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LIGHTNESS CONSTANCY: OBJECT IDENTITY AND TEMPORAL INTEGRATION

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Studies of lightness constancy typically involve the comparison of two objects of the same shade that have been placed under different illuminations. In this study, we introduce factors such as object identity and immediate prior experience to measure the effect of these manipulations on constancy.

In the first experiment, conditions sufficient to reproduce classical constancy failure (illumination difference, target values, articulation level) were determined.

In the second experiment a lightness judgment was made for a grey target that was then seen to move into another illumination level for the second match. Motion was used in an attempt to stress the target's identity. The shade was still judged significantly lighter when placed under the higher than under the lower illumination. Failure of constancy thus occurred even when object identity was not in question.

In the third experiment a priming paradigm was used, to assess the strength of constancy: one shade would appear in one illumination level and another shade in the other illumination level. Motion was used to trick observers into thinking that only a single object was presented. The estimated shade varied as a function of the shade of the prime.

In the last experiment, observers were asked to make another match when the object was removed from view: the match of its true color independent of illumination. The value of this match-from-memory was based on the value obtained in the higher illumination level.

Taken together, the experiments show that through object identity, immediate prior experience can influence lightness in systematic fashion.

Key words: *Lightness, Constancy, Illumination levels, Color perception, Priming.*

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Due to visual phenomena called *constancies,* we perceive a stable world with recognizable objects, independent of ever-changing viewing conditions. A projection of an object is shrinking as a function of increased distance, however there is no difference in perceived size of a person walking away from us. This is size constancy. Similarly, shape changes with viewpoint angle: when viewing plates of acircular shape, we are mostly exposed to elliptical projections. But there is never an ellipse in our precept. This is an example of shape constancy. Relevant viewing condition in color perception is illumination level, but thanks to the color constancy we do not perceive a color change every time illumination alternate.

It might seem that objects should be perceived and learned independent of viewing conditions, after all, they did not really change. Nevertheless this phenomenon represents a hard problem for vision science. Namely, the system does not have direct information about the non-changing object but only its retinal projections, which are based on variable viewing conditions.

The present study focus on a form of color constancy, called lightness constancy. Color has three dimensions: hue (corresponds to different wave lengths: yellow, blue, green), saturation (amount of gray in a shade: magenta vs. maroon) and lightness (achromatic variation: level of gray shades from black to white). Just as with other object properties, the visual system does not perceive color directly, rather the information is carried in the beam of light reflected by the object. The intensity of light coming to the object multiplies with the object's lightness to create luminance, the intensity that would reach the eye. As mentioned, the current illumination level represents a variable viewing condition. As a consequence of this arrangement, two identical grays, one in a spotlight, one in shadow, will send different amount of light to the eye but they will produce identically gray percepts.

These phenomena were quickly noticed by early scholars, color constancy first being described by Monge in 1789 (as cited in Mollen, 2006). Lightness constancy was described and investigated in detail by authors such as Katz (1911, 1935) and Koffka (1932). It immediately became obvious that the visual system must use relations in the scene in order to perform lightness constancy (e.g. Koffka, 1932). In his classical paradigm Katz would put identical shades under different illumination levels and have observers compare them. The exact measurements showed that the constancy was not always perfect as it would seem from everyday experience. Katz described one of the crucial factors in the scene, *articulation*. Articulation represents the number of surfaces within a field of illumination. In a very well articulated scene, constancy is 100%. As articulation deteriorates, constancy fails. An extreme case of a non-articulated scene is a void. Gelb (1929) showed that even the darkest shade presented alone in a void and singularly illuminated appears white, exhibiting 0% constancy. Starting from Gelb's condition, Cataliotti and Gilchrist (1995) demonstrated that constancy could be enhanced by adding more surfaces in the field of illumination.

However, more recently we have begun to understand that it is not the number of surfaces that enhanced constancy: rather this is an artifact of a different process. Namely, articulation makes a field of illumination into a strong frame of reference, which highly influences lightness of a target. Arroyo et al. (1995) showed that a middle gray target embedded in a highly articulated Mondrian presented in a spotlight appears white, a nuance lighter than a coplanar white patch in the ambient illumination. Hence, in such set up, a strong frame of reference led to poor constancy.

