grey), task (global/local), congruency (congruent/incongruent) and figure (figure which had to be identified: square/diamond). The experiment was divided into three sessions, one for each background color. Every session consisted of two blocks, one local and one global figure identification task. Before each block, the participants were instructed to identify either the stimulus on a global level (large figure) or on a local level (small figures) by pressing the corresponding key on the keyboard. Prior to each stimulus, the participants were instructed to fixate a cross (black (x = [0.2642], y = [0.2463]); size: 0.11 x 0.11 degrees of visual angle) which was situated in the middle of the screen. The cross was presented for 750ms. When the cross disappeared, the stimulus was then presented for 200ms. For every trial, the stimulus appeared on a random point which was situated on a radius of 1.54 degrees of visual angle from the middle of the screen. The participant had 9 seconds to give an answer. If he/she had not answered by that time, the response was marked as incorrect. Each block was preceded by 8 practice trials, in which the participants were given feedback on their answer (Correct/incorrect, reaction time in case that answer given was correct). No feedback was given on the subsequent experimental trials. Half of the subjects performed the global tasks first, followed by the local tasks. The other half of the participant completed the tasks in the opposite order. The order of the color and the tasks as well as finger-response mapping was counterbalanced across participants.

Data analysis

For each subject, the median reaction time (RT) of all correct answers and mean error rate (ER) for each of the 24 experimental conditions was computed. For the ANOVA, the reaction times were further normalized by an inverse transformation (1/RT) (see Appendix D, Table D1). The median of the inverted reaction times per condition and the error rates were each compared in a 3x2x2x2 repeated measures analysis of variance defined by a combination of Background (Red/Green/Grey), Task (Global/Local), Congruency (Congruent/Incongruent) and Figure (Square/Diamond). Furthermore, both reaction times and error rates were subjected to a 2x2x2 ANOVA (Task, Congruency, and Figure) per background color.

Pilot study - Results

Reaction time: Main effects

The results show that the participants reacted faster in the identification of the large shapes (mean = 530 msec) compared to the identification of the smaller shapes (mean = 579 msec). This is indicated by a significant *task* main effect ($F(1,11) = 66.634$, MSe = .073 , $p<0.001$) (Figure 1). Furthermore, participants reacted faster on the congruent stimuli (mean = 526 msec) compared to their incongruent counterparts (mean = 556 msec) which is indicated by a significant main effect of the factor *congruency* ($F(1,11) = 21.096$, MSe = .036, $p=0.001$). No significant differences in reaction time have been found between the different backgrounds or between the reaction times on squares compared to diamonds (both main effects are non-significant).

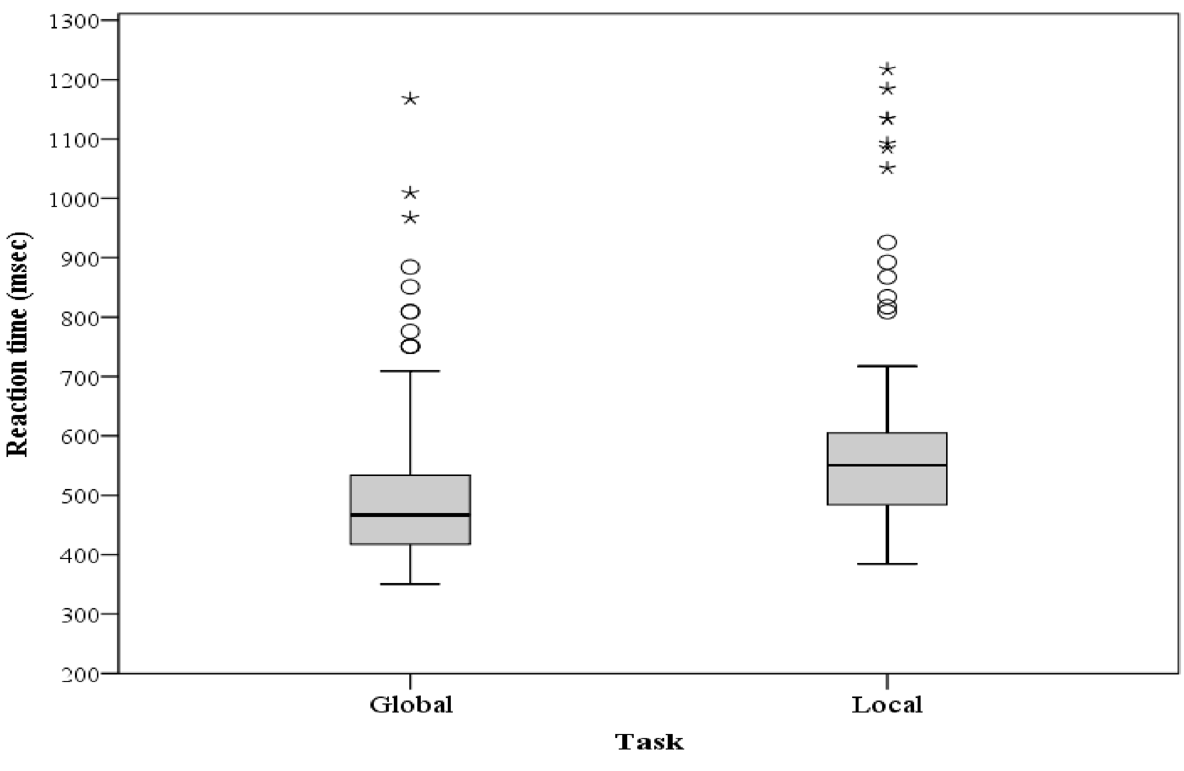

Figure 2. Pilot study: Boxplot of the median reaction times of all 12 participants on the global and the local task. The circles indicate outliers which are further than 1.5 interquartile ranges from the median while the stars indicate "extreme" outliers which are further than 1.5 interquartile ranges from the median. The error bars indicate the smallest (lowest) and the biggest (highest) non-outlier value. The horizontal line within each boxplot indicates the median per condition.

Reaction time: Interaction effects

The results show that the amount of interference (Incongruent – Congruent) of the local shapes on global tasks (mean = 15 msec) was significantly lower than the interference of the global shapes on the identification of local shapes (45.782 msec), which indicates the presence of the global precedence effect. This is shown by the significant *task* x *congruency* interaction effect (F(1,11) = 9.090, MSe = .014, p=0.012) (figure 3). In addition, participants identified squares faster than diamonds for congruent stimuli (Square = 509.495 msec, Diamond = 543.321) but identified diamonds faster than squares in incongruent stimuli (Square = 570 msec, Diamond = 542.751 msec) which is shown by a significant *congruency* x *figure* interaction effect (F(1,11) = 65.929, MSe = .009, p < .001). Contrary to our predictions, no differences in the amount of global-to-local interference in the identification of small shapes (GPE) has been found across the three different backgrounds since significant three way interaction between the factors *background*, *task* and *congruency* was not significant (F(1,11) = 1.339, MSe = 22, p = .283) (figure 4).

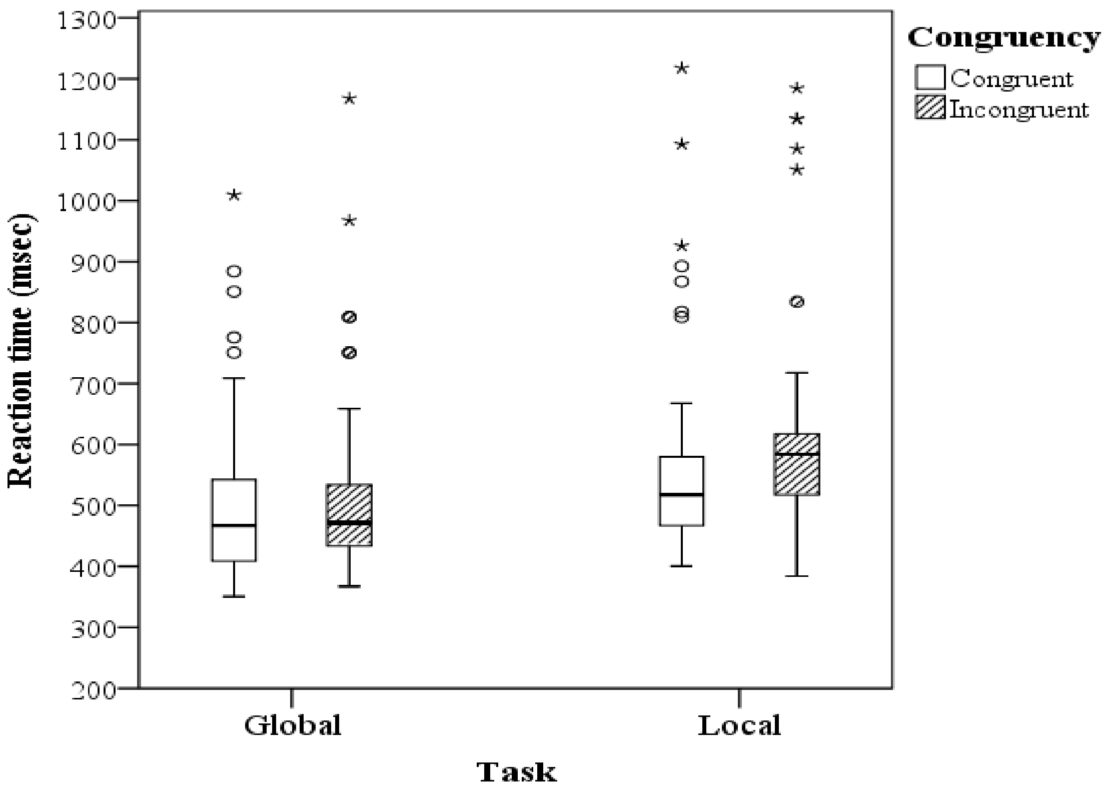

Figure 3. Pilot study: Boxplot of the median reaction time of all 12 participants for the global and local tasks divided into congruent/incongruent stimuli. For further information about the elements of the boxplot see figure 2.

Reaction time: Effects per color

The analysis per background color shows that the amount of global-to-local interference is significantly higher than the local-to-global interference in both the *red* and the *grey* background, indicating the global precedence effect. This can be seen by a significant *task* x *congruency* interaction effect for red ($F(1,11) = 11.092$, MSe = .009, $p = .007$) and grey ($F(1,11) = 5.087$, MSe = .022, $p = 0.045$) (Figure 4). Contrary to our expectations and the non-significant *background* x *task* x *congruency* interaction effect, there was no significant difference in the amount of interference (global-to-local vs. local-to-global) in the green background which may be an indication that the global precedence effect did not take place in this color condition (as seen by a non-significant *task* x *congruency* interaction ($F(1,11) = .939$, MSe= .016, $p = .353$). An overview of all effects per background color can be found in the appendix (Appendix, Table E2)

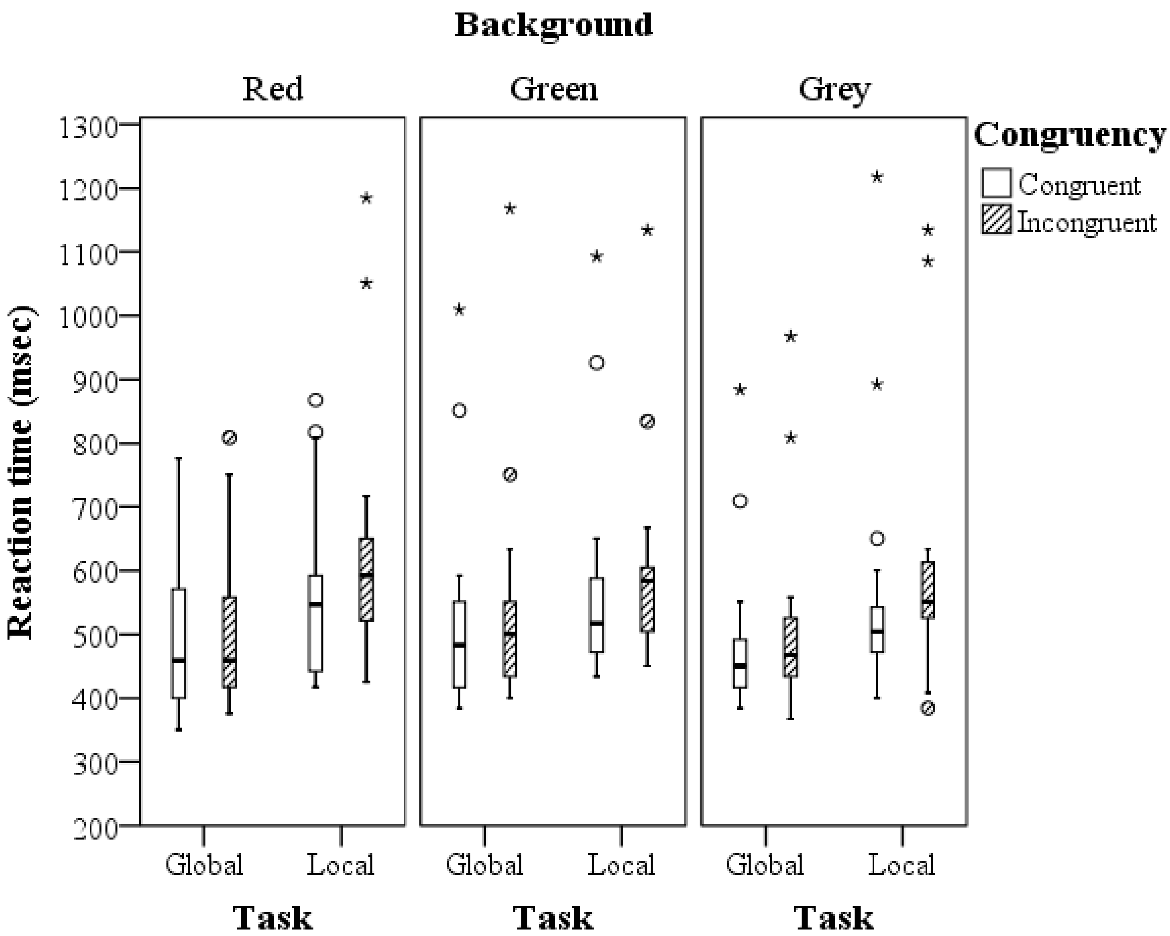

Figure 4. Pilot study: Boxplot of the median reaction time of all 12 participants for the global and local tasks divided into congruent/incongruent stimuli for the red, green and grey background. For further information about the elements of the boxplot see figure 2

Error rate: Main effects

Participants made more errors in identifying the large shapes (6.34%) compared to the identification of the smaller shapes (5.19%) which is shown by a significant *task* main effect ($F(1,11) = 5.569$, $MSe = 17.200$, $p = 0.038$). Furthermore, participants have a higher error rate for incongruent stimuli (6.87%) compared to their incongruent counterparts (4.67%) which is indicated by the significant *congruency* main effect ($F(1,11) = 13.392$, $MSe = 26.071$, $p = 0.004$).

Error rate: Interaction effects

We found a lower difference in error rate between congruent and incongruent judgments in the global tasks (Incongruent = 6,721%, congruent = 5,961%) than in the local tasks (Incongruent = 7,010%, congruent = 3,365%), which is shown by a significant *task* x *congruency* interaction effect (F1,11) = 6.653, MSe = 22.513, p = 0.026). Furthermore, in the global tasks, participants made more errors identifying diamonds (6,950%) than squares (5,732%) while in the local tasks, they made more errors identifying squares (6,257%) than identifying diamonds (4,118%) which is shown by the significant interaction between the factors *task* and *figure* (F1,11) = 8.505, MSe = 23.849, p = 0.014) (figure 5). Lastly, we found that participants made more errors identifying the diamonds in comparison with the squares in congruent stimuli (squares = 3.361%, diamonds = 5.965%) while they made more errors identifying the squares in incongruent stimuli (squares = 8.628%, 5.103%) which can be seen by the significant *congruency* x *figure* interaction effect (F(1,11), MSe = 54.518, MSe = 12.403, $p < .001$). An overview of the effects on error rate per background color can be found in the appendix (Appendix E, Table E3)

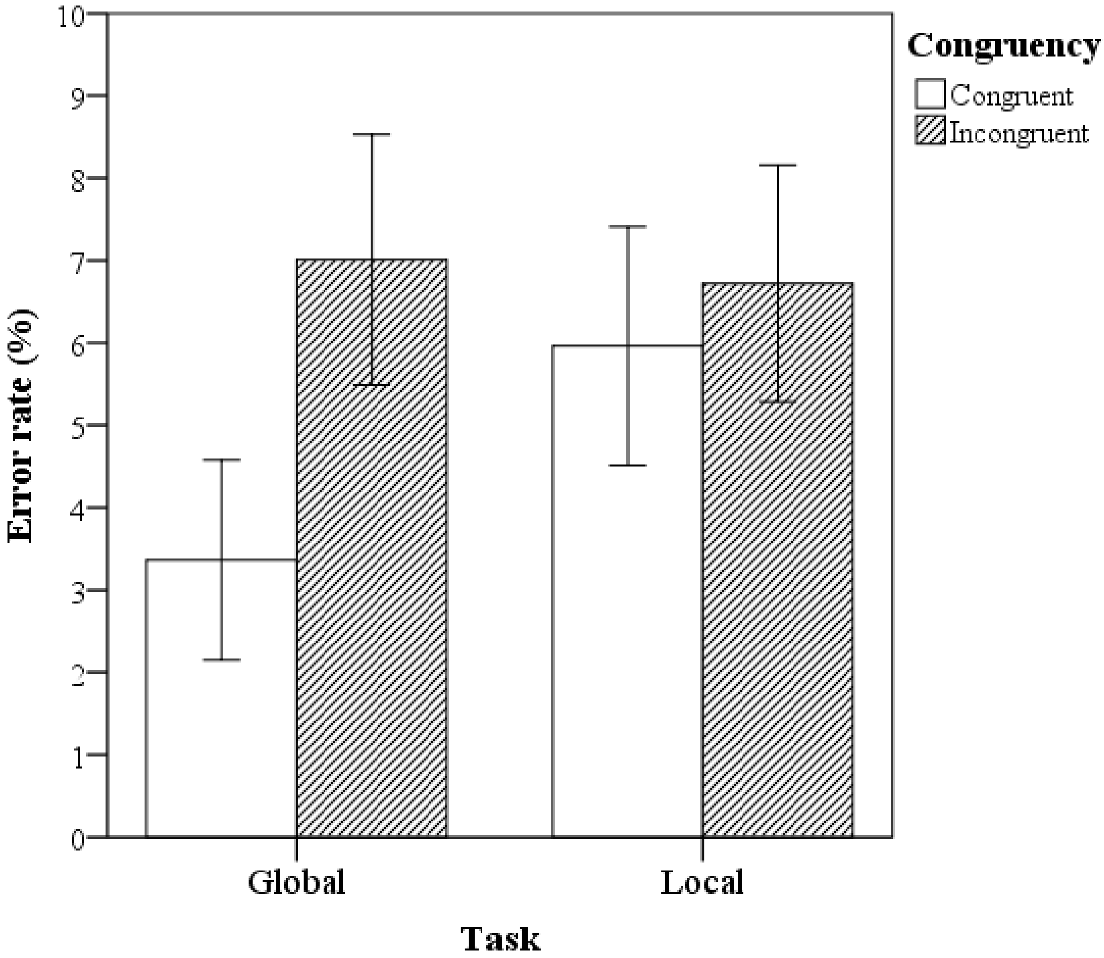

Figure 5. Pilot study: Mean error rates (%) of all 12 participants for the global and local tasks divided into congruent and incongruent stimuli. The error bars indicate the 95% confidence interval.

