Ajda Car, Sabina Bračko
University of Ljubljana, Faculty of Natural Sciences and Engineering, Aškerčeva 12, 1000 Ljubljana, Slovenia

Influence of Basic Colour Parameters on Colour Memory
Vpliv osnovnih parametrov barve na barvni spomin opazovalca

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Abstract
We frequently need to compare two or more colours, and we can rely only on the colour impression from our memory. Colours are not stored in our memories in their actual state and they can gradually be erased. This paper addresses the subject of short-term colour memory. The approach is based on an experiment where subjects observed a given colour for a certain period of time. The purpose of the research was to determine the relation between the reference colour, time delay and the accuracy in recalling of the colour from the subject's memory. The colours studied in the research were presented with no association to bodies, shapes or textures. The main variables in the observing conditions were the basic colour parameters which define the colour, i.e. hue, saturation and brightness. The analysis of the final results showed that colour is not stored in our memories correctly and that it loses its basic parameters after 10 s. As the time delay increases, the accuracy of the colour impression in our memory diminishes. Colour is stored in our memory as clearer and more saturated. Bright colours are remembered as even brighter, while dark colours are stored as darker. The sensation of hue is generally stored very precisely, while the deviation in hue depends on the observed colour.
Keywords: colour memory, simultaneous colour comparison, colour perception, hue, saturation, brightness

Izvleček
V vsakdanjem življenju se pogosto znajdemo v situaciji, ko želimo primerjati dve ali več barv, ki jih ne opazujemo hkrati eno ob drugi, temveč si moramo pomagati z barvnim vtisom iz spomina. Pri tem si ljudje barvo zapomnijo z napako ali sčasoma postopno pozabijo videno barvo. Raziskava se navezuje na področje kratkoročnega barvnega spomina. Raziskovalni pristop je temeljil na poskusu opazovanja, v katerem so udeleženci določen čas opazovali dodeljeno barvo. Namen raziskave je bil ugotoviti, kakšna je povezava med opazovano referenčno barvo, časovnim zamikom in ponovnim priklicem barve iz spomina. Barva je bila v raziskavi obravnavana neodvisno od asociacij z različnimi telesi, oblikami ali teksturami. Glavne spremenljivke pri nespremenjenih opazovalnih pogojih so bili tako osnovni parametri, ki določajo barvo, tj. barvni ton, nasičenost in svetlost. Analiza pridobljenih rezultatov je pokazala, da si ljudje barvo zapomnijo z napako ali jo v spominu pomešajo že po desetih sekundah. Natančnost barvnega vtisa v spominu se z večjim časovnim zamikom postopno manjša. Barve se v spominu ohranijo kot bolj nasičene in bolj čiste. Svetle barve si zapomnimo svetlejše, temne si zapomnimo temnejše. Pomnjenje barvnega tona je razmeroma dobro, spominski preskok pa je odvisen od opazovane barve.
Ključne besede: barvni spomin, sočasna primerjava barv, zaznavanje barv, barvni ton, nasičenost, svetlost

1 Introduction

The memorial restoration of a certain event or sensation (e.g. colour) is far from being perfect. Contrary to a common belief, our memory is not infallible. As confirmed by several investigations, our colour memory is rather poor and the sensation of a colour is not always remembered accurately [1–3].

Corresponding author/*Korespondenčna avtorica:*
Assoc Prof dr. Sabina Bračko
E-mail: sabina.bracko@ntf.uni-lj.si
ORCID: 0000-0002-3140-7263

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This can present a serious obstacle when selecting or buying an item which is meant to be of a defined colour or to be matching a certain hue, for example, when buying a textile or apparel.

The ability to discriminate and remember different colours depends on several conditions, e.g. the age and gender of the observer, the viewing conditions and the colour itself. Although the research in this area has been intensified in the last years, the results are not easily compared as different authors apply various approaches to study the colour memory [4]. According to Pérez-Carpinell [3], the colour memory is a successive colour matching which occurs when some time has elapsed between the observation of a colour and its restoration from the memory. In our daily life, the situations where a remembered colour has to be reproduced or a present colour has to be judged in comparison with the remembered one are much more common than a simultaneous comparison of two colour samples. For example, we often need to evaluate the quality of food in a store regarding its colour or we want to buy a garment to match the one we have at home [5–7].