There are two current anchoring models, Gilchrist (1999) and Bressan (2006), which base their theories on these previous findings and on tradition of Gestalt psychology in general. Although the models differ in certain points, they are based on a common idea that the lightness of each surface in the scene is observed in relation to an anchor. The anchor of the scene is the surface of the highest luminance, which additionally must cover a significant portion of the scene. This anchor will appear white and every other surface will be seen relative to it. Finally, both models predict a high degree of constancy in everyday situations with articulated scenes that contain surfaces of all shades.

These anchoring models and gestalt theory in general, insist that everything needed to perceive a target is given in the scene. Target lightness will always be estimated solely based on its relation to other surfaces. Some of those other surfaces, such as anchors, coplanar or adjacent fields and objects under the same illumination level, are more important for target estimation. But only in the sense that their luminance value will have a stronger affect on the target.

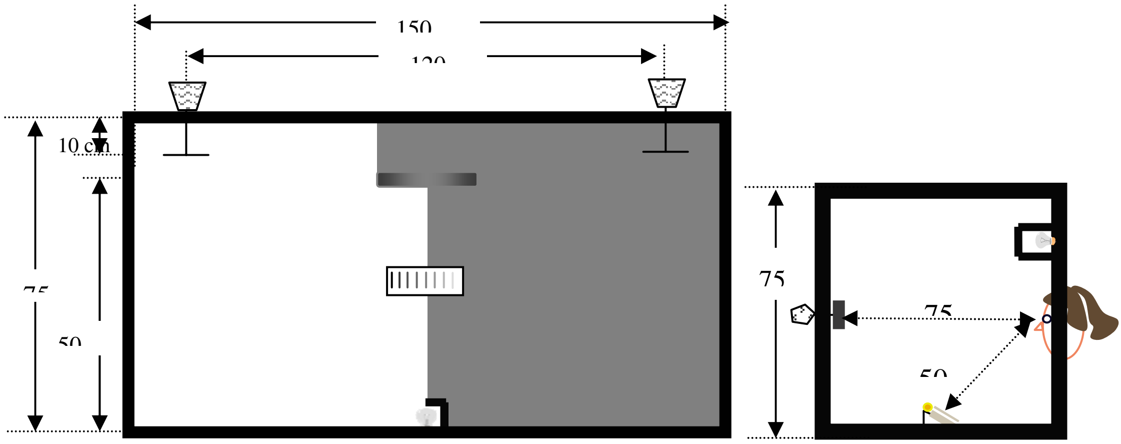
In summary, anchoring models can explain, with a limited number of rules, a wide range of lightness phenomena, illusions and constancy.

Would this type of explanation still hold if something as important as object identity is introduced? In the classic experiments, the two targets in different illumination are of the same shade but they are two independent objects. In everyday experience, constancy holds very well because we see familiar object move from one illumination level to another. This is exactly what has been done in the present experiments. In a setup that produces constancy when two objects are presented independently, a single object was moved from one illumination level to another. Would observer still make lightness matches based on luminance ratios in each illumination level or would the object identity enhanced constancy?

EXPERIMENTS

Subjects. Subjects were all first year undergraduate students of psychology, naïve to the purpose of the experiment and experimental manipulations. All of them had normal or corrected to normal visual acuity and normal color vision.

Figure 1. a) The top view of the chamber, with regions of higher and lower illumination, b) side view with observers head under the light source, Munsell scale on the floor and the target on the opposite wall



Apparatus and stimuli. The experiments were conducted in a specially designed chamber (150 cm wide, 75cm deep and 75cm tall) depicted from top view in Figure 1a. The inside of the chamber was painted homogenous black (3.8% reflectance, equivalent of 1.3 on Munsell chart). A single light source illuminated the chamber (220V, 60W), placed 13 cm above the observer's head (Figure 1b). The light source fully illuminated only half of the chamber. The light was blocked in the other half by an opaque light-blocker. This created a 1:13 illumination difference between the two parts of the chamber. Since the chamber's illumination is quite intense, the portion in shadow was still well illuminated.