Pilot study - Conclusion

The results of the first pilot study show that global stimuli are processed faster than local stimuli with mean difference of ~70 ms. This effect has been found in various other experiments on global and local processing (Goto et al., 2004; Hübner & Volberg, 2005; Love, Rouder, & Wisniewski, 1999) and is in line with the findings of Michimata Chikashi et al. (1999).

Furthermore, the significant interaction effect between task and congruency indicates a global precedence effect. This goes in line with preceding research indicating that reaction times on global features are not only faster, but that reaction times on local identification may be higher if the global features are incongruent to the local information.(Hughes, Layton, Baird, & Lester, 1984; Kimchi, 1992; Navon, 1977,Navon 1981). An analysis of the error rates revealed a higher error rate in global compared to local stimuli. Furthermore, we can see a significant congruency main effect, indicating that congruent stimuli are processed faster than incongruent stimuli. However, if we take into account the task x congruency interaction effect, we can state that this is only true for the global tasks, while no differences between congruent and incongruent stimuli can be found in local tasks. Contrary to the results of Michimata Chikashi et al. (1999), the global precedence effect does take place in tasks with a red background. Even more, the current results indicate that the global-to-local interference takes place in the red background but not in the green background, which is the opposite of what the original study suggested. Furthermore, we found significant interaction effects between the type of figure and the congruency of the stimulus. However, this interaction surpasses the scope of this experiment and will not be discussed further.

Experiment 1 – Introduction

In the pilot study we tried to replicate the effect of Michimata et al. (1999) who proposed that the global precedence effect in the processing of hierarchically organized stimuli can be attenuated by a red background. Although the results of our study suggest the existence of a global-to-local advantage as well as a global-to-local interference in the processing of the stimuli, we did not find an indication for an attenuation of the GPE by a red background. We even found contradicting results, which suggest that the global precedence effect does not occur in the green background. However, there were some difference between the pilot and the original study, which may hinder a direct comparison of the effects of the two studies. The first difference was, that the luminance of the background in the pilot study (40 cd/m^2) was significantly higher than in the original study (4 cd/m^2). Given that our backgrounds were ten times as bright as the backgrounds in the original study, this difference in luminance may have affected color perception of the participants. Furthermore, the size of the stimuli between the pilot and the original study differed. Studies showed that stimulus size may also have an influence on visual processing of hierarchically organized stimuli (Blanca Mena, 1992; Kinchla & Wolfe, 1979) in terms that big stimuli are usually processed faster than small stimuli, an effect that is most striking in local tasks. Although this effect does not explain the absence of the effects of background color, the stimulus size in our study was larger than in the original one. Lastly, the location of the stimulus in the pilot study was a random point on a diameter around the middle of the screen. Research found that in a non-attended stimulus (i.e. when the participant cannot anticipate the location where the stimulus will appear) the global precedence effect takes place far less than in attended stimuli (Paquet & Merikle, 1988). Although this difference does not account for the differences in the effects of the background color, it is a factor which has to be changed to allow direct comparison of our results and the results by Michimata et al. (1999). In Experiment 1, we changed the parameters screen brightness, stimulus size and stimulus location according to the original study to investigate the effects of background color on the global precedence effect in visual perception. Based on the results of Michimata et al. (1999) we expect that global-to-local interference will take place in the identification of local stimuli, which will result in a prolonged reaction time. We furthermore expect that the global-to-local interference will be more present in the green background, compared to the red background.

Experiment 1 - Method

Participants

Eighteen participants (14 male, 4 female) took part in the experiment. The age of the participants ranged from 22 to 46 years with a mean age of 27.22 years. All participants were recruited via non-probability convenience sampling and were employed by Philips at the moment of the study. Sixteen of the participants were right-handed and 2 of the participants was left-handed. All participants signed an informed consent prior to participating in the study.

Materials

Computer

The same computer and display as in the pilot were used for the assessment in this experiment.

Background colors

Three different background screen colors were used. The indicated *x* and *y* values refer to the CIE 1931 color space (CIE, 1931), which can be found in the attachments (Appendix A). The three colors ([x], [y]) used were: Red ([0.6166], [0.3193]), Green ([0.2338], [0.6207]) and Grey ([0.3173], [0.3224]). Luminance was assessed with a photospectrometer (JETI Specbos 1211, JETI Technische Instrumente, Jena, Germany) prior to the experiment. All backgrounds were equiluminant with a luminance of 4 cd/m^2. The room in which the experiment took place was illuminated with dim light (illuminance was equal to 6 lx). The chin rest was placed 54 cm in front of the screen.

Stimuli

For this experiment, the same kind of stimuli as in the pilot were used. However, the size of the stimuli was adjusted to fit the size of the stimuli used in the study of Michimata et al. (1999). Small figures had a diameter of 0.5 x 0.5 degrees of visual angle. Big figures had a diameter of 3.5 x 3.5 degrees of visual angle. As in the pilot, the stimuli were colored black (*x* [0.2642], *y* [0.2463]) had a luminance of 0,23 cd/m^2.

Procedure

Prior to the experiment the participants filled in an informed consent (Appendix B) and a demographic questionnaire (Appendix C).The procedure of Experiment 1 was identical to the procedure of the pilot. However, the position of the stimuli was always fixed to the middle of the screen and stimulus presentation time was changed to 150 ms.

Data analysis

For each subject, the median reaction time (RT) of all correct answers and mean error rate (ER) for each of the 24 experimental conditions was computed. Furthermore, the reaction times were normalized by taking the inverse (1/RT) (see Appendix D, Table D2). The inverted reaction times and the error rates were each compared in a 3x2x2x2 analysis of variance defined by a combination of Background (Red/Green/Grey), Task (Global/Local), Congruency (Congruent/Incongruent) and Figure (Square/Diamond). Furthermore, both reaction times and error rates were subjected to a 2x2x2 ANOVA (Task, Congruency, and Figure) per background color.

Experiment 1 - Results

Reaction time: Main effects

In the overall analysis, the global task (mean = 468 msec) was performed faster than the local task (mean = 528 msec) which is shown by a significant *task* main effect ($F(1,17) = 64.654$, $MSe = .110$, $p < .001$). Furthermore, participants reacted faster to the congruent stimuli (mean = 489 msec) than to the incongruent stimuli (mean = 507 msec) which produced a significant *congruency* main effect ($F(1,17) = 51.208$, MSe = ,013, $p < .001$). No differences in reaction time were found between the three different background or the two different figures (squares and diamonds).

Reaction time: Interaction effects

As expected, the amount of interference (Incongruent – Congruent) was higher in the local task (mean = 32.671 msec) in comparison to the global task (mean = 3.8 msec). The presence of the global precedence effect is indicated by the significant *task* x *congruency* interaction effect ($F(1,17) = 15.475$, $MSe = .019$, $p = .001$) (figure 6).

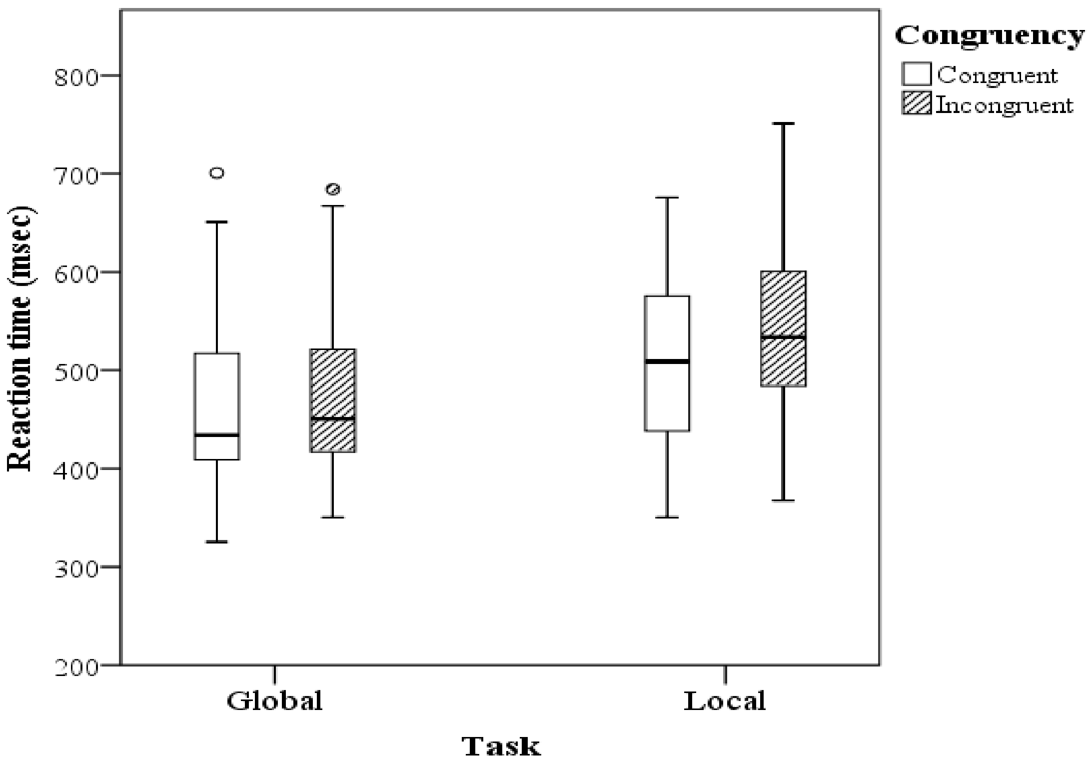

Figure 6. Experiment 1: Boxplot of the median reaction time of all 18 participants for the global and local tasks divided into congruent/incongruent stimuli. For further information about the elements of the boxplot see figure 2.

Furthermore, we found that participants were faster in identifying squares than diamonds in congruent stimuli, while they were faster in identifying the diamonds in incongruent stimuli, which is shown by the significant *congruency* x *figure* interaction effect ($F(1,17) = 23.869$, $MSe = .014$, $p < .001$). Contrary to the expectations, the global precedence effect took place in every condition and was not modified by the background color which is shown by a non-significant interaction between the factors *background*, *task*, and *congruency* ($F(2,34) = .742$, $MSe = .009$, $p = .484$) (figure 7). An overview of all effects on reaction time can be found in the Appendix (Appendix E, Table E4).

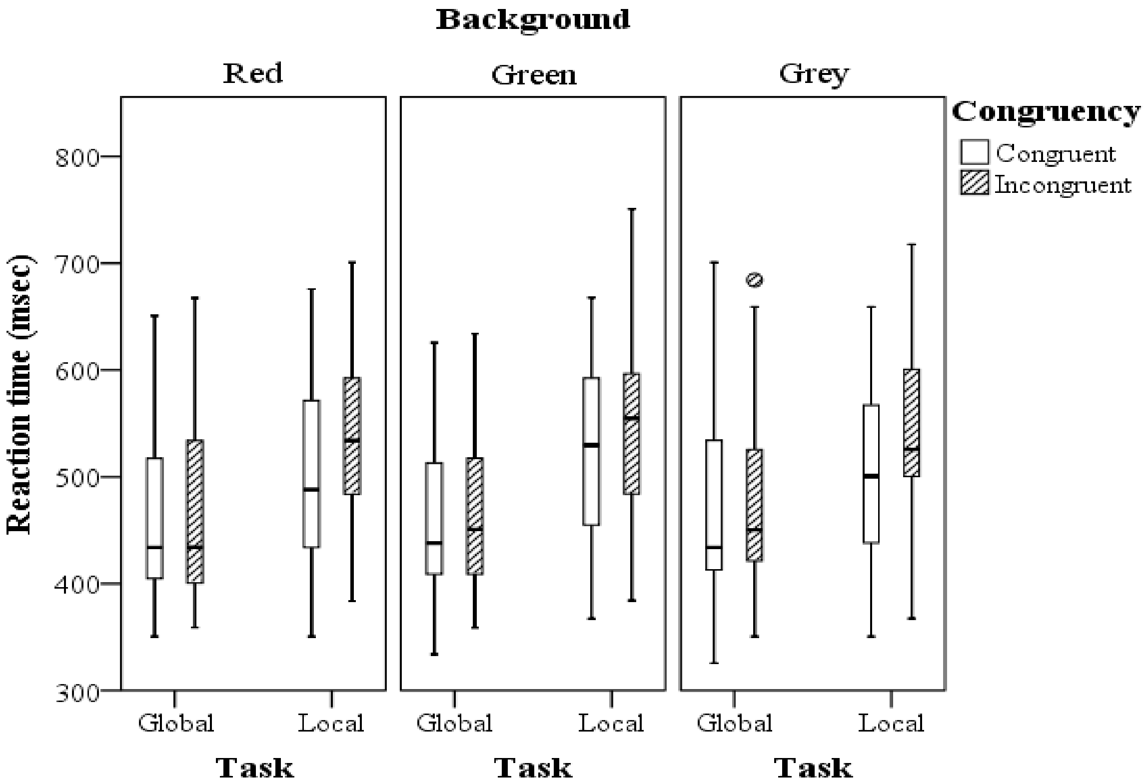

Figure 7. Experiment 1: Boxplot of the median reaction time of all 18 participants for the global and local tasks divided into congruent/incongruent stimuli for the red, green and grey background. For further information about the elements of the boxplot see figure 2.

Error rate: Main effects

The analysis of the error rates revealed that participants made more errors in the incongruent (7.991%) than in the congruent (5.984%) stimuli which is indicated by a significant *congruency* main effect ($F(1,17) = 5.019$, $MSe = 86.672$, $p = .039$). No differences could be seen between the different tasks, figures or backgrounds, although we may suspect that participants in the red background made significantly more errors compared to the green and the blue background, which is indicated by an almost significant *background* main effect (F(2,34) = 3.124, MSe = 39.095, p = .057).

Error rate: Interaction effects

The analysis of the interaction effects revealed that the advantage of congruent compared to incongruent stimuli in the identification of the smaller shapes is way stronger in the green background compared to the red and grey background. This is indicated by a significant three-way interaction between the factors *background*, *task*, and *congruency* (F(2,34) = 3.793, MSe = 39.283, p = .033) (Figure 8). Also, we found that participants made slightly less error identifying diamonds in the incongruent stimuli (difference Squares (%) – Diamonds (%) = -1.464), but made less errors identifying the squares in the congruent stimuli (difference = 3.548) which is indicated by a significant *congruency* x figure *interaction* effect (F(1,17) = 6.802, MSe = 99.720, p = .018). An overview of all effects on error rate can be found in the Appendix (Appendix E, Table E5).

