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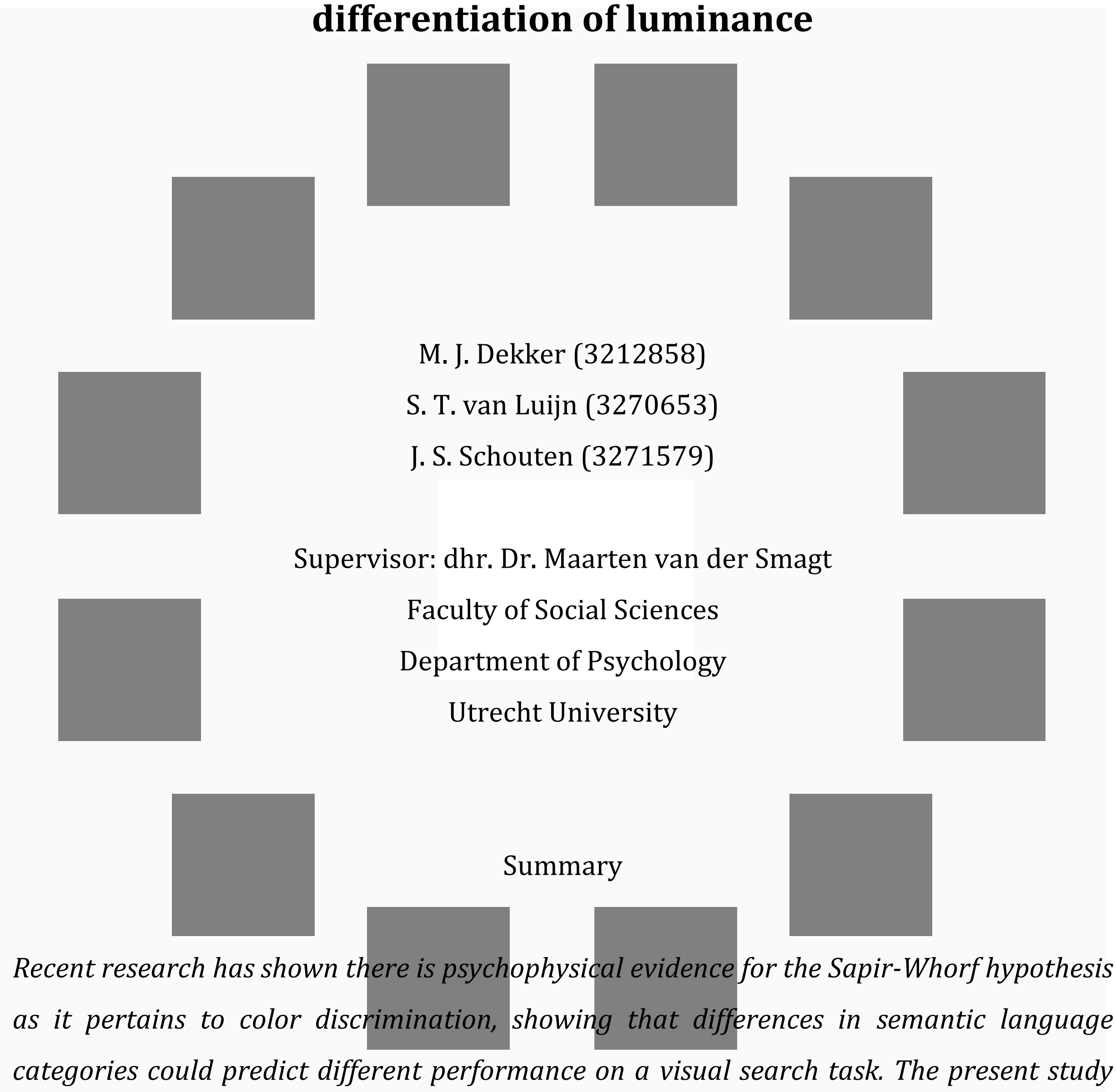
The Sapir-Whorf hypothesis cannot be extended to include differentiation of luminance



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Summary

Recent research has shown there is psychophysical evidence for the Sapir-Whorf hypothesis as it pertains to color discrimination, showing that differences in semantic language categories could predict different performance on a visual search task. The present study investigated the difference in visual field and corresponding hemispheres for categorical perception for brightness. A visual search task consisting of luminance contrasts was used to investigate aforementioned differences. Results showed that the Sapir-Whorf hypothesis cannot be extended to include differentiation of luminance, but some results pertaining to contrast discrimination were found, such as the interaction between lexical categories and polarity of the stimulus, warranting further research in contrast discrimination.

Introduction

It has been widely debated if the language someone speaks influences the way in which he/she perceives the world. Whorf was the first researcher who postulated the idea that humans view the world filtered through the semantic categories of our native language (Regier and Kay, 2009). Since then, the debate has continued to this day, with different researchers advocating for or against this language-perception interaction. Although the Sapir-Whorf hypothesis, as it is generally known, is still a strongly debated subject, the different aspects of the theory are being worked out.