At the beginning of the experimental session, each observer put their head inside the chamber in a specially designed mask. The mask fixated the head in position and provided a chin rest so the observer could only move their eyes (but not their head).

The stimuli, grey squares (5x5 cm), were presented on the wall opposite the observer. There were two estimating positions (shown in Figure 1a), one for each illumination level. At those positions targets subtended a visual angle of 3.82^{o}. The stimulus was placed on a stick, which extended outside the box and enabled the experimenter to move the target from one illumination to the other. Several different shades were used in the following experiments (values are given in Table 1).

Table 1: Reflectance and luminance values of the targets

Color Aid paper	Illumination level	Reflectance	Luminance (cd/m^2)
4.5	Shadow	15.57	184.36
4.5	Spotlight	15.57	2396.75
3	Shadow	6.56	90.70
3	Spotlight	6.56	1179.13
2	Spotlight	3.12	815.93
1.5	Spotlight	2.02	393.44
Background	Shadow	/	average: 110.63
Background	Spotlight	/	average: 3241.09

The wall behind the target had numerous surfaces in all shades of grey, from black to white. The same pattern of surfaces was repeated in both illumination levels to ensure the target has the same position within the luminance range of each illumination field.

There was an occluder, a black glossy rectangle, placed at the illumination border (figure 1a). When the target moved from one illumination level to the other, it went for a brief moment behind the occluder. The observers were instructed that it was necessary to hide the moment of transition between the illumination levels to keep their task from being obviously easy.

A small box containing a Munsell chart was placed on the floor of the chamber (Figure 1), 50 cm from the observer. The Munsell chart is a standardized 16-step scale for lightness measurements. It contains all grey shades from black (3% reflectance) to white (90% reflectance). The chart had its own illumination, which ensured that the scale was independent from the experimental manipulations with illumination levels.

Procedure. The illumination and the targets were set before the subject's arrival. The subject placed their head into the chamber and only then, were instructed about the task. This procedure gave the subject a couple of minutes to adapt to conditions within the chamber. The subject's task was to make lightness matches, one at the time, using the Munsell chart.

Results. The Munsell values obtained in the experiments were transformed into reflectance values they represent (this is a linear transformation) and presented on a log scale (y scale on the graphs). The log reflectances were analyzed in all of the experiments with one-factor ANOVA. The factor was illumination level in experiments 1, 2 and 4 and the shade (of the prime) in third experiment.

EXPERIMENT 1: CLASSICAL CONSTANCY PARADIGM

This experiment is a replication of the classical constancy paradigm in which observers make matches for the same shade in different illuminations. In certain conditions it is possible to demonstrate constancy failure. As mentioned earlier, such conditions would include low articulation or different luminance range for two differently illuminated regions. Due to theoretical issues, we have chosen not to use such conditions. In our experiment, we produced constancy failure simply by making a very big difference between the two illumination levels.

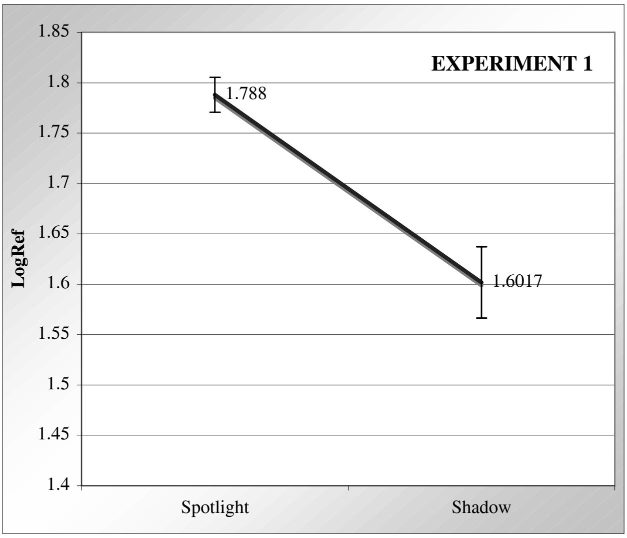
Subjects. There were 11 subjects.