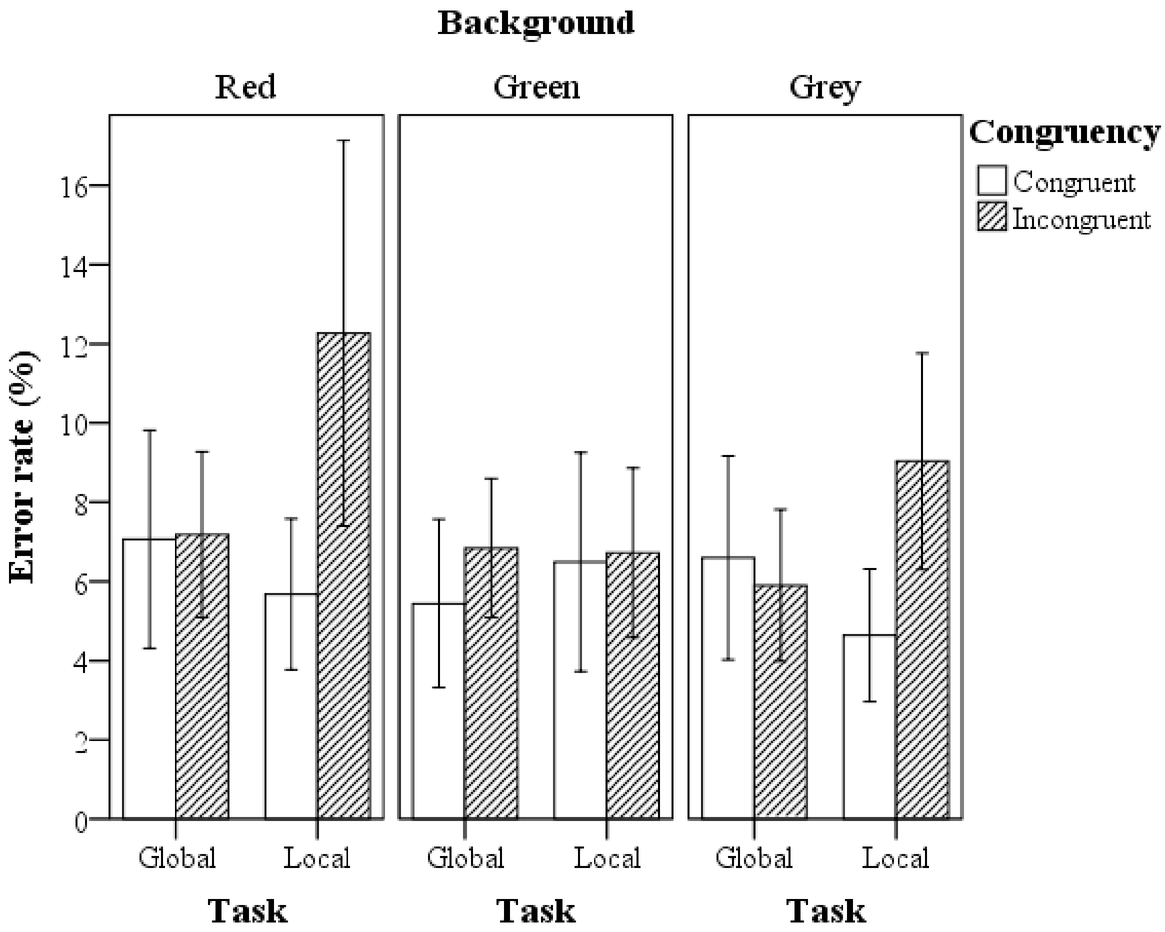

Figure 8. Experiment 1: Mean error rates (%) for all 18 participants for global and local tasks divided into congruent/incongruent stimuli for each background color (columns). The error bars indicate the 95% confidence interval.

Experiment 1 - Conclusion

The results of Experiment 1 indicate that the identification of local stimuli takes less time than the identification of global stimuli, which goes in line with the results of our pilot study as well as other preceding research (Kimchi, 1992; Mottron, 2000; Navon, 1977). Furthermore, the results show that participants identify congruent stimuli faster than incongruent stimuli. However, the interaction between the sort of the task and the congruency reveals that this effect only happens in the identification of the local stimuli. In local tasks, the global stimuli interfere with the identification of the local stimuli which indicates a global precedence effect (GPE) which was also found in preceding research (Goto et al., 2004; Hughes et al., 1984).

However, contrary to the results of Michimata et al. (1999) and contrary to the results of our pilot study, no difference in the appearance of the GPE were seen in the different color conditions. The global precedence effect took place in all three color conditions in Experiment 1, which suggests that the GPE is not moderated by background color. In contrast to the pilot study, all parameters were altered to match the parameters which were reported in the study by Michimata et al. (1999). The only known factor which differed between Experiment 1 and the original study was, that Michimata et al. (1999) started the experiment by letting the participants do a flicker task to set the subjective equiluminance of the green and red background. In our study, the participants did not perform a flicker task since the colors were set to be equally luminant with a photospectrometer beforehand. In this case, the subjective luminance of the colors may have differed in our experiment. However, this may not account for the missing effects of a red background on the global precedence effect. Given that the experiment did not yield the expected results concerning the effects of a red background on visual processing, a second experiment has been carried out.

Experiment 2 - Introduction

The explanation for the absence of the GPE on a red background proposed by Michimata et al. (1999) concerns the function of the magnocellular pathway. Research has shown, that the function of the magnocellular pathway may be inhibited by a red background color (Breitmeyer & Breier, 1994; Chapman et al., 2004; Chase et al., 2003; Edwards et al., 1996). Since the magnocellular pathway is inhibited by a red background color, Michimata et al. (1999) proposed that that the inhibition of the magnocellular pathway on a red background may lead to an absence of the global precedence effect and that the processing of hierarchically organized stimuli is partially mediated by the magnocellular pathway. Neither our pilot study nor the results of Experiment 1 showed an effect of a red background color on the processing of those stimuli. However, we did not control for the inhibition of the magnocellular pathway, which does not permit us to draw conclusions concerning the connection between the processing of hierarchically organized stimuli and the functioning of the magnocellular pathway. Research has shown, that the magnocellular pathway is mostly responsible for the processing of low spatial frequencies, while its counterpart, the parvocellular pathway, is responsible for the processing of high spatial frequencies (Breitmeyer & Breier, 1994; Bruno G. Breitmeyer & Williams, 1990) and that the magnocellular pathway can be inhibited by red light or red background color (Breitmeyer & Breier, 1994; Chapman et al., 2004; Chase et al., 2003; Edwards et al., 1996). Garofalo, Ferrari, & Bruno (2014) carried out an experiment which included a 2-Alternative-Forced-Choice orientation discrimination task on red, blue and grey isoluminant backgrounds. In this experiment, the participants had to identify the orientation of Gabor patches at different spatial frequencies. In accordance with previous research, their results showed lower accuracy and slower reaction times when a red background compared to a blue or a grey background surrounded the stimuli. Furthermore, this effect was strongest for low spatial frequency Gabor patches. However, to date, no experiment tried to combine the inhibition of the magnocellular pathway and its effects on the processing of spatial frequencies with the processing of hierarchically organized stimuli in one experiment. The next experiment of this study will combine the stimuli used by Michimata Chikashi et al. (1999) and Garofalo, Ferrari, & Bruno (2014) with the aim to be able to draw conclusions whether the processing of hierarchically organized stimuli is in fact mediated by the functioning of the magnocellular pathway in colored backgrounds. Based on previous literature as well as our previous experiments, we expect the global shape to interfere with local identification if the stimuli are incongruent (GPE). Furthermore, we expect participants to react slower to low spatial frequency stimuli with a red background compared to a blue or green background due to the suppressive effects of the red background on the magnocellular pathway.

Experiment 2 - Method

Participants

Sixteen Participants (3 female, 13 male) took part in the study. The age of the participants ranged from 22 to 46 years with a mean age of 25.63 years. All participants were recruited via non-probability convenience sampling and were employed by Philips at the moment of the study. All participants signed an informed consent prior to participating in the study.

Materials

Computers

The same computer and display as in the previous experiment were used for the assessment in this experiment.

Background colors

Three different background screen colors were used. Contrary to the previous experiment, the grey background was changed to a blue background. The indicated *x* and *y* values refer to the CIE 1931 color space (CIE, 1931), which can be found in the attachments (Appendix A). The three colors ([x], [y]) used were: Red ([0.6398], [0.3239]), Green ([0.2321], [0.6702]) and Blue ([0.1566], [0.0845]). Luminance was assessed with a photospectrometer (JETI Specbos 1211, JETI Technische Instrumente, Jena, Germany) prior to the experiment. All backgrounds were isoluminant with a luminance of 21,3 cd/m^2.

Stimuli

The stimuli in this study were big figures which were composed of four smaller aligned Gabor patches. The small Gabor patches could either be aligned in a 0 degree angle or a 90 degree angle resulting in a horizontal or vertical orientation for the big stimuli. The grating of the Gabor patches also could be oriented in a 0 or 90 degree angle, resulting in either horizontal or vertical orientation of the Gabor patches. Furthermore, the Gabor patches could have a grating with either low or high spatial frequency (0.5 degree/cycle and 4 degree/cycle respectively). In total, 8 different stimuli were presented to the participants resulting from a combination of global orientation (horizontal/vertical), local orientation (horizontal/vertical) and spatial frequency (low, high) (table x). The big stimuli had a size of 31.5 x 7.5 degrees of visual angle (horizontal) and 7.5 x 31.5 degrees of visual angle (vertical) and the small stimuli had a size of 7.5 x 7.5 degrees of visual angle. However, due to the gauss filter, that was used on the Gabor patches, the perceived size of the stimuli may differ. The stimuli were composed of two different shades of grey ([x], [y]): Shade 1([0.3217], [0.3311]) and shade 2 ([0.3221], [0.3298]) with a contrast (Michelson contrast) of 0.4 and a mean luminance of 46.92 cd/m^2.

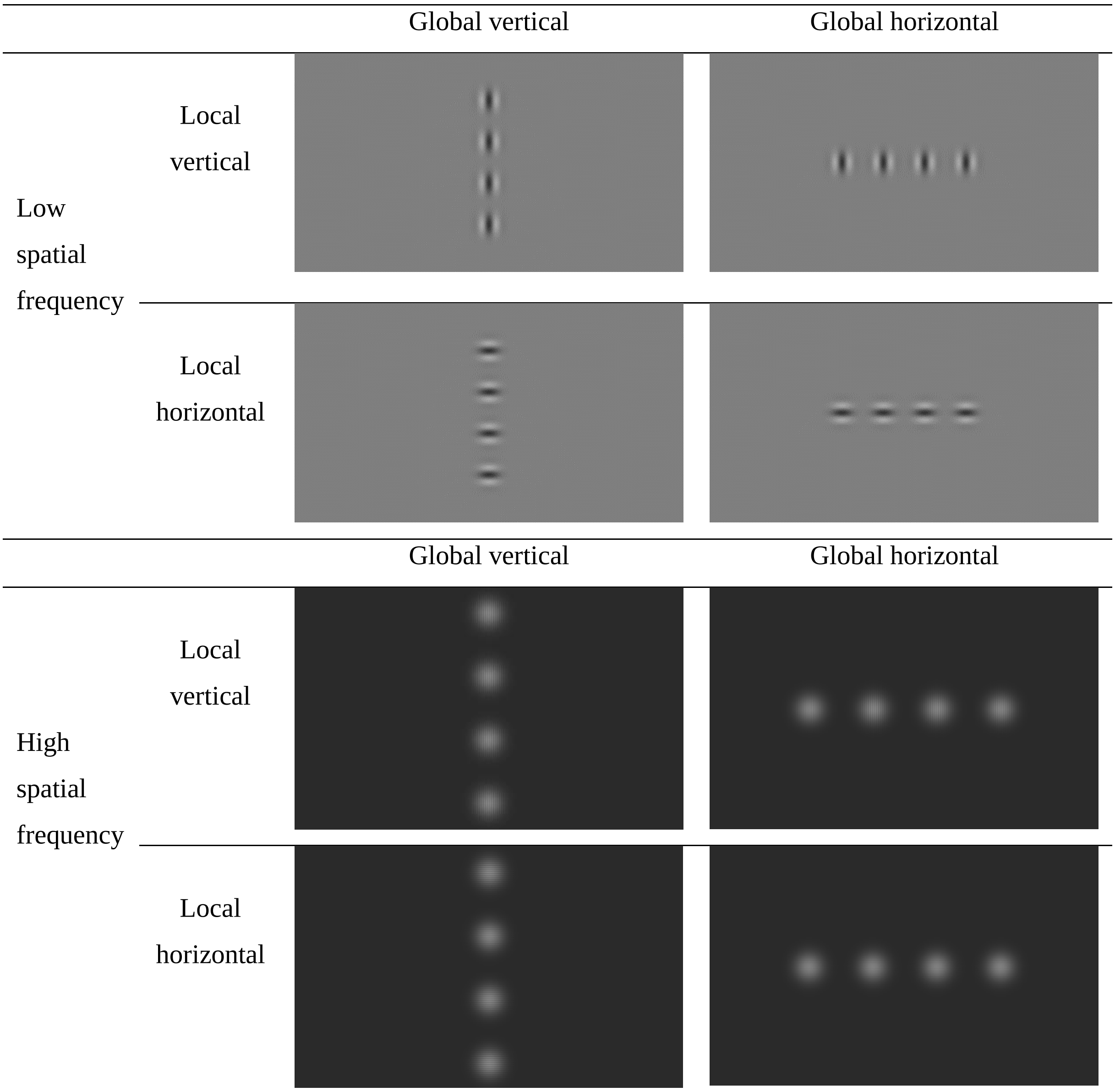

Figure 9. Table of the different stimuli that were used in the study. The stimuli could differ on a global level (Global vertical or global horizontal, columns) as well as on a local level (local horizontal or local vertical, rows). Furthermore, each stimulus was presented at high spatial frequency (4 cycles per degree) or low spatial frequency (0.5 cycles per degree). The table shows all eight possible combinations. For the high spatial frequency stimuli, the contrast was augmented to make them visible in the figure. A high resolution image of the high spatial frequency stimuli Gabor patches can be found in the Appendix (Appendix F).

Procedure

The experiment took place in a laboratory room (illuminance = 7 lx). Prior to the experiment the participants filled in an informed consent (Appendix B) and a demographic questionnaire (Appendix C).

The entire experiment consisted of 576 trials. 24 trials were given for each of the 24 conditions, defined by an orthogonal combination of background color (red/green/blue), task (global/local), congruency (congruent/incongruent) and spatial frequency (high/low). The experiment was divided into three sessions, one for each background color. Every session consisted two blocks, one local and one global search task. Before each block, the participants were told to identify the stimulus orientation (horizontal/vertical) on a global level (big figures) or on a local level (small figures) by pressing the corresponding button on the keyboard. Prior to each stimulus, the participants were instructed to fixate on a cross in the middle of the screen. The cross was presented for 750ms. When the cross disappeared, the stimuli was then presented for 100ms. The stimuli were always presented at the center of the screen. The participant had 9 seconds to give an answer. If he/she had not answered during that time, the response was marked as wrong. Each block was preceded by 16 practice trials, in which the participants were given feedback on their answer as well as their reaction time. Half of the subjects performed the global tasks first, followed by the local tasks. The other half of the participants completed the tasks in the opposite order. Similar to the two preceding experiments, the order of the color and the tasks as well as finger-response mapping was counterbalanced among participants.

Data analysis

For each subject, the median reaction time (RT) of all correct answers and mean error rate (ER) for each of the 24 experimental conditions was computed. Furthermore, the reaction time was normalized by using inverse RTs (1/RT) (see Appendix D, Table D3). The different normalized reaction times and error rates were each compared in a 3x2x2x2 repeated measures Analysis of Variance (ANOVA) defined by a combination of Background (Red/Green/Grey), Task (Global/Local), Congruency (Congruent/Incongruent) and spatial frequency (High/Low). Furthermore, both reaction times and error rates were subjected to a 2x2x2 repeated measures Analysis of Variance (ANOVA) (Task, Congruency, and spatial frequency) per background color.

Experiment 2 - Results

Due to measurement errors, one participant had to be excluded from the data analysis. The following data analysis was conducted with the remaining 15 participants.

Reaction time

The analysis revealed that participants reacted faster when identifying global stimuli (402.669 msec) than when identifying local stimuli (556.500 msec) which is confirmed by a significant task main effect ($F(1,14) = 108.394$, MSe= .381, $p < .001$). Furthermore we can see that participants react faster to congruent compared to incongruent stimuli which is indicated by a significant congruency main effect ($F(1,14) = 17.240$, MSe = .012, $p = .001$). However, we found that this effect can only be seen in the identification of the smaller shapes while no difference can be seen in the identification of the global shapes (figure 10). This is confirmed by a significant interaction between the factors *task* and *congruency* ($F(1,14) = 13.611$, MSe = .013, $p = .002$).