On the basis of our everyday experience, we gradually build a library of colours and hues in our long-time memory, where the colours from our daily life are incorporated. The colours can be easily described by using suitable words. However, when such a "memory colour" of a known object is compared to the colour observed some time ago, a change in colour appearance may occur [1, 8]. A comparison from our long-time memory happens automatically and it has been observed with natural and artificial objects [9]. Consequently, the testing of colour memory strongly depends on the selection of reference colours and surrounding conditions [10].

Bodrogi and Tarczali [4] investigated in what way the colour memory is affected when a coloured sample is observed within the image context. Memory (i.e. *prototypical)* colours of known objects such as sky, plants and skin were observed either as a simple colour patch or as a part of a photo-realistic image. The results showed that an association can be triggered by the image context, and during the time delay, the observed colour was compared to the memorized colour of a known object, stored in the long-term memory. The shifts in detection occurred in the direction of the memory colour of the observed object.

The restoration of such memory colours, i.e. prototypical colours of known objects, works in a similar way and is influenced by the association with a known object even if it is observed in the absence of the image context. Obviously, colour is a subjective sensation which occurs in the brain as a consequence of three factors, i.e. light source, coloured object and observer [10]. Colours which are perceived in our daily life are always connected to a certain object and are also stored in our memory in this way. It is therefore not unexpected that a colour shift into the direction of a memory colour was detected also in the experiment where uniform coloured rectangles were observed [11].

One of the researches concerning memory colours showed that memory shifts are also affected by the nature of the observed object [12]. Apparently, the shifts proved to be much smaller or even negligible when the colour of food was involved. A reasonable explanation could be given by the fact that the colour of food is an extremely important information from the view point of a consumer as it reflects its quality, ripeness and edibility, whereas the colour of the sky is generally not crucial for survival. A similar effect was observed by Seliger [1] as the colour of a yellow banana was remembered much more precisely than the blue sky, green grass or the red traffic light.

The changes in memory can be provoked merely by a hint, for example if context is added to the observed colour. Such denotation influences the perception of colour and consequently the colour memory, which leads to a colour shift towards the colour which is stored in our memory in connection with the given context [12]. Tarczali *et al* [2] compared the precision of remembered memory colours in two cases: in the first one, the colour was given merely by its name and in the second one, a black and white photography was enclosed, showing a scene in connection with the given colour. Based on the study results, the accordance between the observed reference colour and the long-term memory colour was far better when the photography was enclosed.

According to the examined literature, the investigations of colour memory in which the colours are represented independently and without any context are very rare [7, 10, 13]. The research focuses mainly on the observers (age, gender) and does not answer the question, how well the colour is remembered or what kind of shift occurs in our colour memory. Colour is a subjective perception which depends on several physical, physiological and psychological factors. The colour memory also depends on the former experiences of an individual and its understanding represents a complex problem. The purpose of our research was therefore to establish the relationship between the observed reference colour and the ability of the observer to recall this colour from the memory when the reference colour is presented independently, without any connotation to shapes, textures or environment. In the experiment, the reference colours, which were defined merely by their basic characteristics, i.e. hue, saturation and lightness, were observed for a certain period of time under controlled and constant conditions. After a short pause (10 s, 60 s, 300 s), the observers were asked to restore the reference colour from their memory on the basis of selected colour samples. The colour differences were calculated in order to establish the deviations in hue, saturation and lightness, and the dependence of total colour difference on time, with the aim to evaluate the influence of basic colour properties on our ability to remember colours and to predict the colour changes which occur with time.

