Decline of the McCollough effect by orientation-specific post-adaptation exposure to achromatic gratings ☆

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Abstract

The McCollough effect is a contingent color after effect induced by adapting to colored gratings for several minutes. It has been demonstrated that a long-lasting adaptation effect such as the McCollough effect can be diminished by exposure to achromatic versions of the induction stimuli. However, the orientation specificity of this effect of post-adaptation exposure is not known. Here we report the findings from two experiments conducted to determine the influence of achromatic gratings and their orientation on the strength of the McCollough effect. After adaptation to the McCollough stimuli, participants were exposed to achromatic gratings or to one of two control conditions (either waiting in the dark or different-orientation achromatic gratings). Results suggest a significant decline of the McCollough effect after perceiving achromatic gratings in comparison to waiting in the dark or being exposed to different-orientation achromatic gratings. Thus, the effect of post-adaptation exposure to achromatic gratings is orientation specific.

Keywords: McCollough effect, adaptation, after effects, color vision

1. Introduction

The McCollough effect (ME) is a contingent color after effect induced by adapting to colored gratings for several minutes (McCollough, 1965, 2000).

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For example, a horizontal grating may be paired with green, alternating with a vertical grating paired with magenta. Following this adaptation procedure, achromatic gratings of the same orientation will appear tinted with weakly saturated hues approximately complementary to those paired with each orientation during the induction process. In the example above, the gray portions of vertical gratings would appear slightly green and the gray portion of horizontal patterns would appear slightly pink. However, when the orientations of the gratings were rotated 45°from the adapted orientations, no color after effects were reported. Here we investigate whether a similar orientation specificity is observed for the decline in the McCollough effect induced by the post-adaptation exposure to achromatic gratings.

One of the most interesting aspects of the ME is its longevity, relative to the time it takes to build up of the effect. A recent study performed by Vul et al. (2008) suggests two separable timescales of adaptation: a quick adaptation (supported by a short timescale) and a slow decay (supported by a long timescale). The 30-second (fast) timescale appears to be consistent with classic contrast adaptation dynamics. The “infinite” (slow) timescale is responsible for the long-lasting characteristic of the McCollough effect and it is presumably this permanent component that has been measured in classic studies of the persistence of the McCollough effect (ME). The interpretation of Vul et al. (2008) of this “infinite” timescale is that the de-adapting stimuli are encountered very rare in the world. Hence, the longevity is a consequence of the lack of a de-adaptation opportunity.

Several studies in the past have examined how de-adaptation influences the decay characteristics of the ME (MacKay & MacKay, 1974; Skowbo et al., 1974; McLoughlin, 2005). Skowbo et al. (1974) demonstrated that a prolonged exposure to achromatic patterns similar in spatial composition to the induction stimuli causes the ME to decay unusually fast in comparison to other visual stimuli such as colored homogeneous fields, natural visual stimulation or complete darkness. These results were replicated in several studies with different control conditions (White & Graves, 1976; Skowbo & Clynes, 1977; Skowbo et al., 1985; Skowbo, 1988). However, since as far as we know none of these studies included the most stringent control condition of achromatic gratings with a different orientation than the induction stimuli, these studies cannot exclude the possibility that the decay of the ME is caused by the exposure to gratings per se, whether it is the same orientation as the adaptation stimuli or another orientation. Here we investigate this issue in two experiments in which we first replicate the basic result found by previous studies that post-adaptation exposure to gratings reduces the ME, and then test whether there is a difference between same orientation gratings or opposite orientation gratings as post-adaptation stimuli.

2. General Methods

2.1. Equipment and participants

We conducted both experiments at the University of Leuven (K.U. Leuven) with undergraduates and graduates. Sixteen participants (mean age = 23.62, standard deviation = 2.20; including 6 males) participated in the first experiment and sixteen participants (mean age = 23.31, standard deviation = 1.45; including 4 males) participated in the second experiment. All participants were naïve to the purpose of the experiment and each participant participated in only one of the two experiments. We used a pc computer running Windows XP to run the experiment. To present the stimuli we used a gamma corrected monitor set to a resolution of 1024 x 768 at a refresh rate of 85 Hz. Participants carried out the task in a dark room for the entire duration of both experiments. The ethical committee of the Faculty of Psychology and Educational Sciences approved the procedures and we obtained written informed consent from the participants.