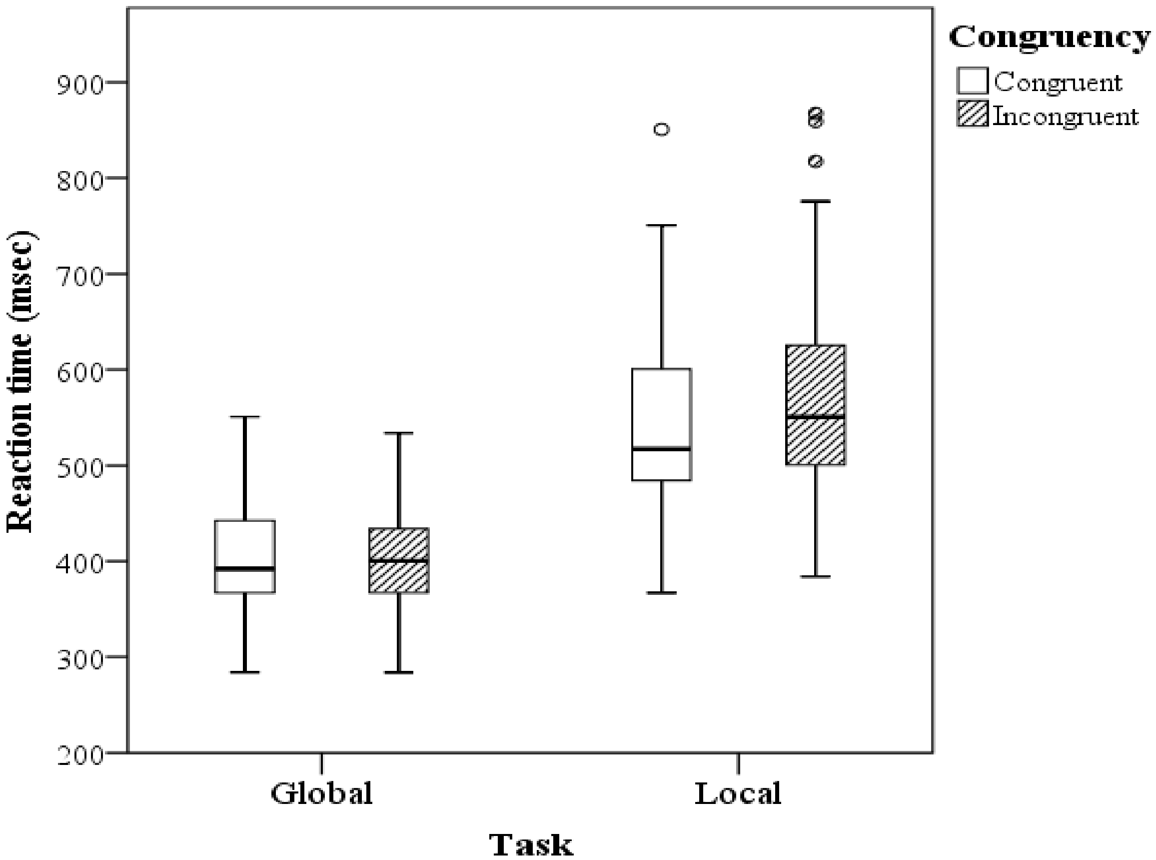

Figure 10. Experiment 2: Boxplot of the median reaction time of all 15 participants for the global and local tasks divided into congruent/incongruent stimuli. For further information about the elements of the boxplot see figure 2.

Contrary to our expectations, the reaction times of identifying low spatial frequencies did not differ across the three background colors, which is indicated by a non-significant two-way interaction between *background* and *spatial frequency* ($F(2,28) = .046$, $MSe = .013$, $p = .955$). The analysis furthermore revealed that in the local tasks, participants reacted faster to low frequency stimuli (548.629 msec) than to their high frequency counterparts (564.372 msec) but no such difference could be seen in the identification of global stimuli which is shown by a significant *task* x *spatial frequency* interaction effect ($F(1,14) = 9.852$, $MSe = .012$, $p = .012$,) (figure 11).

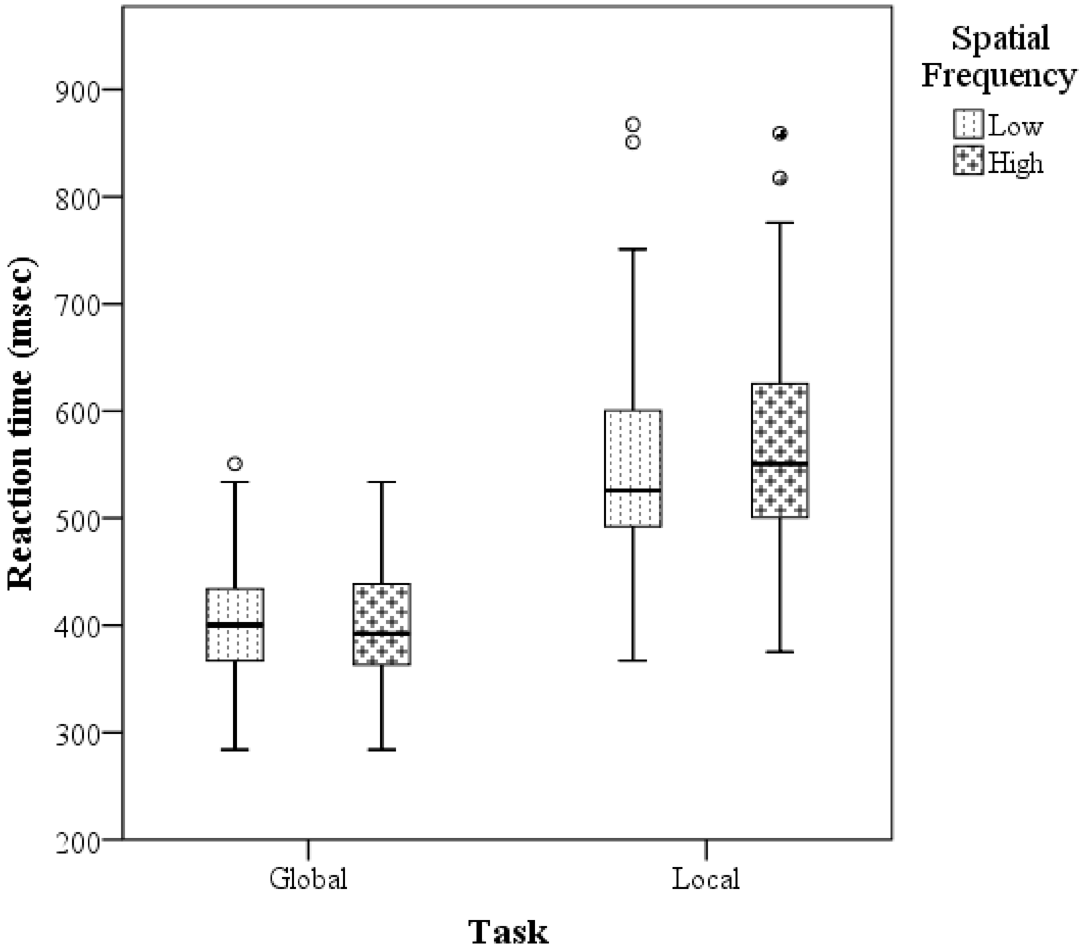

Figure 11. Experiment 2: Boxplot of the median reaction time of all 15 participants for the global and local tasks divided into high (4 cycles/degree) and low (0.5 cycles/degree) spatial frequency stimuli. For further information about the elements of the boxplot see figure 2.

Lastly, we found that the amount of global-to-local interference in the identification of the smaller shapes (GPE) did not differ between the different background color which is indicated by a non-significant three-way interaction between the factors *background*, *task*, and *congruency* ($F(2,28) = .034$, $MSe = .010$, $p = .967$) (figure 12).

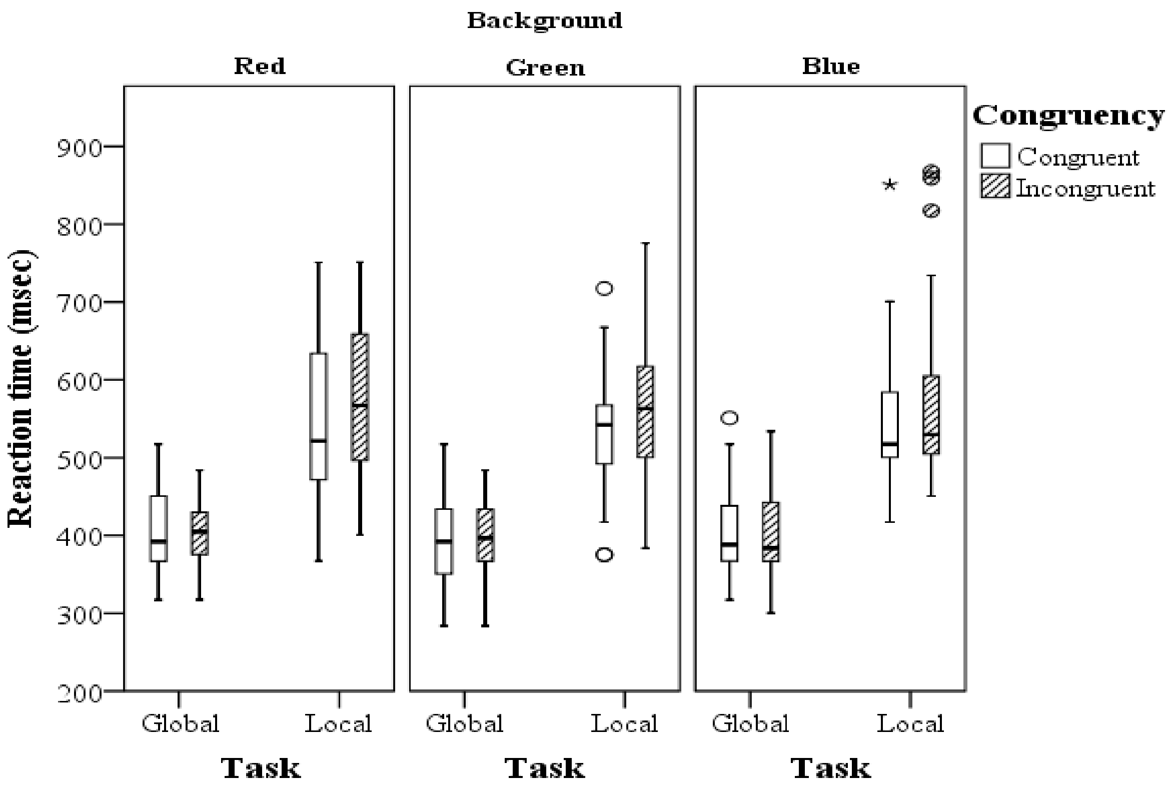

Figure 12. Experiment 2: Boxplot of the median reaction time of all 15 participants for the global and local tasks divided into congruent/incongruent stimuli for the red, green and blue background. For further information about the elements of the boxplot see figure 2.

Reaction time per color

The results of the analysis of the effects per color shows that the advantage of low compared to high spatial frequencies in the identification of local elements did not occur in all color conditions. We can see participants reacted faster to local low compared to local high spatial frequency stimuli in the blue color condition, as indicated by a significant *task* x *spatial frequency* interaction effect for the blue background ($F(1,14) = 27.822$, $MSe = .004$, $p < .001$) (figure 13). However, in the green and red background, this advantage cannot be found which is shown by a non-significant two way interaction of the factors *task* and *spatial frequency* in the red ($F(1,14) = 1.799$, $MSe = .010$, $p = .200$) and green ($F(1,14) = 3.394$, $MSe = .010$, $p = .087$) background.

Furthermore, the analysis revealed that the global precedence effect seems to have taken place in all colors with high frequency stimuli but does only occur in the green and red condition with low frequency stimuli. The only condition in which the global precedence effect seemed to be suppressed is a blue background with low frequency stimuli since the three-way interaction between the *task*, the *congruency* and the *spatial frequency* was only significant in the blue background (F(1,14) = 5.149, MSe = .007, p = .038). An overview of the other effects per background color can be found in the Appendix (Appendix E, Table E6).

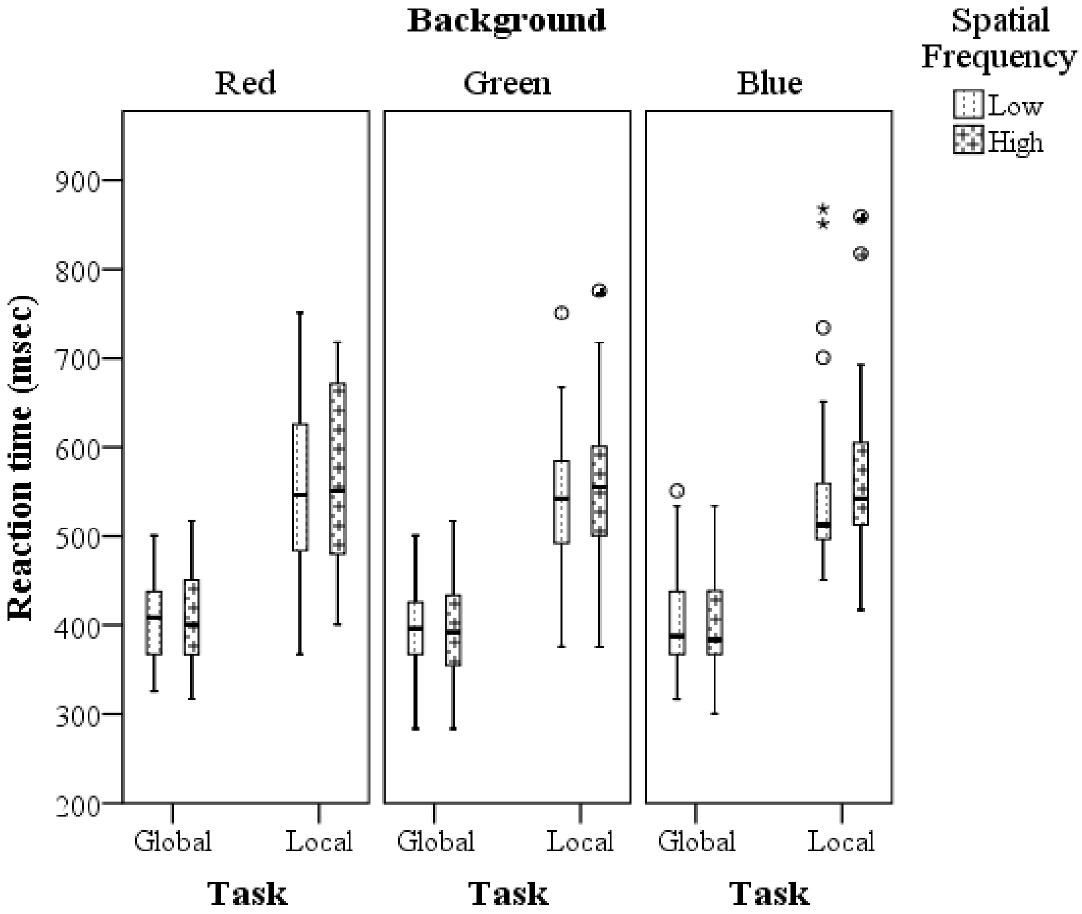

Figure 13. Experiment 2: Boxplot of the median reaction time of all 15 participants for the global and local tasks divided into high (4 cycles/degree) and low (0.5 cycles/degree) spatial frequency stimuli for the red, green and blue background. For further information about the elements of the boxplot see figure 2.

Error rate

The analysis of the error rates revealed that participants made significantly more errors identifying the incongruent stimuli compared to the congruent stimuli which is indicated by a congruency main effect (F(1,14) = 16.025, MSe = 19.210, p = .001). No differences in error rate have been found between the different *tasks*, *backgrounds* or *spatial frequencies* as indicated by no significant main effect for any of those factors. Furthermore the analysis revealed that a higher error rate on incongruent (compared to congruent) stimuli could only be found in the identification of the smaller shapes with a high spatial frequency, which is indicated by a significant *task* x *congruency* x *spatial frequency* interaction effect (F(1,14) = 7.700, MSe = 22.528, p = .015). An overview of all effects on error can be found in the Appendix (Appendix E, Table E7).

Experiment 2 - Conclusion

The overall analysis shows a significant global advantage in reaction time as well as a global precedence effect (GPE) in incongruent stimuli. Both effects align with previous research (Bouvet, Rousset, Valdois, & Donnadieu, 2011; Goto, Wills, & Lea, 2004; Kimchi, 1992) as well as the results of our previous experiments. Contrary to the findings of Michimata Chikashi, Okubo and Mugishima (1999), a red background did not attenuate the global precedence effect, which goes in line with the results of the results of our first two experiments. The reaction time advantage on low compared to high spatial frequencies was only found in the identification of local elements but not in the identification of the global shape. A possible explanation for this is that a higher spatial frequency of a stimulus leads to longer reaction times in visual identification tasks (Gish, Shulman, Sheehy, & Leibowitz, 1986). However, the changes in spatial frequency in our stimuli did hardly affect the global shape, which is why no differences between high and low spatial frequencies were found in the global tasks. Due to the suppressive effect of a red background on the magnocellular pathway, we expected that the advantage of low compared to high spatial frequency stimuli to be less strong in the red background, since reaction times on low spatial frequency stimuli were expected to be higher. Based on the previous argumentation it is important to discuss the low-to-high-advantage in the local identification only, since it does not occur in the global tasks. The analysis per background color revealed that participants took more time identifying low spatial frequencies (compared to high spatial frequencies) in local tasks in the blue background while no such significant difference was seen in the red and green background. A possible explanation for this could be that higher wavelengths (i.e. red and green background lighting) attenuate the magnocellular pathway which leads to longer identification time of low spatial frequency stimuli. The explanation is backed up by the fact that the low-to-high advantage in local tasks is strongest in the blue background, weaker (but still almost significant) in the green background and weakest in the red background. However, this explanation faces one major constraint. The results show that the attenuation of the low-to-high advantage does not occur because the reaction times for low spatial frequency are higher in the red and green conditions compared to the blue condition, but because the reaction times on high spatial frequencies are higher in the blue condition. Thus, although there is scientific evidence for an attenuation of the magnocellular pathway by a red background (B G Breitmeyer & Breier, 1994; Garofalo et al., 2014), these mechanisms cannot fully explain our results.