2 Experimental

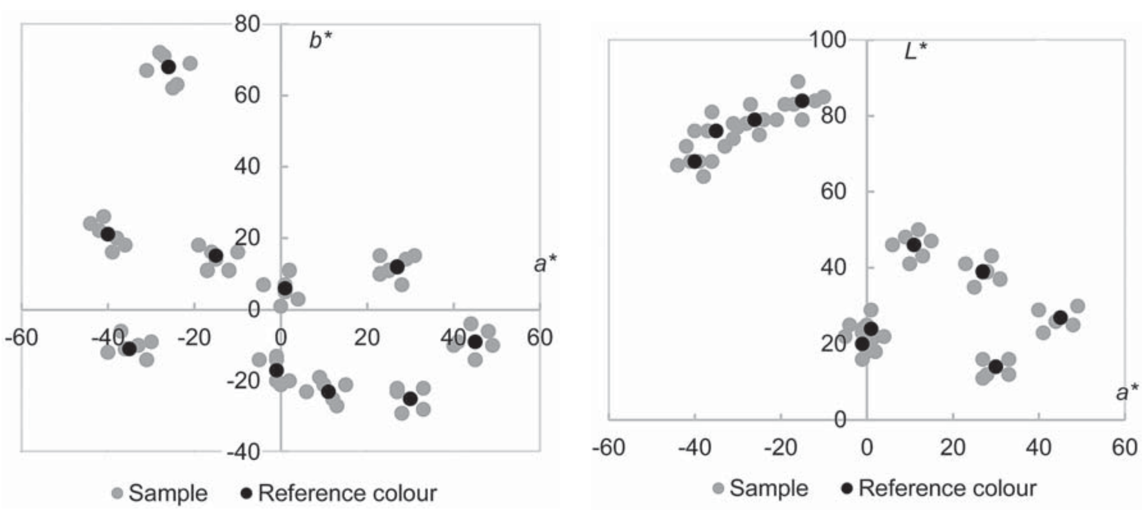
2.1 Selection of reference colours and samples

To study colour memory, ten reference colours were systematically selected using the HSB and afterwards converted to the CIELAB colour space, regarding the following conditions: 1. reference colours should not be associated with well-known coloured objects, 2. reference colours should be positioned as widely as possible to cover the visible spectrum. The aim of the research was to study the colour memory separately from any associations; therefore, the selection of independent reference colours was crucial. The CIELAB coordinates of ten reference colours are presented in Table 1.

For each of the ten reference colours, six accompanying samples were carefully selected. To define each of them, only one basic colour parameter was changed in such a manner that the possibility of selecting all directions in the colour space is given (cf. Figure 1). The colour difference between the reference colour and an individual sample was approximately 5 CIELAB units, as suggested in previous research [3].

Table 1: CIE $L^*a^*b^*$ coordinates of reference colours I–X

Reference colour	L^*	a^*	b^*
I	39	27	12
II	79	–26	68
III	76	–35	–11
IV	24	1	6
V	14	30	–25
VI	20	–1	–17
VII	84	–15	15
VIII	68	–40	21
IX	46	11	–23
X	26	46	–9



a) b)

*Figure 1a and 1b : Reference colours I-X and corresponding colour samples in CIEa*b* and CIEa*L* plane of CIELAB colour space*

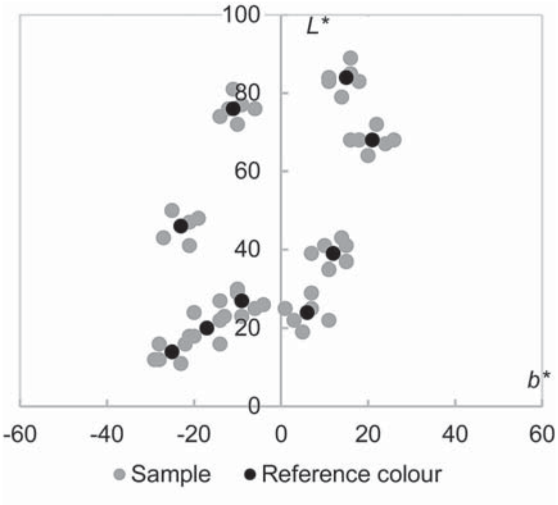


*Figure 1c: Reference colours I-X and corresponding colour samples in CIEb*L* plane of CIELAB colour space*

2.2 Observers

The research was based on 18 graduated or undergraduated student volunteers (convenience sampling method), 9 male and 9 female, aged 20–30 years. At this age, the colour vision is at its peak, which also affects the colour memory [7, 13]. Prior to the testing, the participants were subjected to the Ishihara and Farnsworth-Munsell hue tests to prove their normal colour vision and the ability to distinguish colours. As several investigations proved that there are no major differences between the observers with different experiences, our group of observers was not divided according to their previous education or field of work [4, 10, 14].