Sapir-Whorf Hypothesis for Colors

For instance, Luke, Tan, Chan, Kay, Khong and Yip (2008) have conducted a visual discrimination task while monitoring subjects with an MRI-scanner. Their participants had to name various colors, which would consist of easy-to-name colors (e.g. 'blue') and hard-to-name (e.g. 'turquoise') colors. Colors are a handy tool to measure perception, because although the color spectrum is a continuum, depending on the language spoken it appears to be segmented into qualitatively different semantic categories. Research indicates that perception between categories is easier, thus quicker and more accurate than within-categories perception, a phenomenon called categorical perception (CP). In the above experiment, hard-to-name colors were almost straddling these category boundaries, while easy-to-name colors were not. They found that when participants had to name both these colors, largely overlapping cortical areas showed activation. Crucially, in comparison with hard-to-name colored, perceptual discrimination of easy-to-name colors evoked stronger activation in the left posterior superior temporal gyrus and inferior parietal lobule, two regions responsible for word-finding processes (Luke et al., 2008). When the colors were far away from a category boundary, i.e. more prototypical for that color category, cortical areas involved in word finding were more strongly activated. This finding suggests that the language processing areas of the brain are directly involved in visual perceptual decision, thus providing psychophysical support for the Whorf hypothesis.

From the above study it can be suggested that some interaction exists between language and perception processes. Research conducted by Kay and Kempton (1984) indicates that English speakers judge colors that almost straddle the English semantic category boundary between 'blue' and 'green' as less similar than speakers of Taramuhara, an Uto-Aztecan language of Mexico that, like the majority of the world's languages, uses a single word for these colors (like the Japanese word 'aoi' which can apply to both the 'aoi' (blue) sea and an 'aoi' (green) field of grass). These results suggest that language may affect perceptual discrimination through the spontaneous but unspoken use of lexical codes.

Even though there are differences, there are still strong commonalities across languages in the placement of color boundaries, so the question remains whether observed categorical perception for color can be entirely a result of learned categories or may rely to some degree on innate ones. Tan, Zhou, Mo, Kay, Kwok and Ip (2010) tested whether there is categorical perception for natural, as well as for artificial color categories. In their visual search task the reaction times were shorter in the right than they were in the left visual field when the target and distractor colors, initially sharing the same linguistic term (e.g., 'blue'), became between-category colors after training (i.e., when two different shades of blue had each acquired a new name). These results offer further evidence that color categories are learned, as opposed to being biologically set.

Gilbert, Regier, Kay and Ivry (2006) contributed to the Whorfian debate by stating that if language influenced perception, this effect should be stronger in the left hemisphere than in the right hemisphere, since the human language centre is located in the left hemisphere. Because of the contralateral nature of the brain (stimuli presented in the right visual field are being processed in the left hemisphere (see Figure 1, Gazzaniga and Heatherton, 2006), the location of the language center) a comparison was made between stimuli presented in the right or left visual field. Their results showed that reaction times were shorter when the distractor stimulus and the target stimulus had different color names, but only in the right visual field. When a verbal interference task was given this pattern disappeared, in accordance with the Sapir-Whorf hypothesis. In another research conducted by Drivonikou, Kay, Regier, Ivry, Franklin, Gilbert and Davies (2007) the results of preceeding study were largely replicated. They also found a reduction in reaction times when the target stimuli and distractor stimuli had different color names. However, they also found this effect in the left visual field. These results are support for CP, but not per se for the Whorf effect.

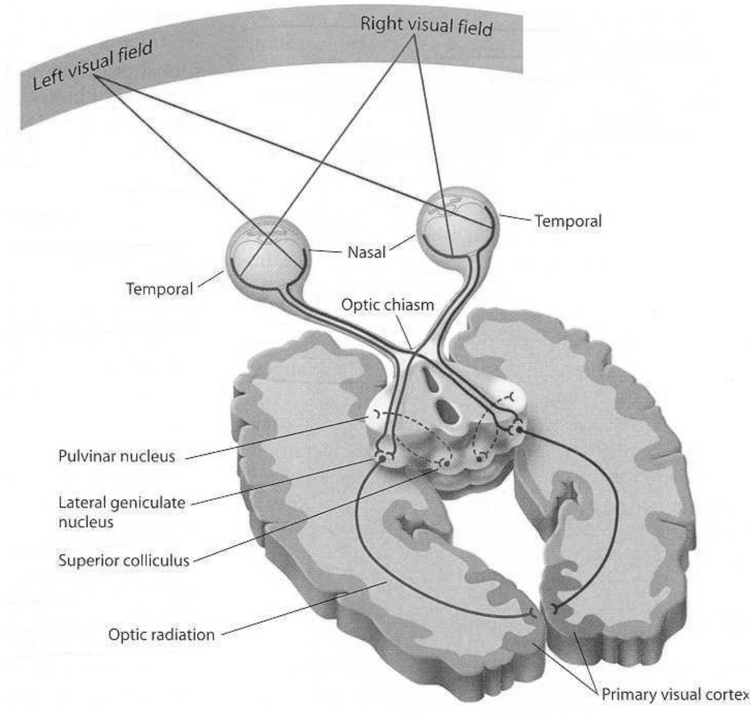

Figure 1. *The visual information from the right visual field is transported through the optic chiasm to the visual processing areas in the left hemisphere and vise versa (Gazzaniga and Heatherton, 2006).*