Experiment 3 - Introduction

After a pilot and two experiments on the effects of color on visual processing, no indication has been found that the color has a systematic moderating influence on the appearance of the global precedence effect. Furthermore, the expected effects of a red background on the processing of low spatial frequency stimuli did not occur in Experiment 2. Given together we may conclude that our color manipulations did not yield the expected results on the visual processing. The fact that we did not find any systematic effects of color conflicts with the original aim of the study, namely investigating whether the effects of color, may also be reproduced with ambient lighting. However, the last experiment of this study will investigate whether ambient lighting may affect the processing of hierarchically organized stimuli.

In the previous experiments we aimed to find effects of background color on visual processing based on the suppressive effects that a red background has on the magnocellular pathway (M. Livingstone & Hubel, 1988). However, research led by Elliot et al. (2007) shows that the effects of color may also take place through color priming. In their experiments, participants were asked to complete anagram and IQ tests. The results show that participants performed worse on these tests when the cover letter of the given tests or the participant number on the cover letter were colored red compared to the participants with a green cover letter or participant number. This shows that the effects of red do not necessarily require a tonic red suppression of the magnocellular pathway to affect cognitive functioning but may also be achieved with a different manipulation. From this, we may theorize that the attenuation of the M-Channels is not the only mechanism responsible for the effects of red. Given that this mechanism was the premise for our expected effects we decided to broaden the scope of the experiment. By eliminating possible effects of magnocellular suppression, we aim to investigate the effects of color and light in a broader sense in the next experiment. To move a bit further away from the tonic red suppression, a different light source (i.e. ambient lighting) can be used which would eliminate any possible effects which may have be caused by a center-surround suppression mechanism of the (red) color that surrounded the stimuli in the visual field.

To investigate the effects of lighting, we chose to conduct an experiment with the same stimuli and procedure as in Experiment 2 but we chose to replace the colored background with ambient lighting. Based on the previous experiments we expected the global precedence effect to take place independent of the color condition. Furthermore, we expected no effects of the background color on the identification of low spatial frequency stimuli due to an elimination of possible tonic red suppression. Due to the more explorative nature of the last experiments, no specific expectations were formulated on the remaining effects of color on visual processing.

Experiment 3 - Method

Participants

Twenty-two Participants (6 female, 16 male) took part in the study. The age of the participants ranged from 21 to 46 years with a mean age of 26 years. All participants were recruited via non-probability convenience sampling and were employed by Philips at the moment of the study. Due to measurement errors, 6 of the participants had to be excluded from the analysis.

Materials

Computers

The same computer was used as in the previous experiments.

LED cubes

To induce ambient lighting, two multi-channel LED cubes were used (Thouslite, Changzhou City, China). Through single-channel control of eleven individual channels the cubes are able to produce a wide array of different colored light and white light in the spectrum from 400 to 700 nanometers. The cubes have a maximum luminance of 20289 cd/m^2. Measured at the point of the eyes of the participants, both LED cubes had an illuminance of 7.2 (+/- 0.2) lx and were set equiluminant for all three colors. With the dim ceiling light and the screen, total illuminance at the eye was equal to 9.2 (+/- 0.2) lx, as measured by a photospectrometer (JETI Specbos 1211, JETI Technische Instrumente, Jena, Germany). The Led cubes were situated to the right and left of the screen respectively in a 45 degree angle. Both LED cubes were situated 52 cm from the position of the participant’s eyes and 20 cm in height from the table (figure 12). Both cubes were 29.7 cm wide and 29.7 cm high and were connected via USB to a computer and were operated using custom written software in MATLAB R2015b (The MathWorks Inc., 2015). Contrary to the previous experiments only one background color was used. The background ([x], [y]) was set to grey ([0.3167], [0.3200]) and had a luminance of 4 cd/m^2.

Color was manipulated by changing the colored lighting from the LED cubes. With help of the single-channel control of the cubes, we set each light of the cubes to match the dominant wavelength of the corresponding color from Experiment 2. The indicated *x* and *y* values refer to the CIE 1931 color space (CIE, 1931), which can be found in the attachments (Appendix A).

The three colors ([x], [y]) of light provided by the LED cubes were: Red ([0.6880], [0.3032]), Green ([0.2279], [0.7114]) and Blue ([0.1615], [0.0441]).

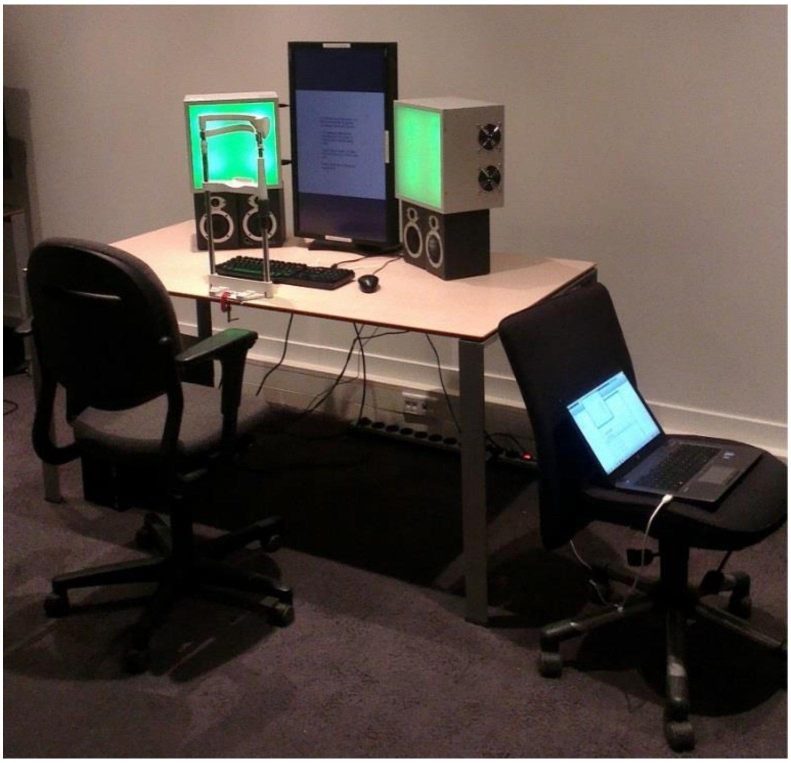

Figure 14. Experimental setup for experiment 3. The task was carried out on the vertically oriented screen on the table, while the led cubes were run using the laptop computer on the right. In this photo, luminance levels were increased to improve the visibility of the setup. During the experiment, the light was set to an illuminance of 7 lx.

Screen

For this experiment, the screen was used in a vertical orientation (31 x 58 cm) to minimize the distance between the LED cubes and the stimuli. Furthermore the visual window in which the stimuli were presented was reduced to a size of 1440 x 1440 pixels while the rest of the screen was set to black (*x* [0.2642], *y* [0.2463]; luminance = 0.23 cd/m^2). A chin rest was placed 54 cm in front of the screen.

Stimuli

In this experiment the same stimuli were used as in Experiment 3.

Procedure

Prior to the experiment the participants filled in an informed consent (Appendix B) and a demographic questionnaire (Appendix C). The rest of the experimental procedure was identical to the procedure of Experiment 2.

Data analysis

For each subject, the median reaction time (RT) of all correct answers error rate (ER) for each of the 24 experimental conditions was computed. Furthermore, the reaction times were inverted (1/RT) in order to normalize their distribution (see Appendix D, Table D4). The different reaction times and error rates were each compared in a 3x2x2x2 analysis of variance defined by a combination of Color (Red/Green/Blue), Task (Global/Local), Congruency (Congruent/Incongruent) and spatial frequency (High/Low). Furthermore, both reaction times and error rates were subjected to a 2x2x2 ANOVA (Task, Congruency, and spatial frequency) per background color.

Experiment 3 - Results

Due to technical problems, the data from six of the participants had to be excluded from the analysis. They were replaced by six other participants, giving a total dataset of 16 participants.

Reaction time

Participants reacted faster to global compared to local stimuli, which is indicated by a significant task main effect ($F(1,15) = 266.058$, $MSe = .119$, $p < .001$). Furthermore, participants reacted faster to congruent compared to incongruent stimuli, which can be seen by a significant congruency main effect ($F(1,15) = 14.837$, $MSe = .015$, $p = .002$). No significant differences in reaction time across the different color conditions or the different categories of spatial frequency were found. We can see that the global form of incongruent stimuli interfered with the identification of the local stimuli, which resulted in a longer reaction time. For congruent stimuli, this effect could not be found which goes in line with our predictions of the global precedence effect and aligns with the results of the previous experiments. This is indicated by a significant task x congruency interaction effect ($F(1,15) = 21.712$, $MSe = .010$, , $p < .001$) (figure 15).

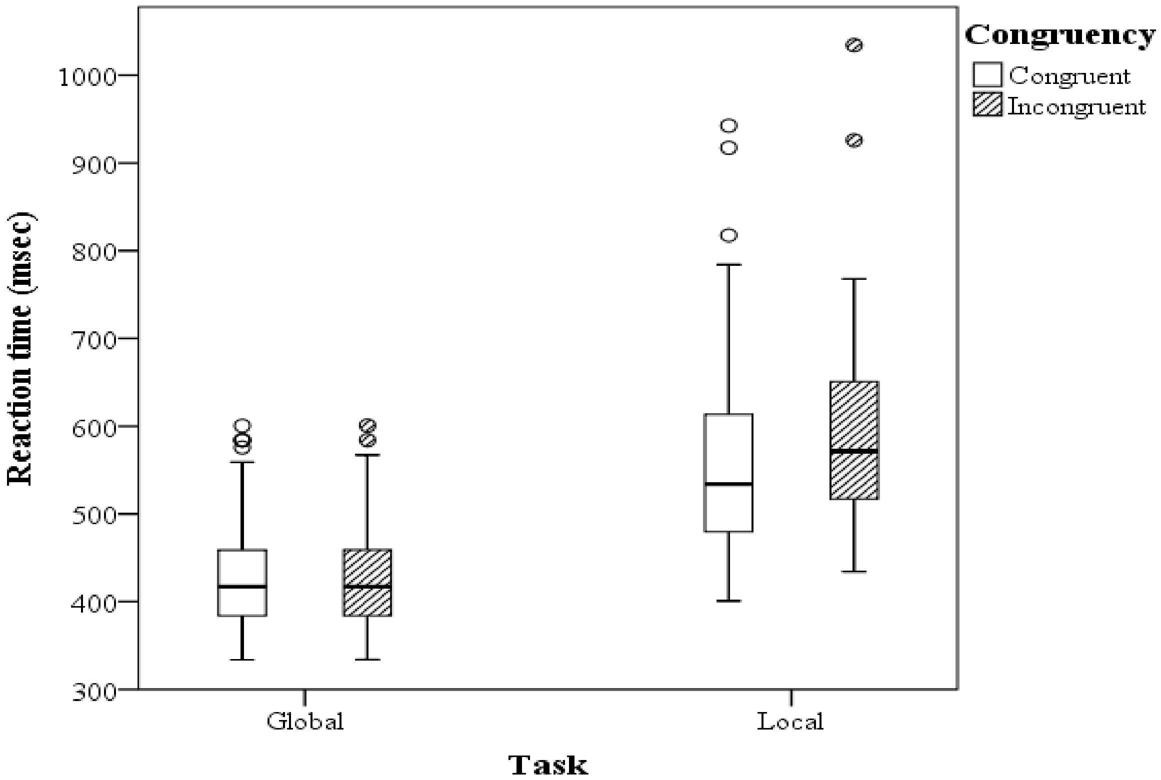

Figure 15. Experiment 3: Boxplot of the median reaction time of all 16 participants for the global and local tasks divided into congruent/incongruent stimuli. For further information about the elements of the boxplot see figure 2.

The results furthermore revealed that the global-to-local interaction did not differ between the three color conditions of red, green and blue ambient lighting. This shows that the global precedence effect was not moderated by the color of the light and is reflected in the non-significant interaction between the *color*, the *task* and the *congruency* (F(2,30) = .981, MSe = .006, p = .387) (figure 16).

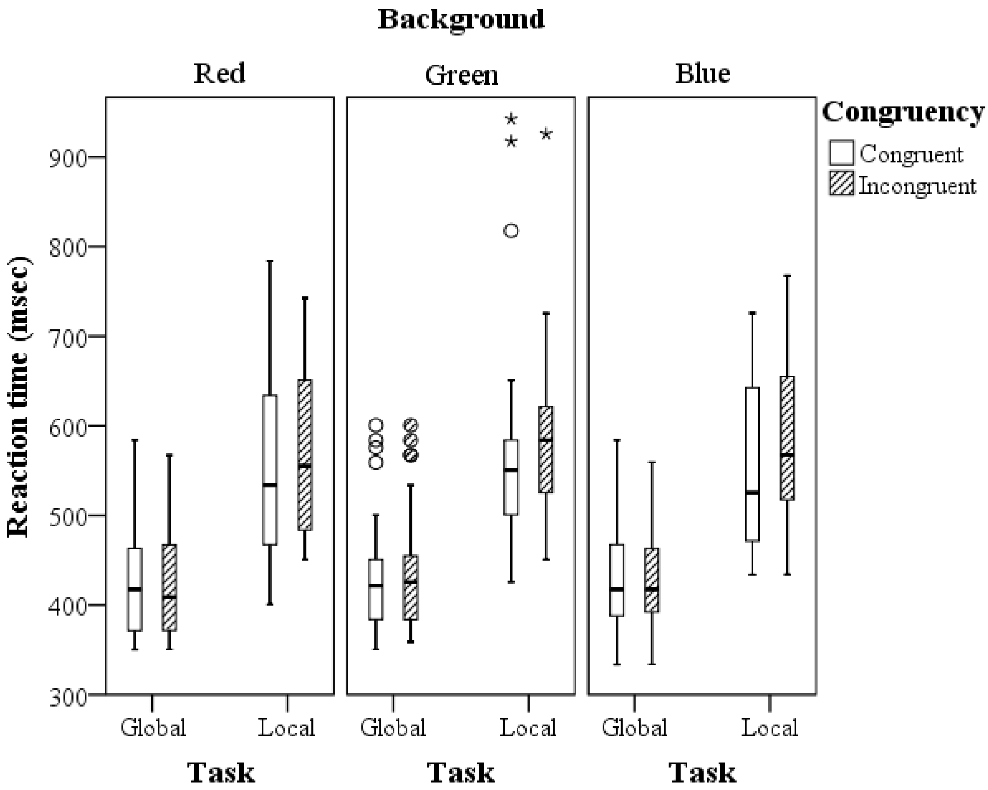

Figure 16. Experiment 3: Boxplot of the median reaction time of all 16 participants for the global and local tasks divided into congruent/incongruent stimuli for the red, green and blue color condition. For further information about the elements of the boxplot see figure 2.

The analysis also revealed that participants reacted significantly slower on low spatial frequency compared to high spatial frequency in the local tasks while no differences in reaction time between low and high spatial frequency could be seen for the global tasks. This is shown by the significant interaction effect between the *task* and the *spatial frequency* (F(1,15) = 18.190, MSe = .003, p < .001) (figure 17).

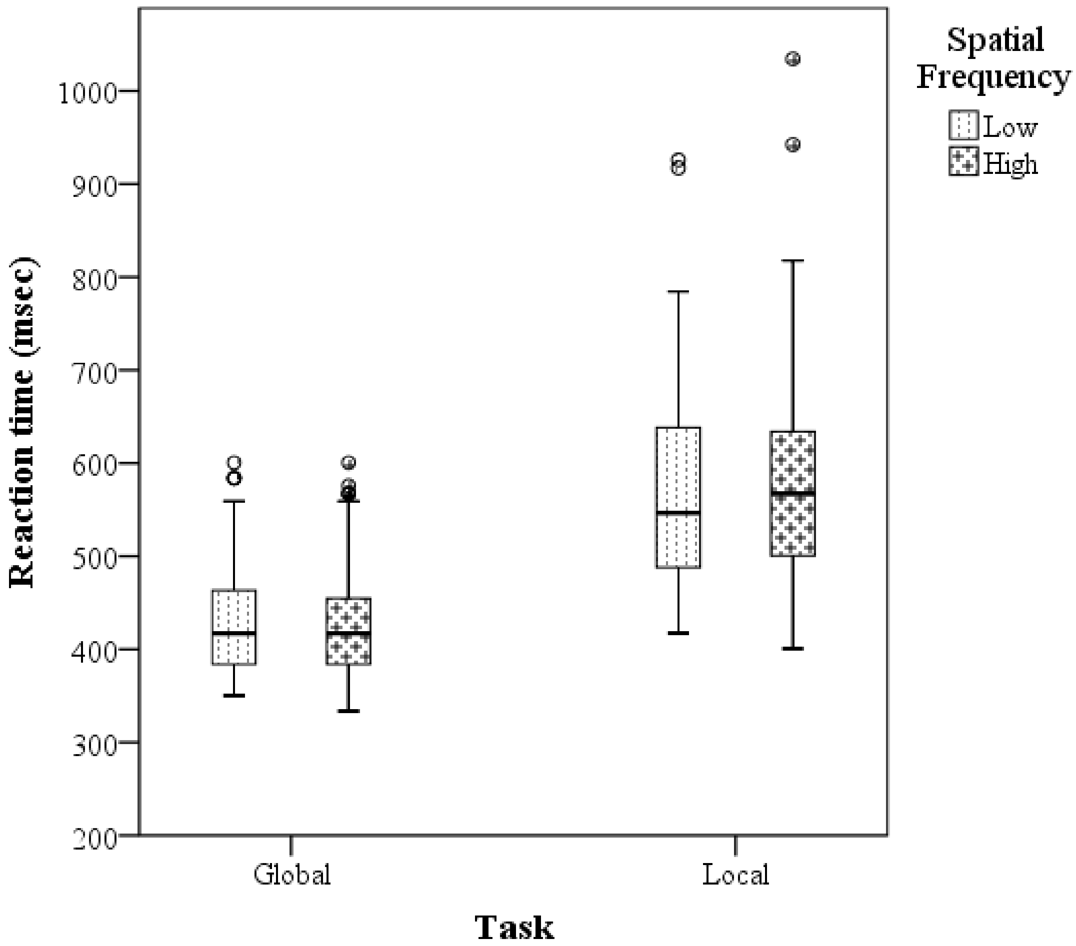

Figure 17. Experiment 3: Boxplot of the median reaction time of all 16 participants for the global and local tasks divided into high (4 cycles/degree) and low (0.5 cycles/degree) spatial frequency stimuli. For further information about the elements of the boxplot see figure 2.