2.2. Testing Procedure

We presented an adaptation stimulus for 5 seconds, followed by a one second fixation cross during the adaptation phase. The adaptation phase lasted 10 minutes. Afterwards, an one minute rest period followed during which the participants waited in a dark room to avoid possible retinal after effects. We presented achromatic gratings for 750 milliseconds and these were followed by a 250 milliseconds fixation cross.

We used two grating orientation sets: cardinal (horizontal and vertical) and oblique (45°and 115°). The adaptation and achromatic gratings were 2.5 cycles/degree and subtended a total of 15°visual angle horizontally and 20°of visual angle vertically (Figure 1). The adapting grating colors were always red and green with following CIE xyY color space coordinates: red (0.402, 0.233, 70) and green (0.318, 0.631, 70). The achromatic gratings were black (0.316, 0.419, 17.8) and gray (0.357, 0.148, 70) corresponding with the background. We counterbalanced the color-grating pairings (e.g. vertical with pink and horizontal with green) across participants. We separated the two

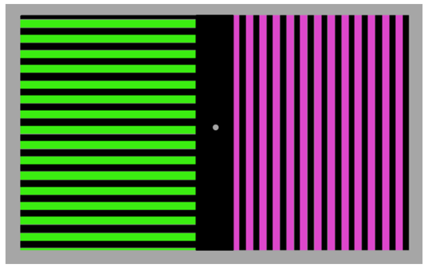

Figure 1: An example of an adaptation stimuli with the cardinal grating orientation set.

gratings by a black bar located across the center of the screen and it subtended a total of 3°visual angle horizontally and 20°of visual angle vertically. The two gratings appeared adjacent to the black bar, either on the left or the right half of the gray background which was randomly chosen for each trial. We opted to randomly select the phase of each adaptation or test grating in every individual trial.

The post-adaptation phase followed the adaptation phase, in which participants were exposed to a visual stimulation (waiting in the dark or gratings) (Figure 2). After each adaptation post-adaptation (APA) sequence participants matched the color of the after effect. Participants matched the colors by adjusting RGB values of a circle below a test grating by pressing one of three buttons (changing the color dimension (red/green/blue); less color in current color dimension; and more color in current color dimension). When the color of the circle matched the color of the after effect in the test grating participants pressed the stop button. We trained the participants in the color matching task before the experiments were started. In order to minimize carry-over between two adaptation periods, we alternated the orientation set (cardinal or oblique) between successive adaptation periods. All conditions (orientation-color pairing, oblique or cardinal adaptation and/or post-adaptation and whether the wait/opposite grating condition occurred in the first or second run) were counterbalanced across participants.

3. Experiment 1

The goal of Experiment 1 was to test whether intervening stimulation with gratings influences the strength and the duration of the ME. Two different post-adaptation conditions were presented to each participant and each