2.3 Testing conditions

The experiment was conducted at constant and controlled conditions. The reference colours and corresponding samples, all 6 cm × 6 cm in size, were shown on a neutral grey background ($L^* = 75$, $a^* = -3$, $b^* = -2$), on a 27-inch monitor with the resolution 1920 dpi × 1080 dpi, which was previously calibrated and set to D65 standard illumination ($T_C = 6500$ K). The colour temperature was controlled before and after each set of testing to ensure a constant display of colours throughout the testing procedure. The monitor was the only source of light in an isolated dim room. The observers were positioned at the distance of 70 cm from the monitor. The height was adjusted to ensure the viewing angle of 90º.

2.4 Testing procedure

Prior to the testing, the observers were asked to take time to adjust to the conditions of illumination (5 min) and afterwards, to the neutral grey background of the monitor (3 min). In the first part, the colour memory after a certain period of time (10 s, 60 s, 300 s) was tested. The procedure started with the observation of the reference colour for 10 s, after which the observer focused on the grey background. After 10 s (60 s, 300 s), seven colour samples appeared on the monitor, showing the previously displayed reference colour together with six similar, randomly positioned colour samples, lined in two rows. The observer was asked to find the previously displayed reference colour. The time for the decision was not limited since no significant impact of time limitation was noted by the examined literature [2, 7, 13]. Afterwards, the procedure was repeated for different time delays, whereas the seven colour samples were displayed to the observer at each time delay positioned in diverse order.

In the second part of the experiment, a simultaneous comparison of colour samples was performed to establish whether the deviations in colour sensations were a consequence of the limited short-time memory or of the observer's disability to distinguish colours. The observers were asked to select the matching colour among the seven colour samples, prior used in the first part of the experiment, positioned around the central reference colour. The time for the decision was not limited. The position of the reference colour (example: colour III) and appropriate samples is presented in the supplement of the web version of this paper. The testing procedure was repeated for each of the ten reference colours. The reference colours and appropriate samples were marked only with numbers, no names were mentioned in connection with colours in order to avoid any associations which could influence the results of colour memory testing [12, 15].

3 Results and discussion

The analysis of a simultaneous comparison (i.e. time delay $t = 0$ s) and colour memory testing ($t = 10$ s, 60 s, 300 s) was based on the average CIE $L^*a^*b^*$ values of selected samples at a given time for each reference colour. The CIELAB equation was used to calculate the total colour difference, ΔE^*_{ab}, as well as its components, i.e. difference in hue, ΔH^*_{ab}, difference in lightness, ΔL^*, and difference in chroma, ΔC^*_{ab}.

3.1 Simultaneous comparison of colour samples

The results of a simultaneous comparison, i.e. $t = 0$, showed that 96% of total replies were correct (cf. Figure 2), meaning that the observers found the correct reference colour among the seven samples displayed simultaneously. Due to the remaining 4% of incorrect replies, the colour difference $\Delta E^*_{ab} = 0.48$ was calculated (cf. Table 2). The calculated average colour difference at a simultaneous comparison of colours is in accordance with the results obtained in previous research. Pèrez-Carpinell *et al* reported the average $\Delta E^*_{ab} = 0.58$ [7] in a group of observers of the same age as in our experiment, while the difference was slightly higher ($\Delta E^*_{ab} = 1.00$) in a group of various age [3].