Lastly, the analysis revealed that there is an advantage of low compared to high spatial frequency stimuli, which only took place in the identification of congruent stimuli in the blue color condition. This is indicated by a significant three-way interaction effect between the variables background, congruency and spatial frequency ($F(2,30) = 3.852$, $MSe = .004$, $p = .032$) and will be further addressed in the colorwise analysis.

Reaction time effect per color

The analysis of the effects per color revealed that the former found advantage of low compared to high spatial frequency stimuli which only appeared in the global tasks seems have taken place exclusively in the blue background. This is shown by the *task* x *spatial frequency* interaction which is significant in the blue ($F(1,15) = 8.257$, $MSe = .007$, $p = .012$) but not in the green ($F(1,15) = 2.718$, $MSe = .007$, $p = .120$) or red ($F(1,15) = .179$, $MSe = .005$, p =679) color condition.

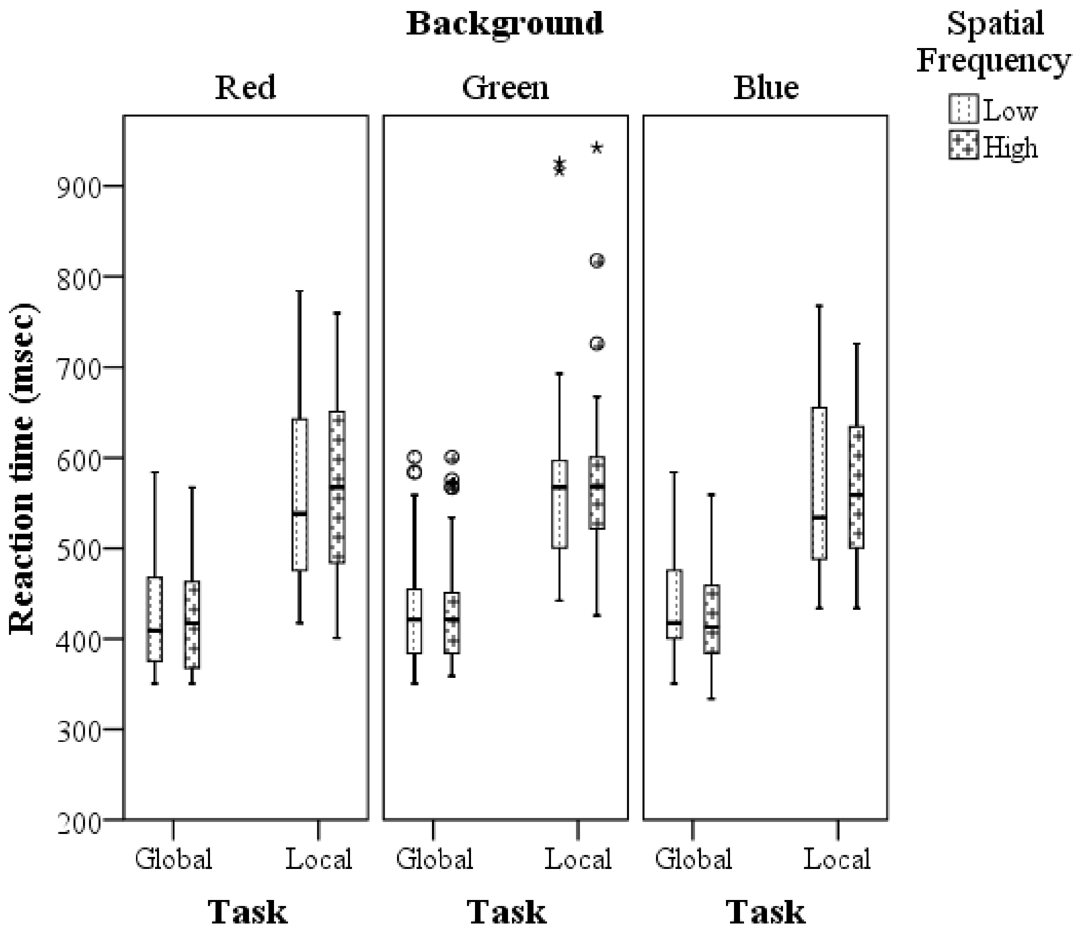

Figure18. Experiment 2: Boxplot of the median reaction time of all 16 participants for the global and local tasks divided into high (4 cycles/degree) and low (0.5 cycles/degree) spatial frequency stimuli for the red, green and blue color condition. For further information about the elements of the boxplot see figure 2.

Lastly, as already indicated by the significant three-way interaction between color, congruency and spatial frequency, the two-way interaction between congruency and spatial frequency was not significant for the red or the green lighting condition. In the blue lighting condition, no differences between high and low spatial frequencies could be seen for incongruent stimuli. However, participants reacted significantly faster to low spatial frequency stimuli compared to their high spatial frequency in a blue background counterparts as indicated by a significant two-way interaction between congruency and spatial frequency in the blue color condition (F(1,15) = 7.852, MSe = .007, p = .013) (figure 19). An overview of all effects on reaction time can be found in the Appendix (Appendix E, Table E8).

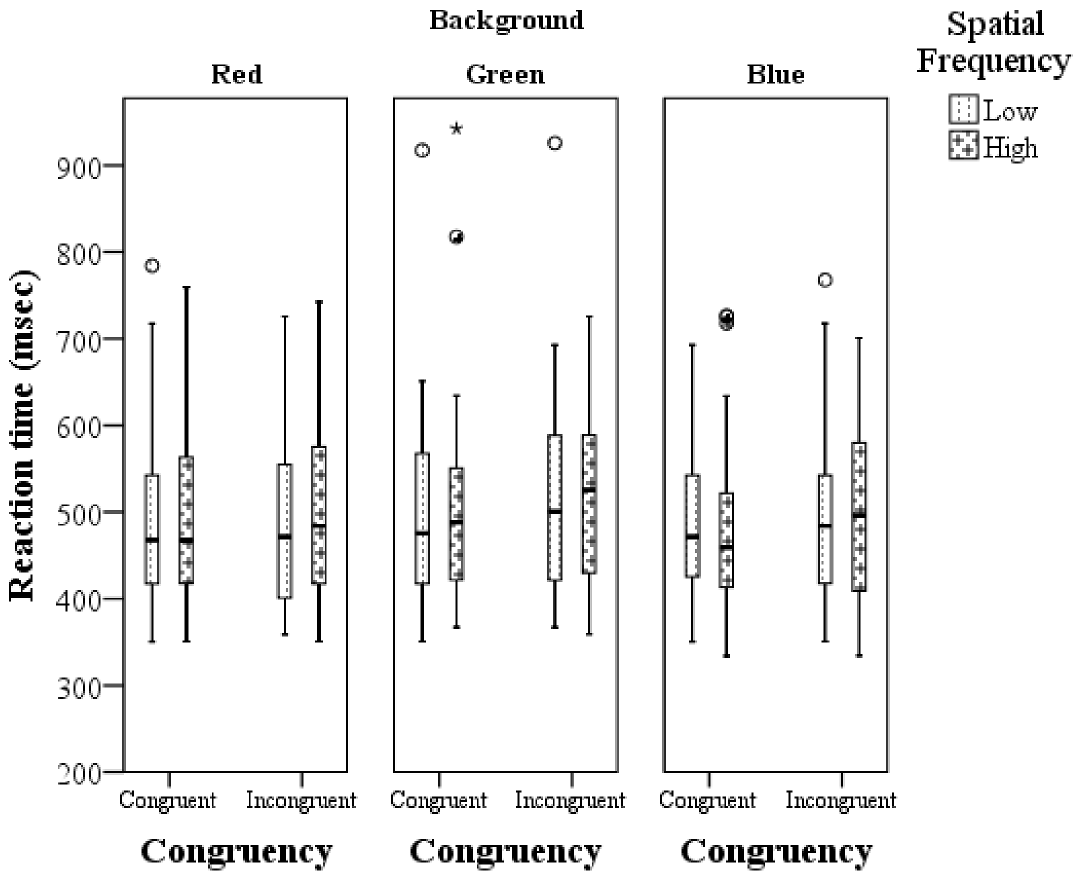

Figure 19. Experiment 3: Boxplot of the median reaction time of all 16 participants for the congruent and incongruent stimuli divided into high (4 cycles/degree) and low (0.5 cycles/degree) spatial frequency stimuli for the red, green and blue color condition. For further information about the elements of the boxplot see figure 2.

Error rate

In the analysis of the error rate, we have found that participants made significantly more errors identifying incongruent stimuli compared to congruent stimuli, which is indicated by a significant *congruency* main effect. (F(1,15) = 12.056, MSe = 48.655, p = .003). No significant effects of *color*, *task* or *spatial frequency* on error rate were found. Lastly we found participant made more errors for high compared to low spatial frequency stimuli in incongruent stimuli while no significant differences could be seen for congruent stimuli. However, this effect only took place in the blue color condition which is indicated by a significant *congruency* x *spatial frequency* interaction in the blue condition ($F(1,15) = 6.050$, $MSe = 21.521$, $p = .027$) which could not be found in the other conditions (figure 20). An overview of all effects on reaction time can be found in the Appendix (Appendix E, Table E9).

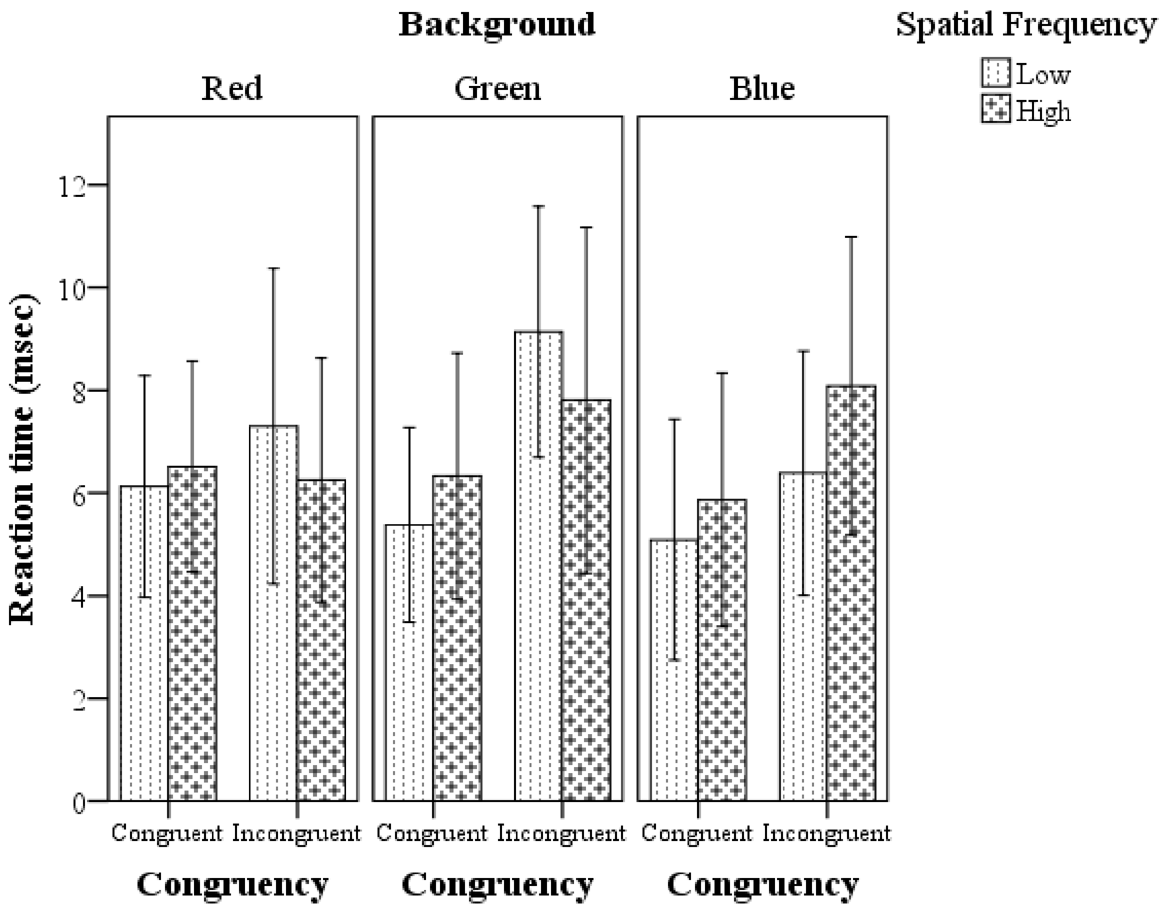

Figure 20. Mean error rates (%) of all 16 participants for the congruent and incongruent stimuli divided into high (4 cycles/degree) and low (0.5 cycles/degree) spatial frequency stimuli for the red, green and blue color condition. The error bars indicate the 95% confidence interval.

Experiment 3 - Conclusion

The results of the fourth experiment of this study mostly align with the results of the previous experiment. The global-to-local advantage in identifying the stimuli shows that participants identified the overall orientation of a stimulus much faster (although not more accurate) than the orientation of the small patches. This shows again, that global features of a stimulus tend to be processed faster than the details and aligns with previous research that has been done in this domain. Although the statistical analysis revealed a significant global-to-local interference, we have to state that this interference is only significant in the identification of local stimuli. This indicates the global precedence effect and states that if the global and the local orientation are not alike, the global feature may interfere with the local identification. This happens because it is processed earlier and results in a prolonged reaction time. The global precedence effect goes in line with our expectations, since it systematically was found in the previous three experiments of this study and has been backed up by several other researchers (Goto et al., 2004; Kimchi, 1992; Navon, 1977). Furthermore, one of the main goals of this study was to test whether the appearance of the global precedence effect can be moderated as suggested by Michimata Chikashi et al. (1999). Based on the results of the last three experiments, we did not expect the global precedence effect to be affected by color. The results confirmed our expectations. The results show that the global precedence effect takes place equally with red, green and blue ambient lighting.

Another goal of the experiment was to see whether the change of the provided light from background lighting of the screen to equiluminant ambient lighting provided by LED cubes would alter the effects of color on visual processing. An interesting finding is, that blue ambient lighting apparently has an effect on the processing of different spatial frequencies in stimuli. As in Experiment 3, the results show an advantage of low compared to high spatial frequency stimuli which only takes place in the local tasks in the blue color condition. Contrary to the results of Experiment 3, it is harder to explain these results with the attenuation of the magnocellular pathway since the suppression of the M-Channel by higher wavelengths should not take place with ambient lighting. Furthermore, we found the same advantage of low compared to high spatial frequency stimuli in the blue color condition which only takes place in congruent stimuli in both reaction times and error rates. The fact that this effect only shows up in incongruent (both global and local tasks) stimuli or local tasks (both congruent and incongruent stimuli) in the blue color condition makes this finding rather difficult to explain and fit into the theoretical framework since previous research has not made similar findings

(Garofalo et al., 2014). Besides these effects no effects of ambient lighting on the processing of hierarchically organized stimuli have been found.

General Discussion and Conclusion

Discussion

The aim of this study was to investigate whether the psychological effects of color may also be obtained by colored lighting. Looking back, we may state that the effects may not be obtained given that we did not find the expected psychological effects of color in the first place.

For this study, we have carried out one pilot and three experiments. Each experiment involved the identification of stimuli that possessed global and local features. Throughout all four experiments, participants showed a clear reaction time advantage in the identification of global compared to local features. This means that the 'big picture' is identified significantly faster than the small details. Another important finding is that participants show a faster reaction time to congruent stimuli compared to their incongruent counterparts. However this advantage can only be seen when it comes to the identification of local features, which goes in line with the global precedence effect. Since it is theorized the identification of global features precedes the one of local features a possible incongruence does not result in an interference when global features have to be identified. However, in the case that the local features haves to be identified the earlier processed global form may interfere with the identification if the features are incongruent (Bouvet et al., 2011; Kimchi, 1992; Navon, 1977). The results of the pilot study and the three experiments conducted in this study provide further evidence for the GPE and show that the interference can be caused by different forms (squares/diamonds; pilot and Experiment 1) as well as by a different alignment of the figures (horizontal/vertical, Experiment 2 and 3).