Stimuli. The target consisted of two identical squares, made of 4.5 Color-aid paper.

Experimental setup: the two targets were presented simultaneously inside chamber, in the two estimation positions previously described.

Procedure. Observers were asked to make a Munsell match for each of the two targets. Half of the subjects started from the spotlight and half from the shadow.

Figure 2. Results from Classical Constancy Paradigm



Results. The target placed in the higher illumination was judged significantly lighter than the identical target in the lower illumination ($F(1,10)= 41.828$, $p<.0001$) (Figure 2).

This experiment confirmed that we could obtain constancy failure with our experimental set up.

EXPERIMENT 2: CONSTANCY IN MOTION

In this experiment we tested constancy while manipulating object identity. A target was placed in one illumination for the first lightness match and then moved to the other illumination for the second match. We reasoned that after the first match was taken, the target (and its lightness) should be already familiar to the observer, i.e. that there would be some identity attached to this object. Would this identity influence the lightness match?

According to anchoring models, identity should not influence the lightness. Targets should still be estimated in relation to the other surfaces within the field of illumination.

However, the process of lightness judgments is not instantaneous. Previous work (Annan and Gilchrist, 2004) shows that there is a hysteresis effect even for the scene anchor. It took several seconds for the anchor to be re-established when, in front of the observer, a full range scene was substituted with the scene containing only dark surfaces[2].

In our experiments, observers were left enough time to view the scene (during the instructions) and to establish the local anchor for two differently illuminated fields as well as to use the anchor from the spotlight region as the global anchor. They also waited before making a second match.

In this experiment motion was primarily used to reveal object identity. Some novel findings suggest that motion might not just enhance object identity but color constancy as well (Werner, 2007). The application of these findings to our experiment is somewhat limited as there are several important differences between Werner's experiments and ours. Her experiments were done in the chromatic domain, the objects were presented on a computer screen, and there was no illumination but background change. However, there are several important characteristics of motion, discussed by Werner, which should equally influence targets in both experiments. Motion captures attention, which in return increases stimulus salience (Pestilli et al., 2007), spatial resolution (Carrasco et al., 2006), contrast sensitivity and other characteristics (for these findings and in depth review Carrasco, 2006). In short, motion singles out the target in an otherwise static environment.

Apart from anchoring models, all other these findings suggest a higher degree of constancy in this experiment, in comparison to classical condition.

Subjects. There were 24 subjects.

Stimuli. A square targets made of 4.5 Color-aid paper.

Procedure. The target was placed either in the spotlight or shadow before the observer assumed their position. The observer was asked to estimate the target using the Munsell chart and than the target would be moved to the other illumination and

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[2] This process should not be confused with dark adaptation, a retinal mechanism triggered by low illumination.

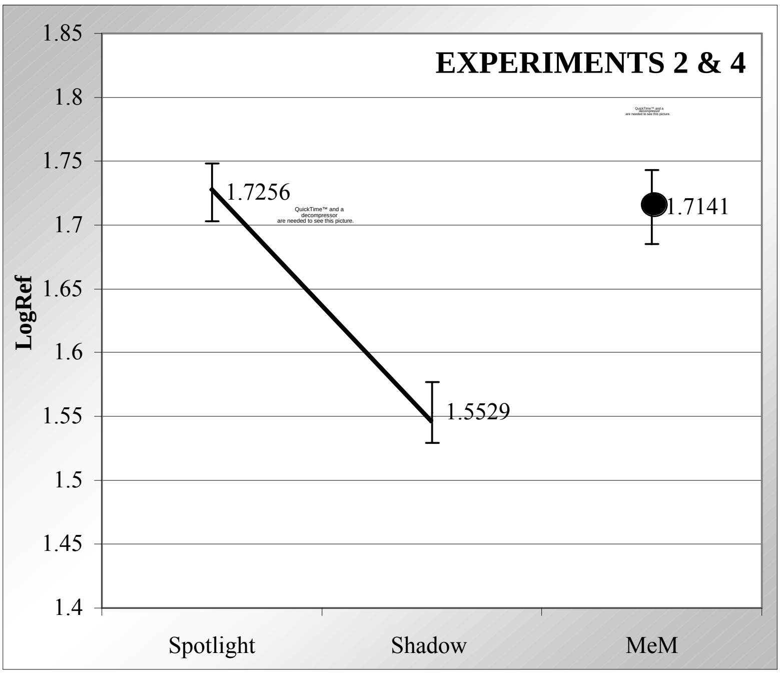
observers would make another match. Half of the subjects started from the spotlight and half from the shadow.