Table 2: Average change in basic colour parameters, ΔH^*_{ab}, ΔC^*_{ab}, ΔL^*, and total colour difference, ΔE^*_{ab}, for all samples after different time delays (0 s, 10 s, 60 s, 300 s)

Colour change	Time delay [s]			
	0	10	60	300
$\lvert\Delta H^*_{ab}\rvert$	0.12	0.66	0.65	0.82
$\lvert\Delta C^*_{ab}\rvert$	0.46	1.14	1.44	1.71
$\lvert\Delta L^*\rvert$	0.00	0.74	0.80	1.00
ΔE^*_{ab}	0.48	1.80	1.92	2.29

Table 2 shows a comparison of the three basic parameters, i.e. hue, lightness and chroma, and their change with time. First of all, we were interested in establishing the magnitude of deviation from the reference colour, not its direction; hence, the changes are represented as absolute values. According to the results, there were no deviations in lightness ($\lvert\Delta L^*\rvert = 0.00$) and only small differences in hue were established ($\lvert\Delta H^*_{ab}\rvert = 0.12$). On the other hand, the average difference in chroma was $\lvert\Delta C^*_{ab}\rvert = 0.46$ units, meaning that the difference in chroma represents the major part of the total colour difference. We can conclude that when comparing two colours simultaneously, an error in saturation is most likely to occur.

For the majority of reference colours, the colour difference at a simultaneous comparison was zero (cf. Table 3), meaning that the selected sample was identical to the observed reference colour. However, some discrepancies were found at reference colours II ($\Delta E^*_{ab} = 1.41$), V ($\Delta E^*_{ab} = 1.41$), VIII ($\Delta E^*_{ab} = 1.00$) and X ($\Delta E^*_{ab} = 1.00$). All of these samples exhibited the largest difference in chroma ($\Delta C^*_{ab} = -1.29$, $\Delta C^*_{ab} = 1.41$, $\Delta C^*_{ab} = 0.89$ and $\Delta C^*_{ab} = -0.98$, respectively). The deviations occurred in both directions, positive and negative; therefore, a colour to be matched was perceived as more or less saturated than the original one. One of the previous researches reported that at a simultaneous comparison of colours, deviations occur randomly [7]. In our research, samples II, V and X with higher chroma also exhibited limited matching at a simultaneous comparison. We can conclude that comparing and distinguishing colours with higher saturation is connected with difficulties. Such limitations of the human eye are also evident from the size and shape of the MacAdam's ellipses [16, 17].

3.2 Total colour difference depending on time delay

The human capability to remember colours is relatively scarce and the reconstruction of a colour sensation becomes even more inaccurate with time [1, 7, 18]. The results of our investigation confirm such findings.

Figure 2 represents the decrease in colour matching with time, which is especially evident during the starting period. The most substantial change occurs during the first time interval as the share of perfect matches decreases from 96% at a simultaneous comparison to 49% after 10 s, decreasing to 28% after 60 s and to 17%

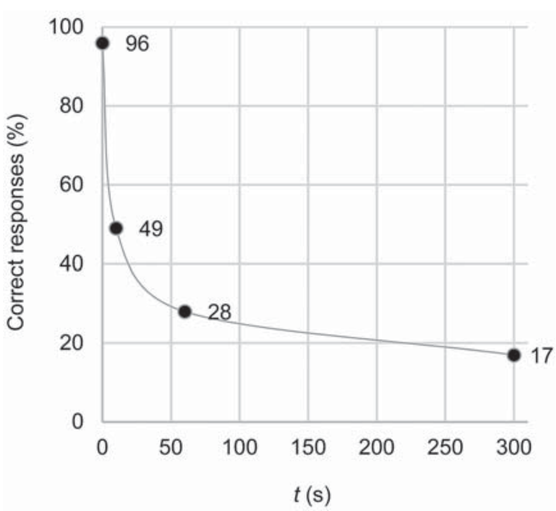


Figure 2: Percentage of correct responses in dependence on time

Table 3: Change in basic colour parameters, ΔH^*_{ab}, ΔC^*_{ab}, ΔL^* and total colour difference, ΔE^*_{ab}, after different time delays (0 s, 10 s, 60 s, 300 s) for samples I–X