Sapir-Whorf hypothesis extended

While colors are an elegant and relatively easy tool for finding a language-perception interaction, Whorf's definition of perception was much broader than color. Because of that, some researchers have tried to use other measures of perception. Franklin, Catherwood, Alvarez and Axelsson (2010) tested the Sapir-Whorf hypothesis by using differently orientated lines. They found that when orientations were between-categories, participants were on average faster and more accurate when compared to when the orientations were from the same category. Their results were not in line with the previously discussed experiments: the effect they found was stronger in the left visual field, indicating a right hemisphere bias in adult orientation perception. Moreover, when interference tasks were given, verbal interference did not reduce reaction times for CP for orientations, while the visual interference task did interfere with CP for orientations. These results are inconsistent with the Sapir-Whorf Hypothesis, because a verbal interference task should logically reduce the reaction times of a line orientation task if that task has a lexical component.

In a different research conducted by Gilbert, Regier, Kay and Ivry (2007) a different kind of semantic categories was used. These semantic categories were of a higher, conceptual order when compared to the previously mentioned study (e.g. Franklin, 2010). The semantic categories consisted of two different everyday animals, namely cats and dogs. Visually similar silhouettes of these animals were presented to the participants. The results showed that reaction times were shorter when the distractor stimulus and the target stimulus were of different semantic categories, but, like the previously mentioned study of Gilbert (2006), only in the right visual field as well.

The Sapir-Whorf hypothesis for luminance

Aforementioned research studied the Sapir-Whorf hypothesis in the light of color differences, line orientations and animal silhouettes. The present study is aimed at a different visual perceptual system, the perception of luminance. Nijboer, Nys, van der Smagt and de Haan (2009) reported the case of a woman with severe impairment in brightness perception, while other sensory processing is normal. Nijboer et al. suggested that the specific deficit is of a cognitive level, in this case the level of semantic knowledge. These researchers referred to this as 'brightness agnosia'.

Since color and brightness are two different aspects of visual perception, and one can lose the ability to distinguish colors (for which a Whorf effect exists, (Gilbert et al., 2006)), one can infer that it is possible that one can lose the ability to distinguish differences in brightness. This could mean that there is a Whorf effect for brightness. Brightness is the subjective experience of luminance reflecting off of objects. Instead of luminance however, this research uses contrast as operative measure, since the human perception system is more sensitive to differences in contrast than it is to absolute luminance (Weiskrantz, Kentridge, and Heywood, 2007). Contrast can be defined as the difference in visual properties that makes an object distinguishable from other objects and the background. In luminance perception, contrast is determined by the difference in the brightness of the object and other objects within the same field of view.

The present study tries to extend the Whorf effect to luminance by building on the paradigms already used by earlier researches (e.g. Gilbert et al., 2006, Drivonikou et al., 2007, Franklin et al., 2010, Gilbert et al., 2007). The psychological construct of interest is the language-perception interaction as measured by reaction time, but only for the right visual field. The present study tries to determine if the language regions in the left hemisphere contribute to a faster response when the target stimuli cross the possible lexical category of dark and light. To establish these lexical categories of dark and light, so-called cross-conditions were created in which the contrasts between the target stimuli and the distractor stimuli remained the same, but the luminance values of the target stimulus crossed the luminance values of the background pertaining to the distractor stimulus. Therefore, the absolute contrast distance remained the same, but the illusion of light and dark were created.

Hypothesis

Stimuli at which this luminance boundary is crossed will be detected quicker in the right than in the left visual field. The prediction that cortical language areas in the left hemisphere play a crucial role in visual discrimination tasks is tested by presenting the target stimulus, alternating visual fields. An effect is expected when the target stimulus crosses the boundary between light and dark, but only in the right visual field.

Methods

Participants

A total of 15 students from Utrecht University participated in the experiment, consisting of seven women and eight men. The mean age was 21.5 years (SD = 1.68), the youngest participant was 19 and the oldest participant was 25. Participants were right-handed to make sure that possible differences in brain anatomy between left- and right-handed participants (for example, the incidence of right-hemisphere language dominance was found to increase linearly with the degree of left-handedness, Knecht, Drager, Deppe, Bobe, Lohmann, Flöel, Ringelstein and Henningsen, 2000) could not account for differences in reaction times. They were all native Dutch speakers and, based on self-reports, they were all able to see differences in contrasts. All participants signed an informed consent form at the beginning of the experiment.

Equipment and stimuli

The experiment took place in a darkened room in which a desk, a desktop computer, a monitor, a keyboard, a chair and a chin support, both with adjustable height, were situated. The participant sat on the chair and leaned with his or her chin in the chin support. This served two purposes. First, to prevent head movements and making sure that differences in reaction time (RT) for left versus right visual field are not due to participants seeing one side better than the other. Second, to make sure that the eyes were at the same height as the fixation cross on the monitor. The distance between the monitor and the eyes of the participant was kept constant at 57 cm, to make sure that 1 cm on the screen corresponds with 1° on the retina of the participant. To test the predictions, a visual search task was used, using an Apple desktop computer with Matlab and the Psychophysics Toolbox 3 extensions.