The motion was performed by the experimenter, who was moving the target from one estimation position to the other. The motion was relatively slow, it took the target about 5 seconds to move across 120 cm, and the speed was not perfectly constant (it was performed by a human). Importantly, this move occurred in the full view of the observer.

Results. Target reflectance varied as a function of the illumination level (F/23,1/= 98.91, p<.0001) and there was no significant difference based on estimation order (F/11,1/= 0.125, p=.73), Figure 3.

Discussion. Again in this experiment a significant failure of constancy was measured even when the identity of an object was not in question. It seems that identity and motion were not strong enough factors to prevail over scene articulation that produced two powerful frameworks. The target was still strongly influenced by local and global anchors, just as the anchoring models would predict.

Figure 3. Results from experiments Constancy in Motion (Spotlight and Shadow) and "True" Color (MeM)



Closer inspection of the, however, shows that the obtained Munsell values are not equal in the two experiments. In the classic setup, the target declined from 1.78 (8.14 on Munsell scale) in the spotlight to 1.60 (6.82 Munsell) in the shadow and in this experiment from 1.73 (7.67 Munsell) in the spotlight, to 1.55 (6.5 Munsell) in the shadow. The values are lower in the motion experiment (only spotlight difference reached marginal significance p=.0356; shadow p=.267), and the amount of constancy failure is equal.

EXPERIMENT 3: PRIMING

So far the emphasis on failure this p has been the constancy. However, the truly fascinating feature of constancy is not that things look different when the viewing conditions change; such explanation is already available at the level of physical analysis. The truly interesting part is that things look mostly the same despite changing conditions.

In the previous experiment we tried to use the object identity to help constancy. It is an intuitive notion that familiarity should enhance constancy: finally that is how constancy functions in most domains. In addition, there were indications from recent literature that motion might contribute as well. The third experiment was designed to amplify the effect of immediate prior experience.

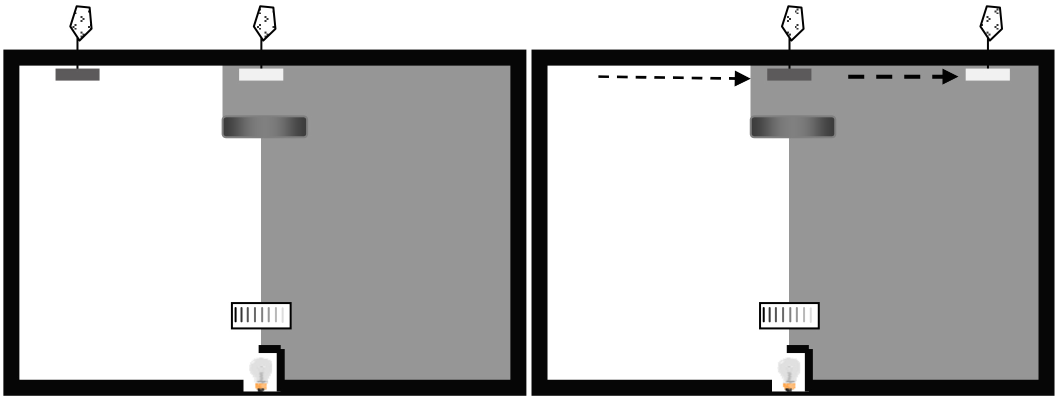
In a priming paradigm, a subsequent target is perceived differently due the effect of a preceding prime. We have used a similar procedure: priming the shade in the shadow with different shades in the spotlight. In this experiment, motion was used to trick observer into thinking that it is the same target in both illuminations. In fact, from the point of view of the observer this experiment was exactly the same as the previous one.