Contrary to our expectations the global precedence effect does not seem to be attenuated by either background color or colored ambient lighting. The results of the pilot study suggest that the global precedence effect seems to be significantly less strong in the green color condition than in the other two conditions. These results were contrary to our expectations, since we expected the effects of color to appear with a red background based on the wide range of studies that concluded effects of specifically red (Garofalo et al., 2014; Kliger & Gilad, 2012; West, Anderson, Bedwell, & Pratt, 2010; Yeshurun, 2004) as well as the study by Michimata et al. (1999) that found an attenuated global precedence effect in stimulus identification with a red background. However, the other three experiments all involved a red background (or a red ambient light in experiment 3) and none of them revealed a significant difference between the colors. Since the effect from the pilot study has not been found in the other three experiments, we may theorize that the effect was not very persistent. From this we may draw the conclusion that there is no systematic effect of the background color on the appearance of the global precedence effect on hierarchically organized stimuli. These results contradict with the results found by Michimata et al. (1999) since a strong effect of red background color on the global precedence has been found in their study. However there are no other publications to date, which can confirm their findings.

The explanation which was given by (Michimata Chikashi et al., 1999) for their results was that the attenuation of the global precedence effect in a red background was (at least partly) due to a suppression of the magnocellular pathway. Research has shown that the magnocellular pathway, which is among other things responsible for the processing of low spatial frequencies, may be attenuated by red light (Breitmeyer & Breier, 1994; Chapman et al., 2004; Chase et al., 2003; Edwards et al., 1996). However, the results of Experiment 2, which was designed to combine measurements of the GPE and M-Channel suppression, did not provide evidence for this theory. While the results show that the advantage of low compared to high spatial frequency in the identification of local figures was higher in the blue condition than in the other two conditions no evidence has been found that low spatial frequency stimuli are processed slower with a red background or in higher wavelengths (which could also include green). Furthermore, similar effects have been found in Experiment 3, where the tonic red suppression could not explain the results due to the use of ambient lighting instead of colored backgrounds. These inconsistencies between our data and previous research concerning spatial frequency are further addressed in the limitations of the study.

Lastly, the replacement of the colored background lighting with colored ambient lighting did not reveal any further effects of colored light on visual processing besides a rather complex interaction between the blue background and congruent high spatial frequency stimuli and the interaction between a blue background and local high spatial frequency tasks. However, the existing theoretical framework cannot explain these effects and needs further attention in future studies.

Possible limitations

One possible limitation of the study is, that participants were aware of the fact that we were measuring the impact on color on their behavior. Given that in every experiment, all three different color conditions (red/green/grey for experiment 1 and 2, red/green/blue for experiment 3 and 4) were presented directly after one another and no other changes were introduced in the different sessions the participants were made aware that color was a crucial factor in the study.

In addition, we did not control for individual isoluminance of the screens or the ambient lightings in our study. In our study, the isoluminance was set with a photospectrometer beforehand. However, in the study of Michimata et al. (1999), the participants completed a flicker task before the visual identification task. With this task, the individual isoluminance was set for each participant. Since participants may have perceived the isoluminance differently, this may have influenced the results.

Another possible limitation concerns our approach to find evidence for M-channel suppression through red light by implementing high and low spatial frequencies in our second experiment. Although research showed that low spatial frequency channels are processed by the magnocellular pathway (Livingstone & Hubel, 1988; Livingstone & Hubel, 1987) and that the working mechanisms of the magnocellular pathway can be suppressed by diffuse red light (Chase et al., 2003; Edwards et al., 1996; West et al., 2010) our study failed to provide conclusive evidence for this mechanism compared to similar studies (Breitmeyer & Breier, 1994; Garofalo et al., 2014). In our experiment, it was not possible to present the small Gabor patches with a spatial frequency lower that 0.5 cycles per degree of visual angle. However, the study by Garofalo et al. (2014) found the highest reaction times on a red background with even lower spatial frequency stimuli (0.25 cycles per degree of visual angle). A possible explanation for the inconsistent results in our study could thus be attributed to the fact that the spatial frequency was still not low enough to be strongly affected by a suppression of the magnocellular pathway. Furthermore, research has shown that there are no definite values for either *high* or *low* spatial frequency but instead these attributes may depend on several factors such as luminance, stimulus size, viewing angle or adaptation to a certain spatial frequency (Ellemberg, Allen, & Hess, 2006; Lange, Sige, & Stecher, 1973; Stecher, Sigel, & Lange, 1973). Another factor is, that the most striking effects of a red background on the reaction time on low spatial frequency stimuli in the study by Garofalo et al. (2014) have been found when the stimuli were presented in a very low contrast (0.15). In our study, the minimum contrast value in which the figures were still visible was 0.4. It is possible that the contrast was not low enough for the effects of a red background on suppression of the M-Channels to occur.

Future research

Future research concerning the current study should address the suppression of the magnocellular pathway by a red background color. As already mentioned, Experiment 2 did not yield the expected results concerning an attenuation of the magnocellular pathway by red background lighting. However, there is strong evidence in research that M-Channel activity can be suppressed by red light (Chapman et al., 2004; Edwards et al., 1996). To induce suppression of the magnocellular pathway, future research should use even lower spatial frequencies than in the current study and use stimuli with a lower contrast. Both methods have been proven to induce longer reaction times in stimulus identification with a red background compared to other colored backgrounds in previous research (Garofalo et al., 2014).

Another suggestion for future research is to change the context in which the effects of color on visual processing are measured. According to the color-in-context theory the effects of color always depend on the context in which the color is presented (Elliot & Maier, 2012). In the current research, no different contexts were compared nor have we set up the research in a way that a specific context is implied. Future research could include the factor context by conducting the experiments in a more academic setting by enforcing the importance of correct answers and by rating the performance of the participants based on reaction time and error rate. The experiments could also be conducted in a more competitive setting by giving the participants a possibility for social comparison, which could be achieved with a high score list for example. The color red has shown to affect cognitive performance in an academic (Gnambs et al., 2010; Meier et al., 2015; Shi, Zhang, & Jiang, 2015a) as well as in a competitive context (Feltman & Elliot, 2011; Greenlees et al., 2008).By conducting the research in a specific context, one could expect effects on visual processing and the identification of hierarchically organized stimuli with a red background compared to other colored backgrounds.

Conclusion

The main aim of the study was to investigate whether the psychological effects of color also can be caused by colored lighting. For this, the effects of color on visual processing were investigated with the aim to investigate the effects of color with the effects of colored ambient lighting. However, finding an answer to the question whether the effects of color may also be caused by colored lighting was hindered by the fact that we did not find the expected effects of color in the first place. Contrary to our expectations and previous literature, the global precedence effect was not attenuated by a red background color. Even the inclusion of spatial frequencies did not yield the expected results. From this we may suggest that the effects of red on global and local processing are not as straightforward as suggested by Michimata et al. (1999) and that the attenuating effect of red could not be confirmed in our study. Following this, we may propose that the underlying mechanisms of the effects of color on visual processing should be given more attention in future research. Especially the suppression of the magnocellular pathway and how it may affect visual processing should be further clarified.

On an additional note, the existing framework about the effects of color and colored lighting provide many different approaches to how the effects can be explained. While every individual approach focusses on a very specific phenomenon, there is no general theoretical framework about how all these different approaches fit together. For a better understanding on the effects of color and light on psychological functioning, there is a strong need for a combining meta-framework which aims to unify the different approaches.

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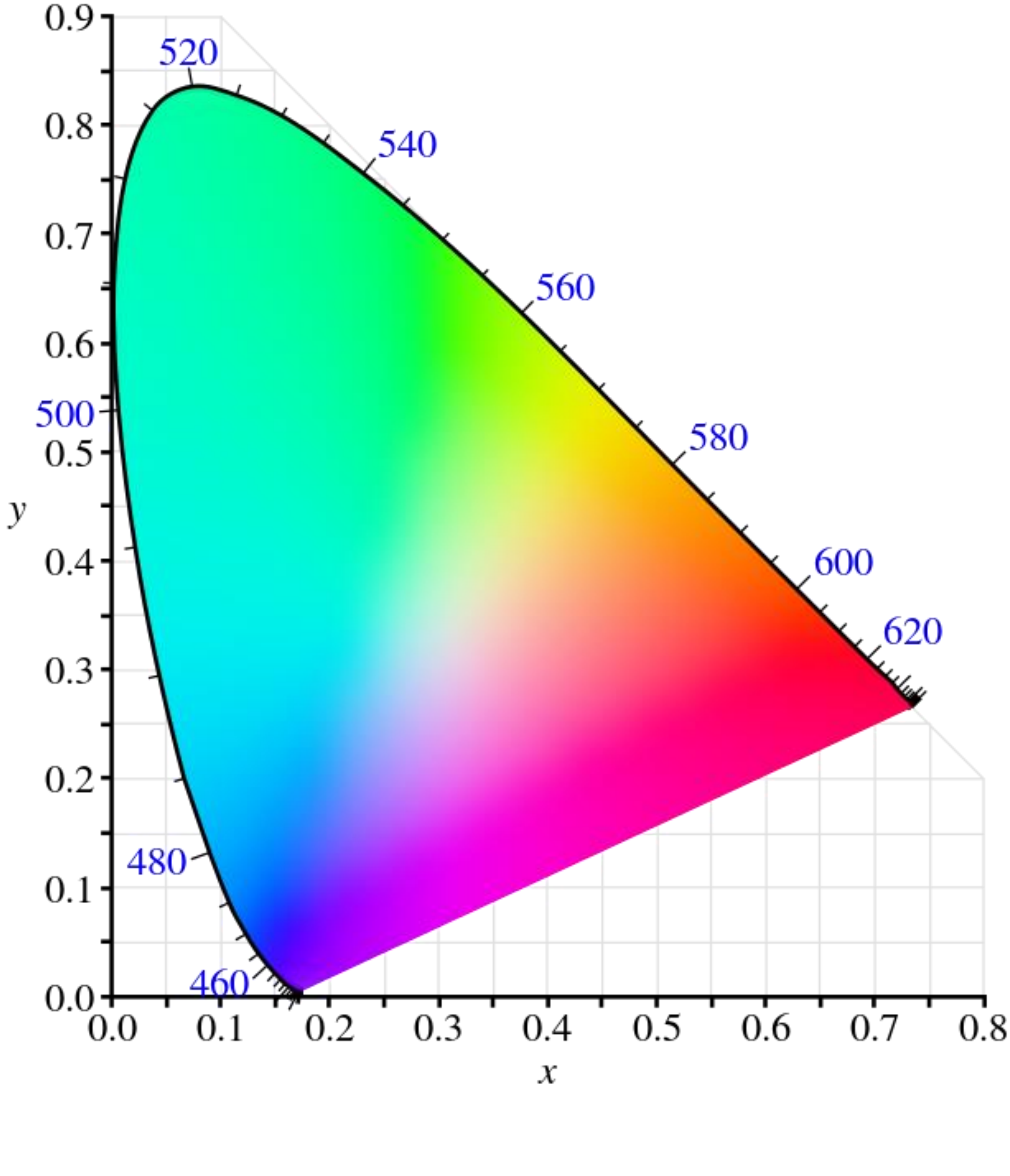
Appendices

Appendix A

The CIE 1931 colour space chromaticity diagram. The outer curved boundary is the spectral (or monochromatic) locus, with wavelengths shown in nanometers. (CIE, 1931)



Appendix B

Informed Consent

Eindhoven, ____ - ____ - 2016

Informed Consent Form: Master Thesis Experiment

In this study we will ask you to take part in a visual search task which is carried out on the computer. You will be asked to identify the form of visual stimuli by pressing the corresponding button. An example will be given to you by the researcher. During the experiment, you are asked to place your head on the provided chinrest to ensure, that every participant is participating in the same conditions.

All information you provide will remain confidential and will not be associated with your name. If for any reason during this study you do not feel comfortable, you may leave the laboratory and your information will be discarded.

Your participation in this study will require approximately 30 minutes. When this study is complete you will be provided with the results of the experiment if you request them, and you will be free to ask any questions. However, it may be that some of the questions cannot be answered before the end of the experiment, since they could potentially influence its outcome.

If you have any further questions concerning this study please feel free to contact me through phone or email:

Sascha Jenderny
s.jenderny@philips.com
+31651860467

Please indicate with your signature on the space below that you understand your rights and agree to participate in the experiment. Your participation is solicited, yet strictly voluntary. All information will be kept confidential and your name will not be associated with any research findings.

____

Name Participant

______________________________ ________________________

Signature of Participant Sascha Jenderny, Investigator

Appendix C

Demographic Questionnaire

Demographic Questionnaire

Participant number:

Date:

Age:

Gender

Male •

Female •

Are you right- or left-handed?

Right •

Left •

Appendix D

Distribution of the reaction times

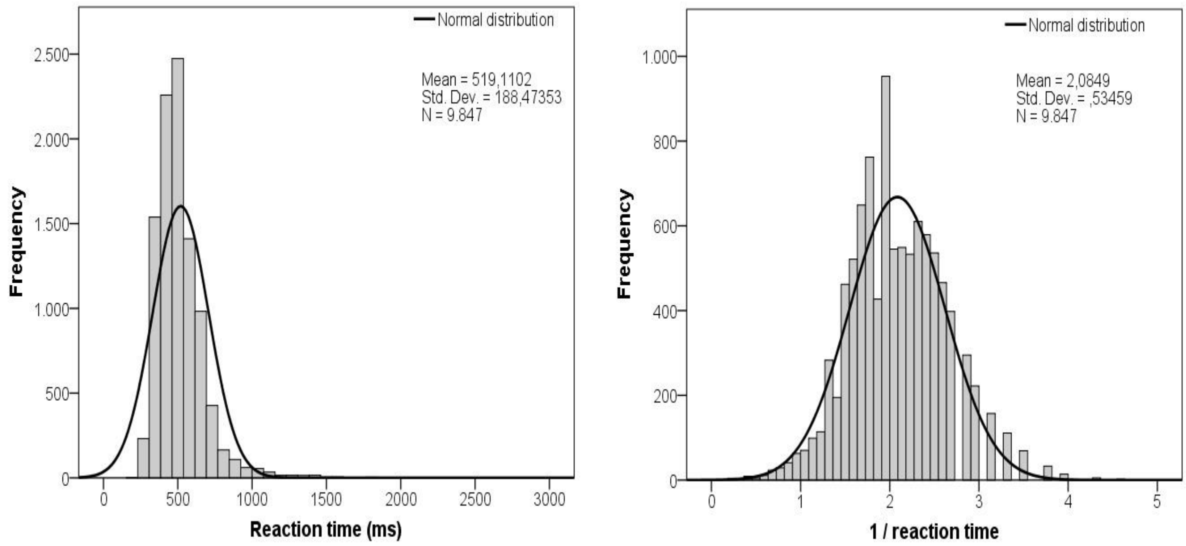


Figure D1. Distribution of the raw reaction times (left) and the normalized reaction times (right) of all 12 participants of the pilot study.

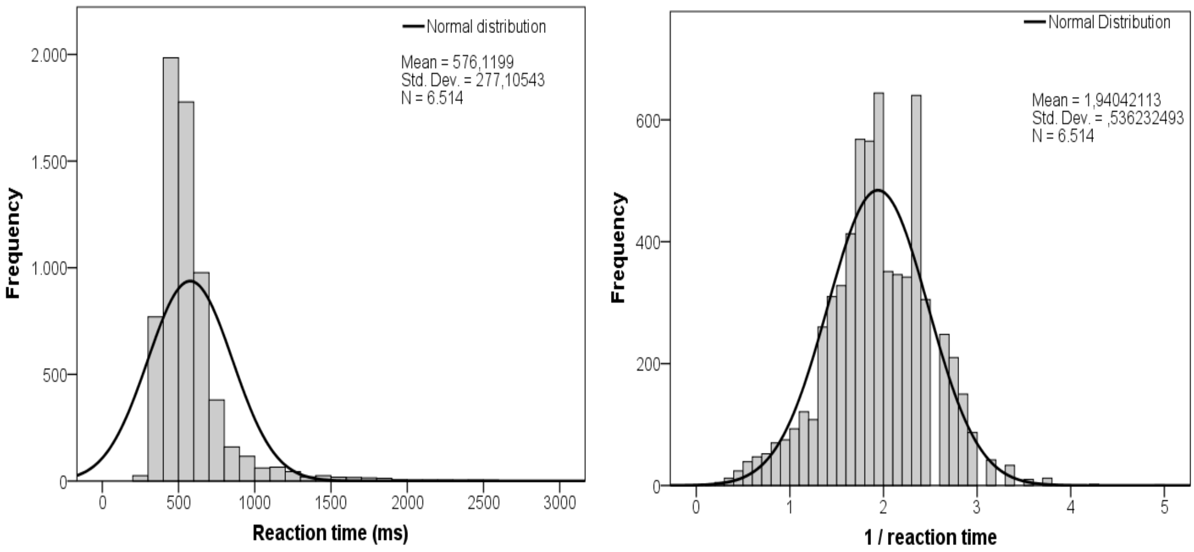


Figure D2. Distribution of the raw reaction times (left) and the normalized reaction times (right) of all 18 participants of Experiment 1.