Reference colour	Colour difference	Time delay [s]			
		0	10	60	300
I	ΔH^*_{ab}	0.00	0.50	0.21	0.99
	ΔC^*_{ab}	0.00	1.32	2.23	2.65
	ΔL^*	0.00	0.00	0.00	0.00
	ΔE^*_{ab}	0.00	1.41	2.24	2.83
II	ΔH^*_{ab}	–0.57	–1.63	–1.63	–1.63
	ΔC^*_{ab}	–1.29	1.53	1.53	1.53
	ΔL^*	0.00	1.00	1.00	2.00
	ΔE^*_{ab}	1.41	2.45	2.45	3.00
III	ΔH^*_{ab}	0.00	0.00	–0.29	–0.61
	ΔC^*_{ab}	0,00	0.00	0.95	1.91
	ΔL^*	0.00	1.00	1.00	1.00
	ΔE^*_{ab}	0.00	1.00	1.41	2.24
IV	ΔH^*_{ab}	0.00	0.00	0.00	0.00
	ΔC^*_{ab}	0.00	0.00	0.00	0.00
	ΔL^*	0.00	–1.00	–1.00	0.00
	ΔE^*_{ab}	0.00	–1.00	–1.00	0.00
V	ΔH^*_{ab}	0.00	–0.88	–0.87	–0.87
	ΔC^*_{ab}	1.41	2.06	2.06	2.06
	ΔL^*	0.00	0.00	–1.00	–1.00
	ΔE^*_{ab}	1.41	2.24	2.45	2.45
VI	ΔH^*_{ab}	0.00	0.11	0.11	1.03
	ΔC^*_{ab}	0.00	1.00	1.00	0.97
	ΔL^*	0.00	–1.00	–1.00	–2.00
	ΔE^*_{ab}	0.00	1.41	1.41	2.45
VII	ΔH^*_{ab}	0.00	0.50	0.65	0.65
	ΔC^*_{ab}	0.00	0.72	2.14	2.14
	ΔL^*	0.00	2.00	2.00	2.00
	ΔE^*_{ab}	0.00	2.24	3.00	3.00
VIII	ΔH^*_{ab}	0.46	0.21	0.91	0.21
	ΔC^*_{ab}	0.89	2.23	1.78	2.23
	ΔL^*	0.00	0.00	0.00	0.00
	ΔE^*_{ab}	1.00	2.24	2.00	2.24
IX	ΔH^*_{ab}	0.00	–0.44	0.44	–0.86
	ΔC^*_{ab}	0.00	0.90	0.90	1.81
	ΔL^*	0.00	0.00	0.00	–1.00
	ΔE^*_{ab}	0.00	1.00	1.00	2.24
X	ΔH^*_{ab}	0.20	2.31	1.34	1.34
	ΔC^*_{ab}	–0.98	1.63	1.79	1.79
	ΔL^*	0.00	–1.00	–1.00	–1.00
	ΔE^*_{ab}	1.00	3.00	2.45	2.45

after 300 s. A similar trend was discovered by Seliger [1]. He reported an evident decrease between the time interval 1 s and 5 s, while no major changes were observed with increasing time, between 5 s, 10 s and 15 s. According to the results of our study, the percentage of correct answers decreased more slowly after a longer period of time, which indicates only a gradual change in the colour impression in the memory. After 60 s, 28% of answers were correct and after 300 s, 17%. Considering the curve of decrease (cf. Figure 2) and the results of previous investigations, an even smaller decrease is expected with increasing time; therefore, it is very likely that the colour memory remains at an approximately the same level. Perez-Carpinell *et al* [3] tested the colour memory after 15 s, 15 min and 24 h, and they found that the colour memory after 15 s is distinctively better than after a longer period of time. However, there were no major differences in the results obtained after 15 min or 24 h. Hamwi and Landis [19] tested the colour memory after a longer period of time, i.e. 15 min, 24 h and 64 h, and the results showed no major differences.

Similar conclusions regarding the colour memory can be obtained on the basis of calculated colour differences (cf. Tables 2 and 3). With no exception, a simultaneous comparison of colours was more accurate than the comparison after a different period of time. After 10 s, the average colour difference was ΔE^*_{ab} = 1.80, after 60 s ΔE^*_{ab} = 1.92 and after 300 s ΔE^*_{ab} = 2.29 (cf. Table 2). Similar results were obtained by de Fez *et al* [20] who found that a simultaneous comparison was more accurate than a successive one for 31 out of 34 colour samples.