The experimental procedure is depicted on Figure 4. One target was placed in the spotlight and another was hidden behind the occluder (Figure 4a). The observer would make a match to the target in the spotlight. They would then observe the target moving behind the occluder and reappearing in lower illumination. However, the target in the lower illumination would be a different shade, i.e. the one that had been hidden behind the occluder. The assumption was that the shade in the lower illumination would vary as a function of a prime, i.e. shade in the higher illumination.

Subjects: there were 14 subjects.

Stimuli: five square targets were made of Color-aid paper. One target was made of each of following values: 4.5, 2 and 1.5, and two targets with value of: 3.

Figure 4. Experimental manipulation in Priming experiment: estimation on the prime (left) and estimation of the target (right)



Procedure. Prior to the experiment one of the four targets (4.5, 3, 2, 1.5) was placed in the estimation position in the spotlight and the target of value: 3 was always hidden behind the occluder. The observer would make a lightness match for the target and then the target would start moving into another estimating position. The first target, the prime, would now stay behind the occluder and the real target would appear in the shadow for the second estimate. This was repeated for all four shades: one of the shades would be a prime in the spotlight and the target of value: 3 would always be estimated in the shadow. Consequently, one time out of four the same shade would be presented in both illuminations (control situation).

The order of four primes was randomized across the observers. However, the prime was always starting from higher illumination. Apart from the technical reasons for such procedure, a) previous experiment showed no order effect and b) such effects did not influence he main hypothesis in this experiment.

During the debrief none of the subjects reported any suspicion in the experimental procedure, nor were they aware of the hidden target.

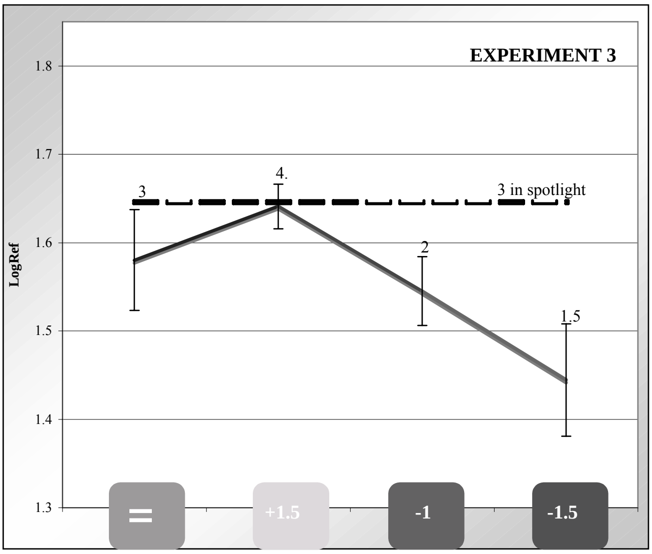
If there is no priming effect, the results for all four estimation of the target in the shadow should be equal.

Results. The estimated shade of the second target varied ($F(4)= 5.71$, $p=.001$) as a function of the prime (Figure 5).

Discussion. The graph shows four significantly different lightness matches for an identical target, presented under identical illumination, in front of identical background. The only difference among the four presentations was the observer's impression that it was a target of a different lightness. This false impression varied in the expected direction, as a function of the prime.

The doted line represents the value of 3 estimated in the spotlight. The color-aid-paper values are given next to the results, but the information about the difference between the prime and the target is labeled on the x axes. The first value (labeled =) is the control, value of 3. The difference between that result and the dotted line is a constancy failure that we have measured in all of the experiments.

Figure 5. Results from Priming experiment



The next value on the graph represents the result for the 1.5 shades lighter value shown in the spotlight. This prime caused an increase in the perceived value in the shadow. This would be the point of perfect constancy: as this value lays exactly on the dotted line.