The stimulus consisted of a ring of twelve squares, surrounding a black fixation cross, presented on a gray background (BG). The squares measure 1.95° by 1.95° and the squares were presented on a virtual circle on the middle of the screen with a radius of 5.58°. Figure 2 offers an example of the test situation. The luminance of one of these squares differed from the others, and this one was called the target stimulus (TS). The remaining eleven squares were called the distractor stimuli (DS). The luminance values of the squares were manipulated on each trial, the possibilities are shown in Table 1.

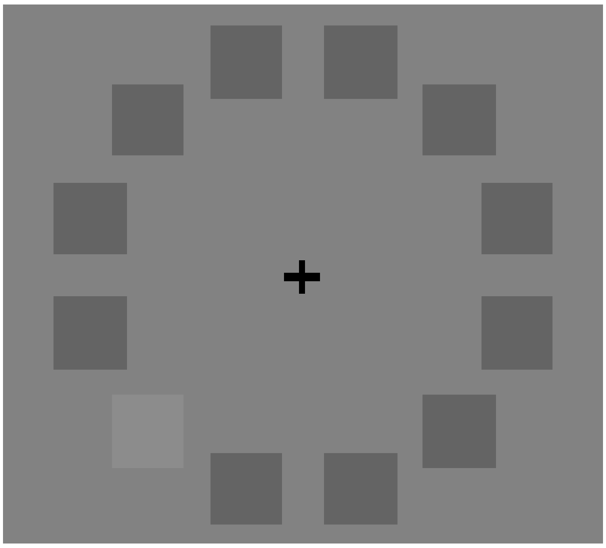

Figure 2. *Example of the Test Situation (Contrasts are Bigger Than in the Original Test Situation).*

Table 1. *Luminance Values for the Different Stimuli, Expressed in Cd/m²*

Background	DS compared to BG	Luminance DS	Luminance TS	
32.2	Darker	DS_A = 27.0	24.3	(outer-condition)
			30.1	(outer-condition)
		DS_B = 30.1	27.0	(not-cross)
			33.4	(cross)
	Brighter	DS_C = 34.5	30.8	(cross)
			38.1	(not-cross)
		DS_D = 38.1	34.5	(outer-condition)
			41.8	(outer-condition)

Three variables were manipulated. The first variable was the luminance of DS. The second variable was the luminance of the TS. The independent variable cross category was being constructed by varying the luminance of DS and TS, as explained below. The third variable was the visual field in which the TS was presented, either left or right.

Luminance values for the DS

To determine the RGB-values for the BG, TS and DS, a luminance meter (Photo Research PR-650) was used. Four different values of luminance were used for the DS, which were randomly alternated each trial: see the third column of Table 1. Weber's contrast was used to calculate the contrast between BG and DS. The aim was to choose the RGB-values so that the contrast in luminance between BG and DS_A is approximately the same as the contrast between BG and DS_D, namely 16-18%. The same holds for the contrast between BG and DS_B and BG and DS_C, the contrasts between these were between 6-7%.

Luminance values for the TS

The luminance of the TS depended on the luminance of the DS. For each DS, two different TS were possible, either brighter or darker. These were called polarities. Which one was presented was randomized per trial: see the fourth column of Table 1. The difference in contrast between a certain DS and the accompanying TS was also kept constant at 10-11% using Weber's contrast. If the DS was darker than the BG, the TS could either be even darker or brighter, but not the same luminance as that of the BG. In some conditions there was also the possibility that the TS exceeded the luminance of the BG: these conditions were the cross-conditions. The same options existed if the DS was brighter than the BG. So, in the eight conditions explained so far, only in two of them the luminance of the BG was exceeded. In these two conditions, the difference in luminance between the mean luminance of BG and DS, and TS was smaller than the difference between BG and TS in the conditions in which the luminance of the BG was not exceeded. So, based on luminance, people were expected to react faster in the conditions not exceeding the BG. If people reacted faster in the cross conditions, it should be explained by another factor.

Task and procedure

The participant was given the instruction to identify if the TS was located on the left or right side of the circle, divided by the vertical meridian. Each trial began with the onset of the central fixation cross. After 500-1000 ms, the circle with eleven DS and one TS appeared around the fixation point. The participant had to respond by pressing the F-key (left) or the J-key (right) on a qwerty-keyboard with their corresponding index finger as fast and accurate as possible. When a response was made, the fixation point and the surrounding circle disappeared. A blank screen was presented for 500 ms. Afterwards the fixation point appeared again to alert the participant of the next trial.

First, the participant was given 32 practice runs with only four squares, to check if the instructions were understood. The experimenter stayed in the darkened room to check the responses made by the participant. After these practice runs, there was an opportunity to ask questions. Once the participant seemed to fully understand the instructions, the real trials were started. Feedback was only provided during the practice runs.

In 8 different conditions (see table 1) multiple TS's could be presented on one of the twelve squares (six left, six right), resulting in 96 possible configurations. These trials were randomized within a single block, and a total of 8 blocks was completed, added up to a total of 768 trials. Between every two blocks the participant was given a resting period of one minute, after which the experiment continued. The whole of the experiment lasted for about 45 minutes. Responses (left or right) and the corresponding RTs were measured and saved for each participant.

Analyses

Due to a technical error, one female participant could not finish the experiment, and only 7 of the 8 blocks were saved and analyzed. Because of the randomization within each block, her trials were equally distributed across conditions.