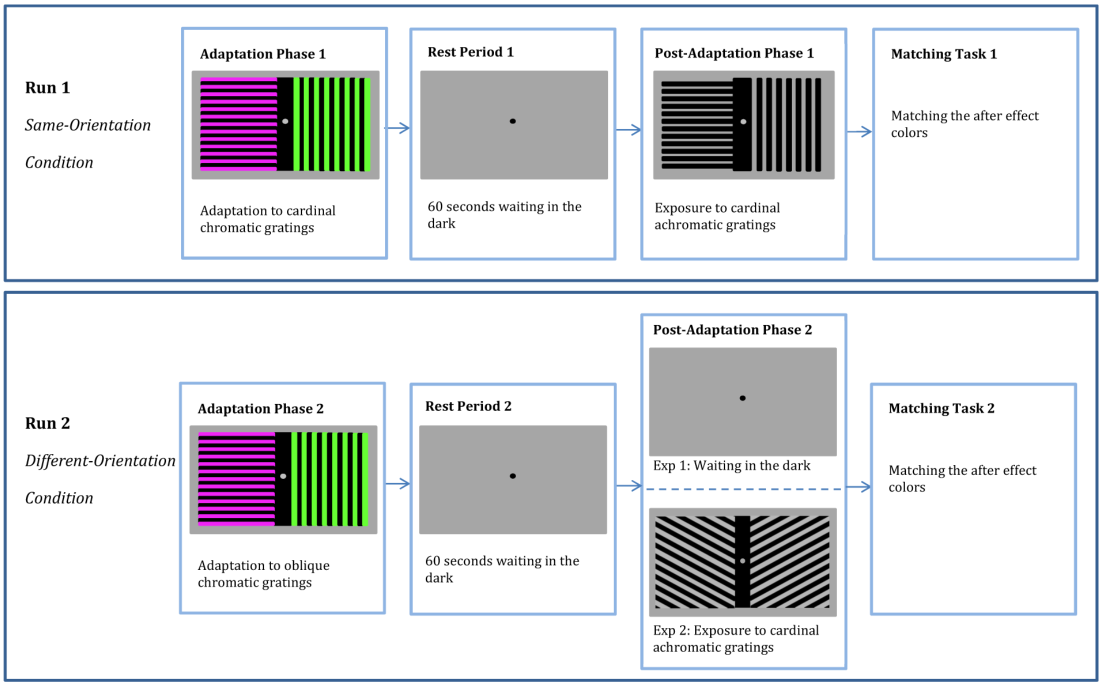

Figure 2: Overview of an example of the two runs of both experiments. All participants completed both runs, with the order of runs counterbalanced across participants.

condition was followed by a matching task.

3.1. Methods

We presented two adaptation periods and each adaptation period was followed by a wait condition (a gray screen was presented) or a same-orientation achromatic grating condition (test gratings with the same orientation as the adaptation stimuli; e.g. cardinal chromatic gratings as adaptation stimuli and cardinal achromatic gratings as post-adaptation stimuli) (Figure 2). Half of the participants were exposed to the short version of the task, namely an post-adaptation phase of 2 minutes. The post-adaptation phase of the other half of the participants lasted for 5 minutes. A matching task (for more details, see section 2) followed after each APA sequence.

3.2. Results

The RGB values of the matched colors of the participants were transformed to CIE xyY values. The Euclidian distance between the two matched after effect colors was calculated in the CIE xyY space for each condition and represented the after effect strength. We analyzed the data as a repeated-measures ANOVA with the duration of the post-adaptation conditions as between-participant factor and as within-participant factor the wait versus same-orientation achromatic grating condition (Figure 3). There was a significant main effect of the post-adaptation condition ($F(1,14) = 10.01$, $p = 0.007$), which showed that the after effect strength was smaller when same-orientation achromatic gratings were presented after adaptation in comparison to the wait condition. There was no significant main effect of duration ($F(1,14) = 0.03$, $p = 0.871$) and no significant interaction effect of the duration with the post-adaptation condition ($F(1,14) = 2.32$, $p = 0.15$).

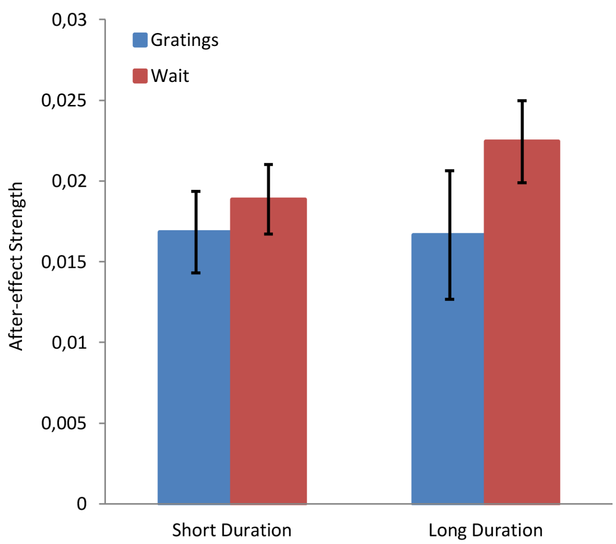

Figure 3: Assessed McCollough effect strength. The heights of the bars are means over participants for all conditions with the error bars representing the standard error of the mean. The after effect strength is the mean over participants for each condition.