The next two values depict the situation in which darker shades are presented in the spotlight and the lighter shade reappears in the shadow. This leads to the perception of very dark shades, much darker than the target really is judged (i.e. compared with control). Additionally, the control falls right where it should be expected: between +1.5 and -1.

In summary, the obtained results show that it is possible to use object identity to prime lightness judgments.

EXPERIMENT 4: THE “TRUE” COLOR

Previous studies (Zdravković et al, 2006) already involved lightness estimation of objects with obvious identity extended through two illumination levels. These studies presented a series of rectangles, which were partially in higher and partially in lower illumination. Again, constancy failure was measured for the parts in different illumination. This is similar to constancy: observers are convinced that it is a single object with illumination border, but make different matches for differently illuminated parts.

Presented with such paradox Zdravković et al. (2006) asked observers to estimate the real color of such objects, independent of illumination. The “true” color was a compromise between the areas of highest illumination and the area of largest illumination.

In the present set up, the observers were also convinced about the object identity, still in the second experiment, they gave two different estimates. We decided to ask them about the “true” color of the target, color independent of illumination level. Subjects observed the target moving from one illumination level to the other few times, until it stopped behind the occluder and out of view. Now observer would try and estimate its true color not relaying on illumination level that targets happens to be in. In order to achieve this, avoid presenting target in one of the illuminations, while asking about true color, he target was removed from the view. This change the subject’s task from a perceptual to a memory task. In this experiment subjects had to perform match from memory (MeM).

There is an analogy between this task and the study by Zdravković et al (2006). In both cases observers had to find the true color of the target independent of multiple illumination levels. However observers in the previous study had to perform spatial integration: the target was partially in one and partially in other illumination. Here they had to perform temporal integration: the target spent part of the time in one and part of the time in other illumination.

In the spatial domain, results suggested that the field of higher illumination carried more weight. So did the largest area of illumination. In our present set up, both areas are equal but we do not think that it is deciding factor. By analogy, the deciding factor should be the amount of time spent in each illumination (Zdravković, 2006). Hence our target spent equal time in both illuminations. In sum, based on the findings from spatial domain, the true color should be based on the match in the higher illumination.

Subjects. There were 14 subjects.

Stimuli. One square targets, made of 4.5 Color-aid paper, was used in the experiment.

Procedure. The target would be placed in one of the two illumination levels (starting illumination level was randomized across the observers). The observers were asked to follow the target as it moved from one illumination to another, oscillating between the two estimating positions three times. The target would stop behind the occluder and once it was out of view they would look at the Munsell scale and make the match.

Results. The main analysis showed that metch from memory was significantly different from matches in the the two illumination levels ($F/23,2/=36.35$, $p<.0001$) (Figure 3, MeM).

However, as a simple observation of the graph shows, this difference is created by the part in the lower illumination ($F/23,1/=46.639$, $p<.0001$), not the part in higher illumination ($F/23,1/=0.194$, $p=.66$).

Discussion. The results agree with the prediction that was based on the experiments from spatial domain. Although the prediction was confirmed, a part of prediction is still unresolved. Namely, we proposed that the second relevant factor, next to the area of highest illumination, is not the largest area of illumination but the time target spent in each illumination. However, both factors were equalized (each illumination had half an area and targets spent half a time in each illumination) so at this point it is inconclusive which of the two made an effect on target. The experiment should be designed to disentangle these two possible factors.

The results reveal another difference among matches in two illuminations and the match made for “true” color: there is much less noise in the results. Such difference might suggest that this match involves completely different set of cognitive functions.

In the previous experiments, the target was compared to the shades on the scale, which is a simple perception task. In this experiment, the matching took place once the target was removed from the view. Therefore this was not perceptual match but a match from memory (MeM).

DISCUSSION

This study represents yet another attempt to understand how the visual and cognitive systems solve the task of perceiving and constructing the stable world from the ever-fluctuating stream of information. The phenomenon of perceptual constancies is at the core of such investigations. We dealt with lightness constancy.