Only the RTs from the correct responses, in which the response from the participants corresponds with the visual field in which the TS was presented, were taken into account. This was because nothing could be inferred from an incorrect response, since the cause for an incorrect response was unknown, it was impossible to explain and therefore no statements could be made on datasets that include incorrect responses.

Instead of means, medians have been used because of the tendency of RTs to produce not a normal distribution but a slanted distribution, which is not a problem when medians are used, as opposed to when means are. The reduced vulnerability medians have to outliers and to make sure the statistical assumptions were met were two other reasons for the use of medians in this study. These median RTs will be denoted as MRTs. The MRTs in the different conditions were analyzed with a three-way within subjects repeated measures analysis using SPSS 16.0 to test the hypotheses. The variables that were taken into account were cross category, visual field and polarity.

Pre-analyses

Because of the possibility of a confounding effect by certain locations, a statistical test will be performed to check if it was necessary that these locations were eliminated from the dataset. The twelve squares around the fixation cross were given a numerical code of 1 to 12, starting in the lower left corner and heading clockwise, with 1 to 6 on the left side and 7 to 12 on the right side, as can be seen Figure 3. The locations closest to the vertical meridian (locations 1, 6, 7 and 12) might have been more difficult to detect because of their position. The data from these locations might produce a ceiling effect when pooled with the data from the other locations. This would be tested by performing a repeated-measures analysis. In the analysis, the squares that were located on the same vertical axis are combined, because they are at the same distance when compared to the meridian and were located in the same visual field. If sphericity was not assumed, it depended on the estimates of sphericity which correction will be used. If the estimates of sphericity were greater than .75, the Huynh-Feldt correction would be used, otherwise, the Greenhouse-Geisser correction would be used instead (Field, 2005).

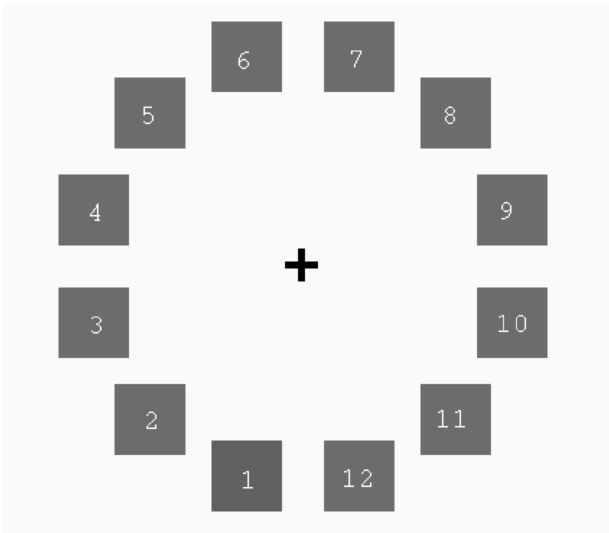

Figure 3. *Locations of the stimuli around the Fixation Cross. The Combinations For Analysis Were 3 and 4, 2 and 5, 1 and 6, 7 and 12, 8 and 11, and 9 and 10.*

Results

Since the aim of the study was to investigate the differences between the cross conditions and not-cross conditions, only the conditions in which the DS is 30.1 of 34.5 Cd/m² (see Table 1), are taken into analysis. Less than 1% of all trials (to be precise, 0.76%) were excluded because of incorrect responses.

As mentioned in the methods, a repeated measures analysis was performed to test for possible confounding effects of location. The results show that the MRTs are significantly affected by the location of the TS, $F(5, 70) = 23.025$, $p < .001$. Contrasts revealed that the MRTs for location 1 and 6 and locations 7 and 12 are significantly longer when compared to the MRTs of the other blocks, as seen in Table 2, in which the mean difference and the significance level are mentioned. Because of the statistical and theoretical support, only locations 2, 3, 4, 5 and 8, 9, 10 and 11 were taken into further analyses.

Table 2. *Mean Differences (in seconds) and Significance Levels between Different Locations*

	Location					
Loc.	3 and 4	2 and 5	1 and 6	7 and 12	8 and 11	9 and 10
3, 4	Mean diff.	.008	-.057*	-.042*	.027*	.022
	α	*.308*	*< .001*	*.001*	*.025*	*.070*
2, 5			-.065*	-.050*	.019	.014
			< .001	*.001*	*.080*	*.207*
1, 6				.016	.084*	.079*
				.210	*< .001*	*< .001*
7, 12					.069*	.064*
					< .001	*< .001*
8, 11						-.005
						.555

Significant at the α = .05 level.

After removing the confounding locations, the main analysis was performed. Based on previous research (Gilbert et al., 2006), it was expected that there is an interaction effect for cross versus not-cross and the visual field in which the TS is presented. Expressed more specific, it states that in trials in which the luminance of the BG lies between the luminance of the TS and the luminance of the DS (see Table 1, the conditions which are labeled 'cross'), it will be detected quicker in the right than in the left visual field. The results show that the MRTs for cross conditions were significantly lower (*M* = .570, *SD* = .022) than the MRTs for not-cross conditions (*M* = 628, *SD* = .023), which means that there is a significant main effect for cross category, *F*(1, 14) = 14.656, *p* = .002. No significant main effect was found for visual field. The MRTs for left visual field (*M* = .608, *SD* = .023) does not differ from the MRTs for right visual field (*M* = .591, *SD* = .020), *F*(1, 14) = 2.827, *p* = .115. An interaction effect between cross category versus visual field of the TS was not found, *F*(1, 14) = 0.264, *p* = .615, Wilks' Lambda = .981. In other words, visual field does not appear to have an influence on performance in cross category. These conditions are shown in Figure 4.