3.3. Discussion

The results of Experiment 1 show that the decay of the ME is accelerated when exposing participants to achromatic gratings that contain the

same orientation as the adaptation stimuli of the ME, in comparison to having minimal visual stimulation after adaptation. The distance between the two matched colors was smaller in the same-orientation achromatic gratings condition than in the wait condition. These results are a clear replication of previous studies (Skowbo et al., 1974; White & Graves, 1976; Skowbo & Clynes, 1977; Jones & Holding, 1975).
The tendency of a greater difference between exposure to same orientation achromatic gratings and the control condition in the longer post-adaptation duration was present, but it was not significant. An enlarged decay of the ME with a longer exposure to achromatic gratings was previously observed by Skowbo & Clynes (1977). However, they did not report any statistics to test whether this tendency was significant in their experiments.

4. Experiment 2

The results of Experiment 1 demonstrate that exposure to test gratings after the adaptation phase decreases the ME. However, this observation by itself does not tell us which aspect of the gratings determines this decrease. We therefore repeated Experiment 1, but replacing the wait condition with an different-orientation achromatic grating condition. In the different-orientation achromatic grating condition participants were exposed to test gratings with a grating orientation different from the adaptation gratings.

4.1. Methods

We again presented two runs to the participants, each run starting with a 10 minutes adaptation period (Figure 2). Afterwards a same-orientation achromatic grating condition or an different-orientation achromatic grating condition followed. We opted for a 5 minutes lasting post-adaptation conditions since results in Experiment 1 suggested that the effect was enlarged (though it was not significant) when the post-adaptation period was longer. Both experimental phases ended with the participant matching the after effect colors.

4.2. Results

After transforming the RGB values of the matched after effect colors to CIE xyY values, the Euclidean distances between the two matched after effect colors were again calculated for each condition, resulting in two after effect strengths for every participant. A paired t-test was performed to determine whether presenting gratings at itself or presenting test gratings influenced the ME (Figure 4). The after effect was weaker after being exposed to same-orientation achromatic gratings than when participants perceived different-orientation achromatic gratings after being adapted to the ME ($t(15) = 2.996$, $p = 0.009$).

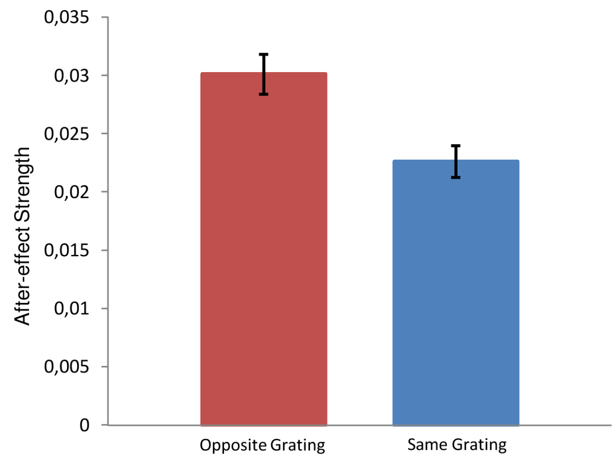

Figure 4: Assessed McCollough effect strength. The heights of the bars are means over participants for each condition. Error bars represent one S.E.M.

4.3. Discussion

The distance between the two matched colors after exposure to different-orientation achromatic gratings was significant larger than after exposure to same-orientation achromatic gratings. These results suggest that a ME deprivation by perceiving achromatic gratings only occurs when the gratings have the same orientation as the gratings used during the adaptation phase. These results are consistent with those of Vul et al. (2008) who did not find any evidence of decay of the after effect when other gratings intervene after adaptation. However they did not included the same-orientation achromatic grating condition.