The most successful group of theories that can account for constancies, are anchoring models. Their explanation of the data from experiment 1 would be that each target is influenced by the anchor in its own field of illumination. Therefore, locally both targets would have the same lightness value (given that semi-fields in the chamber were made completely equal, except in illumination level). In addition, the target in the lower illumination is also influenced by the global anchor (highest luminance in the whole scene) and its final lightness value will be lower than that of the twin target in the higher illumination. In the second experiment we tried to deceive this lightness computation by introducing object identity, a possibly powerful factor from different domain. In order to use identity, motion was introduced, which according to recent literature should have also enhanced constancy. However, this manipulation did not make any change and the results were just as in previous experiments. This outcome would have been expected from anchoring models: none of the factors they value as important have changed.

The third experiment had the same basic idea about the influence of identity but this time it was enhanced beyond naturally possible. The observer was misleading into false assignment of identities. With the difference between the targets that was this big, results clearly showed that that lightness could be affected if we try to assign a value to a familiar object.

Although it might be argued that this experimental manipulation does not meet a requirement of normal usage of visual system, we simply tried to show, in exaggerated scenario, that it is possible to influence lightness with familiarity. In the forth experiment we use more natural scenario asking observers to make a match from memory. They can easily do so and their match resembles the value from the higher illumination. This is not just retaining the last seen target value, because only half of the observers saw target disappearing from the spotlight side.

The next obvious question must be about the temporal extent of such effects. The classical authors were suggesting that such effects might be long term (Hering's memory color for example). Any modern view of Bayesian orientation would basically also predict long-term effects (Kersten, Yuille, 2003; Liu et al., 1995).

We would rather stay within general gestalt view, with all important cues included in the scene. The only addition would be that the scene should not be conceived only in spatial domain but also in the temporal. In this manner immediate prior experience will also be part of the scene.

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REZIME

KONSTANTNOST SVETLINE: IDENTITET OBJEKTA I TEMPORALNA INTEGRACIJA

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U klasičnom eksperimentu koji se bavi konstantnošću svetline, ispitanik poredi dva objekta iste sive nijanse, smeštena u dva različita osvetljenja. U ovoj studiji, uvedeni su dodatni faktori čiji je uticaj na konstantnost svetline meren: identitet objekta i prmovanje.

Prvi eksperimentu je replikacija klasičnih nalaza u kojima se ne postiže visok nivo konstantnosti. Eksperiment je služio da se u našoj eksperimentalnoj postavci utvrde relevantni uslovi za ovakav nalaz.

U drugom eksperimentu je ispitivan uticaj identiteta objekta na konstantnost. Umesto da procenjuju dva nezavisna objekta, jedan objekt, procenjen u jednom osvetljenju bi, pred subjektom, bio pomeren u drugi nivo osvetljenja i tamo ponovo procenjen. Iako je bilo očigledno da se radi o istom objektu, rezultati se nisu razlikovali od predhodnog eksperimenta.

U trećem eksperimentu je korišćeno nešto nalik zadatku primovanja. Meta bi bila procenjena u jednom nivou osvetljenja, a zatim pomerena u drugo osvetljenje. Ono što ispitanik nije znao je da je tokom kretanja meta zamenjena drugom metom, različite sive nijanse. Baš kao pri primovanju, druga mete je bila procenjena u zavisnosti od vrednosti prima.

U poslednjem eksperimentu je ispitanicima pokazana meta koja bi nekoliko puta prešla iz jednog osvetljenja u drugo, dok bi je oni pratili pogledom. Kada bi meta bila uklonjena iz vidnog polja, ispitanici bi pokušali da procene njenu pravu boju, bez obzira na osvetljenje. Vrednost ove procene na osnovu sećanja je bazirana na vrednosti dobijenoj u višem nivou osvetljenja.

Uzeti zajedno ovi ekspreimenti pokazuju da kroz identitet objekta, neposredno iskustvo može da utiče na opaženu svetlinu na sistematski način.

Ključne reči: *svetlina, konstantnost, nivo osvetljenja, opažanje boja, priming.*

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