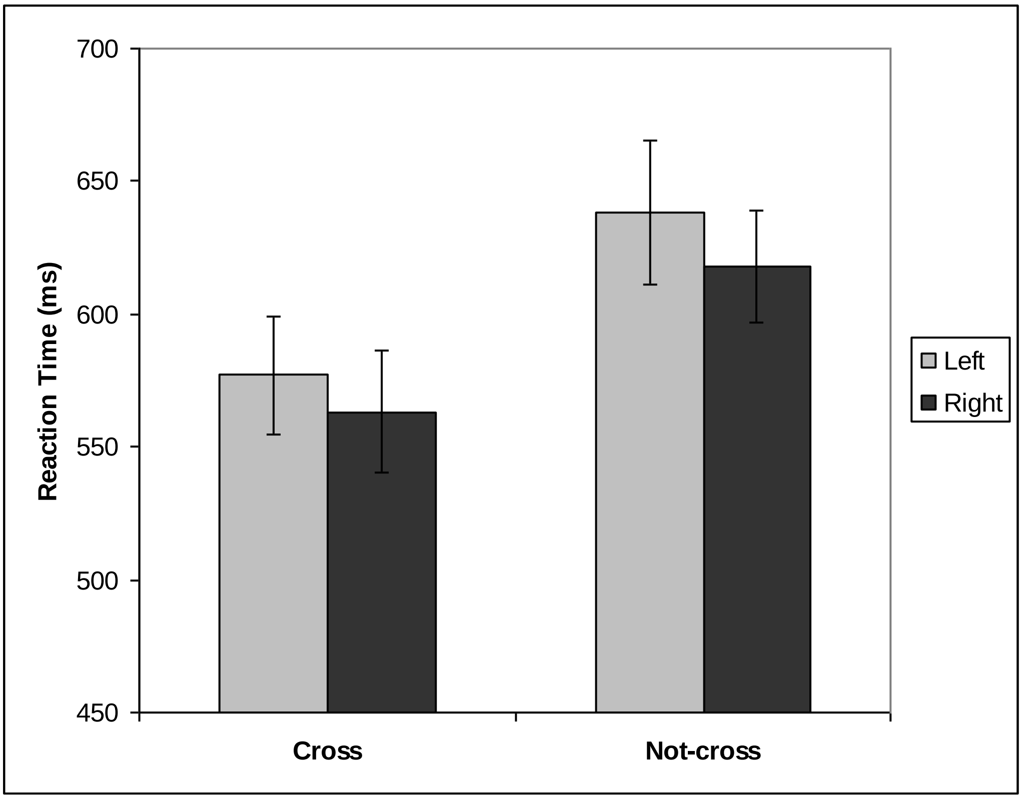

Figure 4. *The difference in cross versus not-cross for left and right in reaction times. Error bars indicate standard error of the mean.*

Polarity

Surprisingly, a main effect was found for polarity. The results show that the MRTs for the conditions in which the TS is brighter than the DS are shorter (M = .577, SD = .020) than the MRTs for the conditions in which the TS is darker than the DS (M = .621, SD = .023). This difference is significant, $F(1, 14) = 17.857$, $p = .001$. There also was a significant interaction effect between cross category and polarity, $F(1, 14) = 8.391$ and $p = .012$, Wilks' Lambda = .625. This means that the polarity does not make a difference for the cross conditions, but that it does for the not-cross conditions. The interaction between polarity and cross category is shown in Figure 5. No significant interaction effect was found between polarity and visual field, $F(1, 14) = .007$, $p = .936$, Wilk's Lambda > .999. The 3-way interaction between polarity, cross category and visual field was not significant, $F(1, 14) = 1.917$, $p = .188$, Wilks' Lambda = .880.