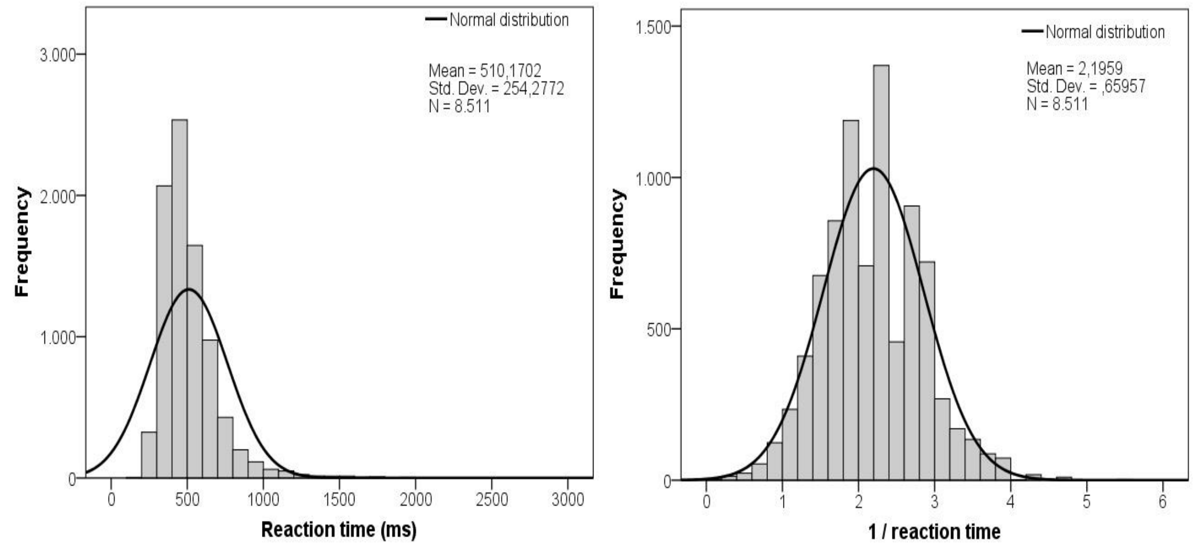


Figure D3. Distribution of the raw reaction times (left) and the normalized reaction times (right) of all 16 participants of Experiment 2.

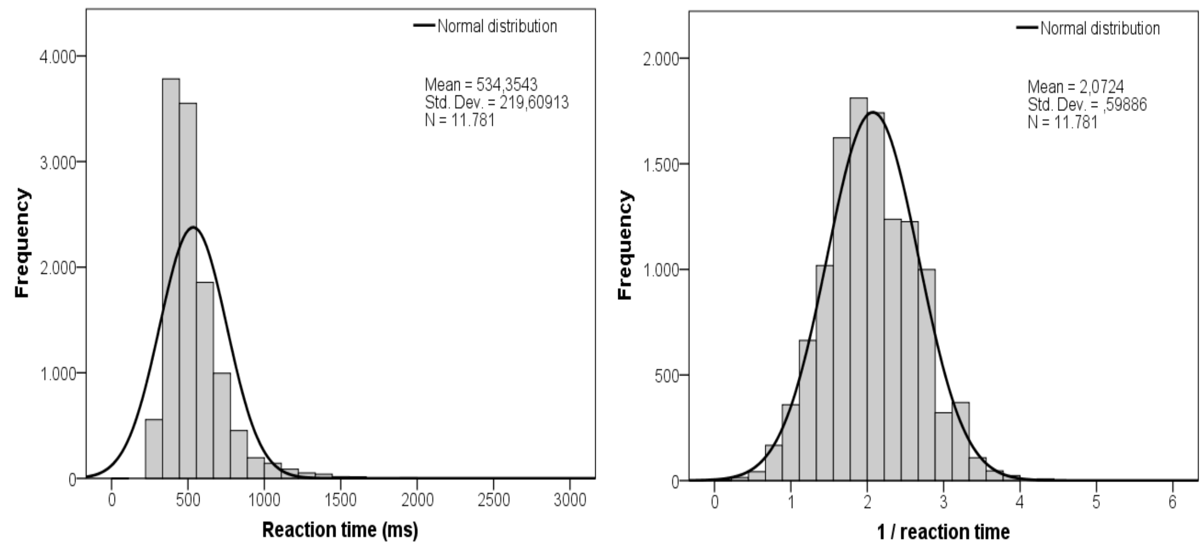


Figure D2. Distribution of the raw reaction times (left) and the normalized reaction times (right) of all 16 participants of Experiment 3.

Appendix E

Effect overview

Symbol	X	X*	S*	S**	N/A
Meaning	not significant	almost significant (0.05 < p < 0.1)	significant with p < 0.05	significant with p < 0.01	not applicable

Figure E1. Legend for the effect overview tables.

Effects on reaction time	Variables	Overall	Red	Green	Grey
Main effects	Background	X	N/A	N/A.	N/A.
	Task	S**	S**	S**	S**
	Congruency	S**	S*	S*	S**
	Figure	X	X	X	X
2-Way interaction	Background x Task	X	N/A	N/A	N/A
	Background x Congruency	X	N/A	N/A	N/A
	Task x Congruency	S*	S*	X	S*
	Background x Figure	X	N/A	N/A	N/A
	Congruency x Figure	S**	S**	S**	S*
	Task x Figure	X	X	X	X*
3-Way interaction	Background x Task x Figure	X	N/A	N/A	N/A
	Background x Task x Congruency	X	N/A	N/A	N/A
	Background x Congruency x Figure	X*	N/A	N/A	N/A
	Task x Congruency x Figure	X*	X	X	X
4-Way interaction	Background x Task x Congruency x Figure	X	N/A	N/A	N/A

Figure E2. Overview of the effect of the repeated measures ANOVA of the median reaction time for the pilot study for the variables background, task, congruency and figure. For a clarification of the symbols see table E1.

Effects on error rate	Variables	Overall	Red	Green	Grey
Main effects	Background	X	N/A	N/A.	N/A.
	Task	S*	S*	X	X
	Congruency	S*	S*	S*	X*
	Figure	X	X	X	X
2-Way interaction	Background x Task	X	N/A	N/A	N/A
	Background x Congruency	X	N/A	N/A	N/A
	Task x Congruency	S*	X*	X	X
	Background x Figure	X	N/A	N/A	N/A
	Congruency x Figure	S**	S**	S*	S*
	Task x Figure	S*	S*	S*	X
3-Way interaction	Background x Task x Figure	X	N/A	N/A	N/A
	Background x Task x Congruency	X	N/A	N/A	N/A
	Background x Congruency x Figure	X	N/A	N/A	N/A
	Task x Congruency x Figure	S*	X	S*	X
4-Way interaction	Background x Task x Congruency x Figure	X	N/A	N/A	N/A

Figure E3. Overview of the effect of the repeated measures ANOVA of the mean error rate for the pilot study for the variables background, task, congruency and figure. For a clarification of the symbols see table E1.

Effects on reaction time	Variables	Overall	Red	Green	Grey
Main effects	Background	X	N/A	N/A.	N/A.
	Task	S**	S**	S**	S**
	Congruency	S**	S*	S*	S**
	Figure	X*	X	X	X
2-Way interaction	Background x Task	X	N/A	N/A	N/A
	Background x Congruency	X	N/A	N/A	N/A
	Task x Congruency	S**	S*	S*	S*
	Background x Figure	X	N/A	N/A	N/A
	Congruency x Figure	S**	S**	S**	S*
	Task x Figure	X	X	X	X*
3-Way interaction	Background x Task x Figure	X	N/A	N/A	N/A
	Background x Task x Congruency	X	N/A	N/A	N/A
	Background x Congruency x Figure	X*	N/A	N/A	N/A
	Task x Congruency x Figure	X*	X	X	X
4-Way interaction	Background x Task x Congruency x Figure	X	N/A	N/A	N/A

Figure E4. Overview of the effect of the repeated measures ANOVA of the median reaction time for Experiment 1 for the variables background, task, congruency and figure. For a clarification of the symbols see table E1.

Effects on error rate	Variables	Overall	Red	Green	Grey
Main effects	Background	X	N/A	N/A.	N/A.
	Task	X	S*	X	X
	Congruency	S*	S*	X	X*
	Figure	X	X	X	X
2-Way interaction	Background x Task	X	N/A	N/A	N/A
	Background x Congruency	X	N/A	N/A	N/A
	Task x Congruency	X	X*	X	S*
	Background x Figure	X	N/A	N/A	N/A
	Congruency x Figure	S*	X	S*	X*
	Task x Figure	X	X	X*	X
3-Way interaction	Background x Task x Figure	X	N/A	N/A	N/A
	Background x Task x Congruency	S*	N/A	N/A	N/A
	Background x Congruency x Figure	X	N/A	N/A	N/A
	Task x Congruency x Figure	S*	X	S*	X
4-Way interaction	Background x Task x Congruency x Figure	S*	N/A	N/A	N/A

Figure E5. Overview of the effect of the repeated measures ANOVA of the mean error rate for Experiment 1 for the variables background, task, congruency and figure. For a clarification of the symbols see table E1.

Effects on reaction time	Variables	Overall	Red	Green	Blue
Main effects	Background	X	N/A	N/A.	N/A.
	Task	S**	S**	S**	S**
	Congruency	S**	X	S*	S*
	Spatial Frequency	X	X	S*	X
2-Way interaction	Background x Task	X	N/A	N/A	N/A
	Background x Congruency	X	N/A	N/A	N/A
	Task x Congruency	S**	S*	S*	S*
	Background x Spatial Frequency	X	N/A	N/A	N/A
	Congruency x Spatial Frequency	S*	X	X	S*
	Task x Spatial Frequency	S*	X	X*	S*
3-Way interaction	Background x Task x Spatial Frequency	X	N/A	N/A	N/A
	Background x Task x Congruency	X	N/A	N/A	N/A
	Background x Congruency x Spatial Frequency	X*	N/A	N/A	N/A
	Task x Congruency x Spatial Frequency	X*	X	X	S*
4-Way interaction	Background x Task x Congruency x Spatial Frequency	S*	N/A	N/A	N/A

Figure E6. Overview of the effect of the repeated measures ANOVA of the median reaction time for Experiment 2 for the variables background, task, congruency and spatial frequency. For a clarification of the symbols see table E1.

Effects on error rate	Variables	Overall	Red	Green	Blue
Main effects	Background	X	N/A	N/A.	N/A.
	Task	X*	S*	X	X
	Congruency	S*	X	S*	S*
	Spatial Frequency	X	X	X	X
2-Way interaction	Background x Task	X	N/A	N/A	N/A
	Background x Congruency	X	N/A	N/A	N/A
	Task x Congruency	X	X	X	X
	Background x Spatial Frequency	X	N/A	N/A	N/A
	Congruency x Spatial Frequency	X	X	X	X
	Task x Spatial Frequency	S*	X	X	X*
3-Way interaction	Background x Task x Spatial Frequency	X	N/A	N/A	N/A
	Background x Task x Congruency	X	N/A	N/A	N/A
	Background x Congruency x Spatial Frequency	X	N/A	N/A	N/A
	Task x Congruency x Spatial Frequency	S*	X	S*	X
4-Way interaction	Background x Task x Congruency x Spatial Frequency	S*	N/A	N/A	N/A

Figure E7. Overview of the effects of the repeated measures ANOVA of the mean error rate for Experiment 2 for the variables background, task, congruency and spatial frequency. For a clarification of the symbols see table E1.

Effects on reaction time	Variables	Overall	Red	Green	Blue
Main effects	Background	X	N/A	N/A.	N/A.
	Task	S**	S**	S**	S**
	Congruency	S**	X*	S*	S**
	Spatial Frequency	X*	X	S*	X
2-Way interaction	Background x Task	X	N/A	N/A	N/A
	Background x Congruency	X	N/A	N/A	N/A
	Task x Congruency	S*	S*	S*	S**
	Background x Spatial Frequency	X	N/A	N/A	N/A
	Congruency x Spatial Frequency	X	X	X	X*
	Task x Spatial Frequency	S**	X	X*	X*
3-Way interaction	Background x Task x Spatial Frequency	X	N/A	N/A	N/A
	Background x Task x Congruency	X	N/A	N/A	N/A
	Background x Congruency x Spatial Frequency	X	N/A	N/A	N/A
	Task x Congruency x Spatial Frequency	X	X	X	X*
4-Way interaction	Background x Task x Congruency x Spatial Frequency	X	N/A	N/A	N/A

Figure E8. Overview of the effects of the repeated measures ANOVA of the median reaction time for Experiment 3 for the variables background, task, congruency and spatial frequency. For a clarification of the symbols see table E1.

Effects on error rate	Variables	Overall	Red	Green	Blue
Main effects	Background	X	N/A	N/A.	N/A.
	Task	X	X*	X	S*
	Congruency	S**	S**	X*	S*
	Spatial Frequency	X	X	X	X
2-Way interaction	Background x Task	X	N/A	N/A	N/A
	Background x Congruency	X	N/A	N/A	N/A
	Task x Congruency	X	X	X	X
	Background x Spatial Frequency	X*	N/A	N/A	N/A
	Congruency x Spatial Frequency	X	X	X	S*
	Task x Spatial Frequency	X	X	X	X
3-Way interaction	Background x Task x Spatial Frequency	X	N/A	N/A	N/A
	Background x Task x Congruency	X	N/A	N/A	N/A
	Background x Congruency x Spatial Frequency	S*	N/A	N/A	N/A
	Task x Congruency x Spatial Frequency	X	X*	X	X
4-Way interaction	Background x Task x Congruency x Spatial Frequency	X	N/A	N/A	N/A

Figure E9. Overview of the effects of the repeated measures ANOVA of the mean error rate for Experiment 3 for the variables background, task, congruency and spatial frequency. For a clarification of the symbols see table E1.

Appendix F

High resolution Gabor patches

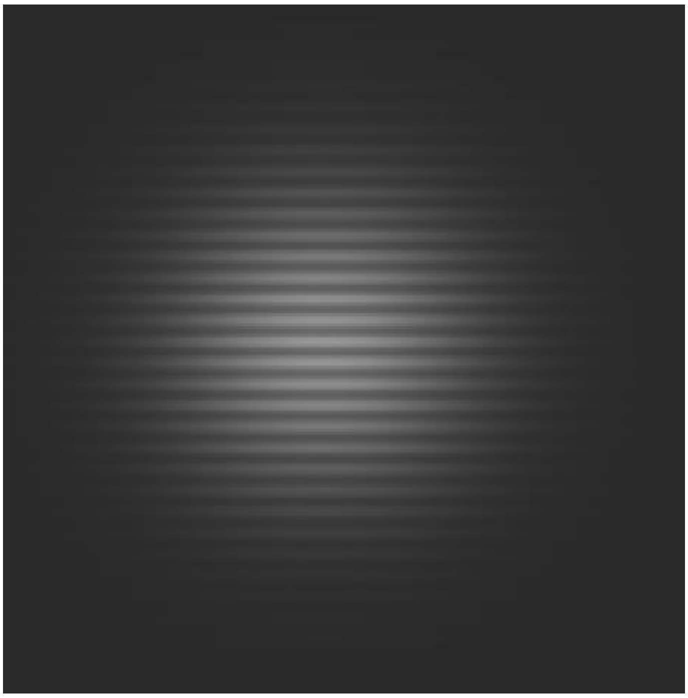


Figure F1. High spatial frequency Gabor patch (4 cycles per degree of visual angle) with horizontal orientation of the grating

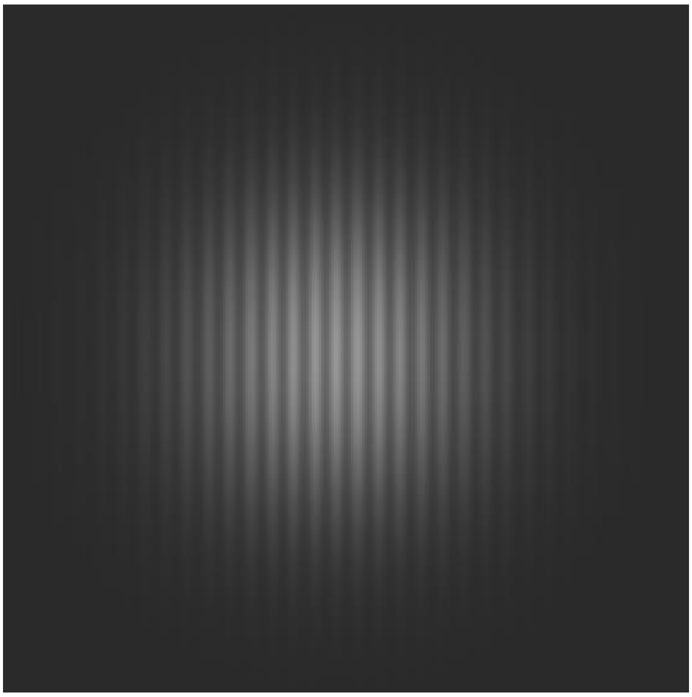


Figure F2. High spatial frequency Gabor patch (4 cycles per degree of visual angle) with vertical orientation of the grating