5. General Discussion

We showed that the rate of decay of the ME can be enlarged by post-adaptation stimulation in a manner that is specific to the orientation of the post-adaptation stimuli. If achromatic gratings with the same orientation as the orientation of the adaptation gratings are presented, the resulting after effect is reduced compared to when achromatic gratings with opposite orientation or minimal visual stimulation presented. These results are in line with previous research on the ME (Skowbo et al., 1974; White & Graves, 1976; Skowbo & Clynes, 1977; Jones & Holding, 1975; Vul et al., 2008), although it is the first time that the role of orientation specificity is directly tested.

It is important to note that the orientation-specific decrease of the ME is not permanent. Previous ME research has already shown that the decay of the ME caused by exposure to achromatic gratings, does not affect the strength of the after effect in the long term. Multiple studies found that a resting period after post-adaptation stimulation results in a similar difference in the strength of the after effect when comparing between the condition of achromatic gratings with same orientation as adaptation stimuli and other visual stimulation conditions (White & Graves, 1976; Skowbo & Clynes, 1977). Hence, after a period with no visual stimulation there is a spontaneous recovery of the diminished ME caused by achromatic gratings stimulation. To conclude, the effect of post-adaptation interference is probably mostly a temporary disruption of the continual process of decay of the ME; and the ME decay ultimately returns to its normal course (Skowbo, 1988).

This suggests that the rapid decay of the ME seen in the studies of Vul et al. (2008) and described by Vul et al. as a cause of the fast timescale, actually could also be a consequence of the repeated exposure to achromatic gratings with the same orientation as the adaptation gratings. It is important to emphasize that this does not suggest that there is no fast timescale and infinite timescale to the ME, but only that there are also other mechanisms characterizing the specific decay of the ME.

There has been much discussion in the literature during the last three decades about the possible nature of such other underlying mechanisms (Skowbo, 1984; Skowbo & Forster, 1983; Siegel et al., 1992; Westbrook & Harrison, 1984; Savoy, 1984; Humphrey et al., 1998). At first Skowbo et al. (1974) suggested that the rapid decay of the ME caused by achromatic gratings supported the idea that the ME is based upon a learning process. Namely, if the after effect of color is considered as a conditioned response, it is possible that line orientation acts as a conditioned stimulus which becomes associated with adaptation in color units. The rapid decay of the ME can then be described as the extinction of a learned response. Recently, a number of neuropharmalogical studies have suggested that the cholinergic limbic system is involved in both the induction and extinction of the ME (Byth et al., 1992, 2000). While this explanation in terms of conditioning seemed promising at first sight, some characteristics of the ME differ significantly from certain characteristics of conditioning. For example, de-adapting the ME in one eye is not transferred to the other eye (Savoy, 1984).

A good explanation of the ME is given by Dodwell & Humphrey (1990). Dodwell & Humphrey (1990) state that MEs serve the adaptive function of maintaining correspondence between general properties of the physical environment and their internal representation. Hence, MEs are due to changes in adaptation level, but changes that are contingent on other stimulus features. Namely, during induction of ME a particular orientation (e.g. vertical) is paired with a specific color (e.g. red) over a period of several minutes. This results in a shift of the 'neutral point' for red towards the over-represented end of the red color continuum, in the presence of verticals. So, when achromatic vertical gratings are represented the 'neutral point' has been shifted toward the red so that the grey light (which was previously neutral) is now on the green side of the color continuum (Dodwell & Humphrey, 1990). When then, for several minutes achromatic gratings with the same orientation as the adaptation stimuli are presented, the 'neutral point' for red can be shifted again to its normal level and the ME diminishes. Our current finding that the effect of post-adaptation exposure to achromatic gratings is orientation-dependent is consistent with this explanation.

To conclude, we have shown a clear influence of achromatic gratings containing the same orientation as adaptation gratings on the rate of decay of the ME. These findings complement the literature on the ME in that we showed that achromatic gratings by themselves do not suffice to cause this enlarged decay of the ME.

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