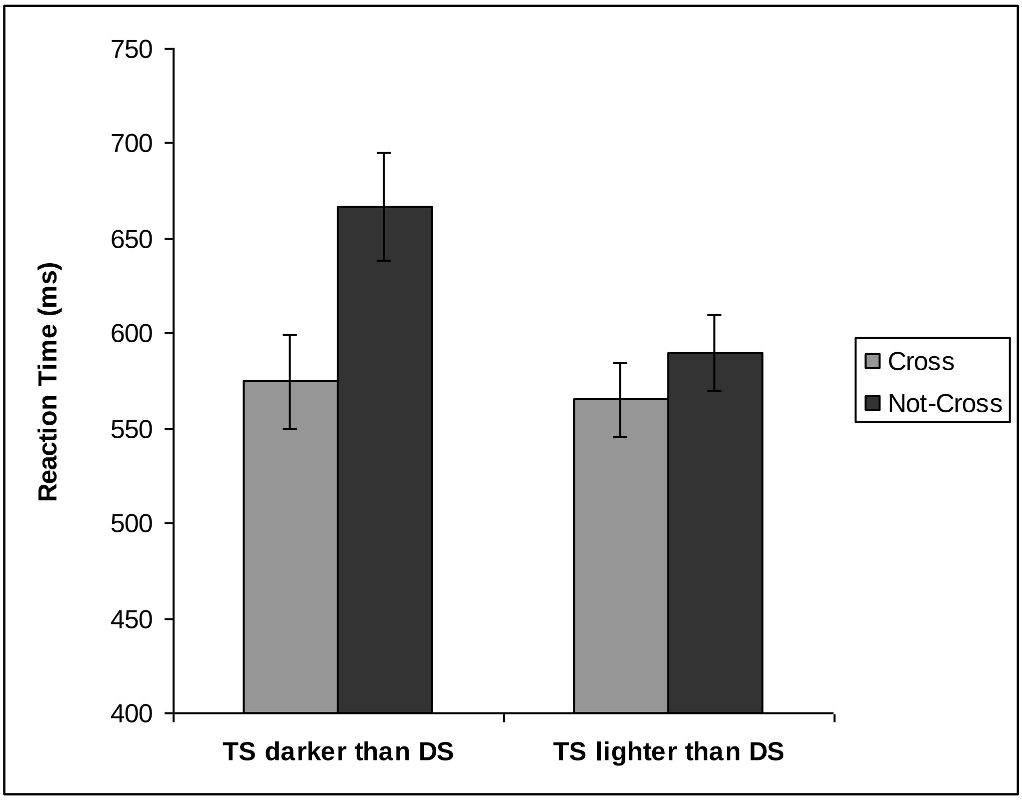

Figure 5. *Average MRT for cross versus not-cross by different polarity signs. Error bars indicate standard error of the mean.*

Outer conditions

To check if there is a main effect for polarity without the influence of cross category, an analysis was performed with only the outer conditions (see Table 1). Because of incorrect responses, 1.79% of the trials were excluded from the analysis. The results show that the MRTs for the conditions in which the TS is brighter than the DS are shorter (M = .961, SD = .307) compared with the conditions in which the TS is darker than the DS (M = 1.212, SD = .421). This difference is significant, $F(1, 14)$ = 19.339, p = .001, which means that the effect of polarity can be extended to the outer conditions.

Discussion

The hypothesis proposed in the introduction was that conditions in which the target stimuli cross the possible lexical boundary will be detected quicker in the right when compared to the left visual field. An interaction effect was expected between the cross conditions and the visual field in which the target stimuli was presented. The median reaction times were expected to be shortest for cross categories in the right visual field. Furthermore it was expected that median reaction times for target stimuli close to the meridian are longer than median reaction times for stimuli further from that meridian, which was confirmed by the results.

The results show that the median reaction times for the cross conditions were shorter than the median reaction times for the not-cross conditions. Because of the luminance contrasts between distractor stimuli and target stimuli were kept constant, categorical perception appears to be responsible for this effect. Visual field did not influence the median reaction times, and the interaction effect between cross versus not-cross and visual field was not found.

Interestingly, a main effect was found for polarity. An interaction effect between cross category and polarity was also found: polarity does make a difference for not-cross categories, but the median reaction times in the cross categories are quite similar irrespective of polarity. No interaction was found between polarity and visual field. Also, no interaction was found between polarity, cross category and visual field.

Lastly, it turned out that median reaction times were shorter when the target stimuli were brighter than the distractor stimuli, compared with conditions in which the target stimuli were darker than the distractor stimuli. This was independent of the luminance value of the distractor stimuli, indicating that brighter targets are easier to detect than darker targets.

The present study found no interaction effect, which can be interpreted in different ways. First of all, it could be stated that the Whorf effect simply does not exist for contrasts in luminance: the Sapir-Whorf hypothesis states that language affects perception (Luke et al., 2008). Originally, Whorf did not include hemispheric laterality in his theory, so it is a possibility that the categorical perception found in the current research can be contributed to the Whorf effect. Given that especially the left hemisphere is responsible for language (Gilbert et al., 2006) and that language should only affect the median reaction times in cross categories, an interaction effect should be a reasonable assumption. The reason that no interaction effect was found could be attributed to language not being a mediating factor for luminance contrasts after all.

However, target stimuli were detected faster in the cross-conditions than in the not cross-conditions, indicating categorical perception for luminance differentiation. This does not mean that a Whorf effect can be excluded: maybe there is another explanation why there is no difference between left and right hemisphere. It might be that the Whorf effect occurs, but that there are other processes in the right hemisphere that obscure the Whorf effect so that the difference in reaction times between the left and right visual field disappears. A possible explanation might be offered by the patient with brightness agnosia (Nijboer et al., 2009). The patient with brightness agnosia had extensive brain damage in her right hemisphere. One could speculate that brightness categorization might be localized in the right hemisphere, which could downplay the Whorf effect in the left hemisphere. However, since a patient is atypical by definition, this does not mean that brightness categorization is lateralized to the right hemisphere in healthy controls. It should be noted, though, that this is speculation and therefore not conclusive. In the current literature, there is no available information about the lateralization of brightness perception. In short, this means the Whorf effect might have occurred, since it is not the only process responsible for luminance differentiation.

Another interpretation is that the hypothetical semantic categories, created by the background luminance in this research, were of a different luminance than the actual semantic categories the humans might possess, meaning the luminance values used in this study are not equal to the semantic definitions of 'light' and 'dark'. If language does not influence brightness perception, the background luminance also accounts for the lack of a main effect for visual field: it would be expected that if language did influence brightness perception the median reaction times in the right visual field for the cross categories would be shorter.

As stated above, there is a main effect for cross category. This is quite unexpected, because based on luminance alone (without taking language into account), one would expect that the median reaction times for the not-cross conditions should be shorter, if anything. This is because the difference between the average luminance on screen (background + distractor stimulus) and the target stimulus were larger for the not-cross conditions than the cross conditions. Since humans are more sensitive to contrast than they are to absolute luminance (Weiskrantz et al, 2007), exceeding the background luminance might create an illusion of a bigger contrast than is actually the case. This is an illusion because the contrasts between the distractor stimulus and accompanying target stimulus were kept constant throughout all the trials.

Interestingly, a main effect was found for polarity. If the luminance of the target stimulus was brighter, the median reaction times were shorter when compared to the condition were the target stimulus is darker than the distractor stimulus, but only in the not-cross conditions. The longer reaction times for darker luminances in the not-cross conditions might be due to the use of too dark luminances throughout the present research: if all luminance values were to be a bit brighter there might not have been an effect for polarity.

Summary and conclusion

In summary, there are three possible explanations for the results found in this research. The first is that light and dark are not semantic categories, which indicate language does not influence the perception of luminance. The second explanation is that there are processes in the right hemisphere that might downplay the Whorf effect. The third explanation is that the luminance values used in this research are not at the correct level. This third explanation offers a recommendation for further research. The conducted research could be repeated, with a different luminance value for the background, and correspondingly different luminance values for the distractor stimuli and target stimuli.

This research does not state that there is no link between perception and language at all. Revisiting the Sapir-Whorf debate, it can be stated that there is an interaction between language and color perception (Gilbert et al., 2006 and Regier and Kay, 2009) On the contrary, Drivonikou et al. (2007) found no effect for hemisphere (and thus for a language interaction). Franklin et al. (2010) suggests an opposite Whorf effect, namely that categorical perception for line orientation takes place in the right hemisphere. Based on this study, the Whorf effect is not the sole contributor for categorical perception of luminance. Therefore, the Sapir-Whorf hypothesis cannot be extended to include differentiation of luminance.

References

Blake, R. and Sekuler, R. (2006). *Perception*. McGraw-Hill Companies: New York (5th edition)

Drivonikou, G., Kay, P., Regier, T., Ivry, R., Franklin, A., Davies, I. (2007) Further evidence that Whorfian effects are stronger in the right visual field than the left. *Proceedings of the National Academy of Sciences of the United States of America* 104, 1097-1102.

Field, A. (2005). *Discovering Statistics Using SPSS*. SAGE Publications: London (2nd edition).

Franklin, A., Catherwood, D., Alvarez, J., Axelsson, E. (2010). Hemispheric asymmetries in categorical perception of orientation in infants and adults. *Neuropsychologia* 48, 2648-2657.

Gazzaniga, M. S., Heatherton, T. (2006) *Psychological Science: Mind, Brain, and Behavior*. W. W. Norton: New York, (2nd Edition).

Gilbert, A., Regier, T. Kay, P., Ivry, R. (2006) Whorf hypothesis is supported in the right visual field but not the left. *Proceedings of the National Academy of Sciences of the United States of America* 103, 489-494.

Kay, P., Kemtpon, W. (1984) What Is the Sapir-Whorf Hypothesis? *American anthropologist* 86, 65-79.

Knecht, S., Dräger, B., Deppe, M., Bobe, L., Lohmann, H., Flöel, A., Ringelstein, E.-B. and Henningsen, H. (2000). Handedness and hemispheric language dominance in healthy humans. *Brain*, 123, 2512-2518.

Loftus, G. R., and Masson, M. E. J. (1994). Using confidence intervals in within-subjects designs. *Psychonomic Bulletin & Review*, 1, 476-490.

Luke, K., Tan, L., Chan, A., Kay, P., Khong, P, Yip, L. (2008). Language affects patterns of brain activation associated with perceptual decision. *Proceedings of the National Academy of Sciences* 105, 4004-4009.

Nijboer, T. C. W., Nys, G. M. S., van der Smagt, M. J. and de Haan, E. H. F. (2009). A selective deficit in the appreciation and recognition of brightness: Brightness agnosia? *Cortex*, 45, 816-824.

Regier, T., Kay, P (2009). Language, thought, and color: Whorf was half right. *Trends in Cognitive Sciences* 13, 439-446.

Tan, L., Zhou, K., Mo, L., Kay, P., Kwok, V., Ip, T. (2010). Newly trained lexical categories produce lateralized categorical perception for color. *Proceedings of the National Academy of Sciences of the United States of America* 107, 9974-9978.

Weiskrantz, L., Kentridge, R. and Heywood, C. (2007). Color contrast processing in human striate cortex. *Proceedings of the National Academy of Sciences of the United States of America* 104, 15129-15131