According to previous investigations, the colour memory is not equally precise for all colours. The results of our investigation (cf. Table 3) show that samples IV (ΔE^*_{ab} = 0.67), IX (ΔE^*_{ab} = 1.41) and III (ΔE^*_{ab} = 1.55) were remembered most accurately as the colour differences were considerably small. On the other hand, the biggest colour differences were found for samples VII (ΔE^*_{ab} = 2.75), X (ΔE^*_{ab} = 2.63) and II (ΔE^*_{ab} = 2.63). Such results imply that a larger colour difference at a simultaneous comparison is connected with the reduced colour memory and that the colours which are hard to differentiate fade more quickly in our memory. These results, however, cannot be generalized. According to Jin and Sheyell [21], the colours of medium and long wavelength region are remembered more easily and with higher precision. Fez *et al*, on the other hand, claim that the colours along the blue-yellow axis are the easiest and those along the green-red axis the most difficult to remember [20].

3.3 Change in basic colour parameters depending on time delay

Each colour is defined by its three basic parameters, i.e. hue, lightness and saturation. Several authors discovered that at restoring colour from our memory, the three parameters are not remembered equally accurately [3, 21]. The aim of our study was therefore to examine the changes in hue, ΔH^*_{ab}, lightness, ΔL^*, chroma, ΔC^*_{ab}, and the total colour difference in dependence on time for the selected reference colours (cf. Table 2). Regardless the time interval (10 s, 60 s, 300 s), the difference in chroma represented on average the major part of the total colour difference ($|\Delta C^*_{ab}|$ = 1.14, $|\Delta C^*_{ab}|$ = 1.44 or $|\Delta C^*_{ab}|$ = 1.71, for increasing time delay), the saturation of colour being remembered the least accurately. A very small contribution to the total colour difference represents the calculated difference in hue, which varies between 0.66 units (after 10 s) and 0.88 units (after 300 s), reflecting that, in general, we are able to memorise a certain hue very well. Only slightly bigger differences in lightness were detected ($|\Delta L^*|$ = 0.74, $|\Delta L^*|$ = 0.80 and $|\Delta L^*|$ = 1.00, respectively).

Analysis of change in chroma

The colours which are recalled after a certain time delay are remembered with a considerable difference in saturation. The calculated values ΔC^*_{ab} were positive for all samples (cf. Table 3), indicating that we remember a colour as more saturated than it originally is. Similar observations were reported by other authors [4, 12, 20]. In some cases, on the other hand, the authors reported that colours with high chroma were remembered as more saturated and vice versa; however, this only occurred in the cases where the colour was connected to a certain object [18, 22].

According to the results (cf. Table 4), remembering the correct colour can be difficult especially for the colours with higher chroma whereas the samples with lower chroma are the least problematic. We can conclude that remembering colours with lower or moderate saturation is relatively easy compared to highly saturated colours which are in general also difficult to distinguish by the human eye. Our samples did not show any correlation between the difference in chroma and their hue.

Table 4: Average change in basic colour parameters, ΔH^*_{ab}, ΔC^*_{ab}, ΔL^* and total colour difference, ΔE^*_{ab}, after different time delays (10 s, 60 s, 300 s) for samples I–X

Colour change	Reference colour									
	I	II	III	IV	V	VI	VII	VIII	IX	X
$\|\Delta H^*_{ab}\|$	0.57	1.63	0.30	0.00	0.87	0.42	0.60	0.44	0.58	1.66
$\|\Delta C^*_{ab}\|$	2.07	1.53	0.95	0.00	2.06	0.99	1.67	2.08	1.20	1.74
$\|\Delta L^*\|$	0.00	1.33	1.00	0.67	0.67	1.33	2.00	0.00	0.33	1.00
ΔE^*_{ab}	2.16	2.63	1.55	0.67	2.38	1.76	2.75	2.16	1.41	2.63

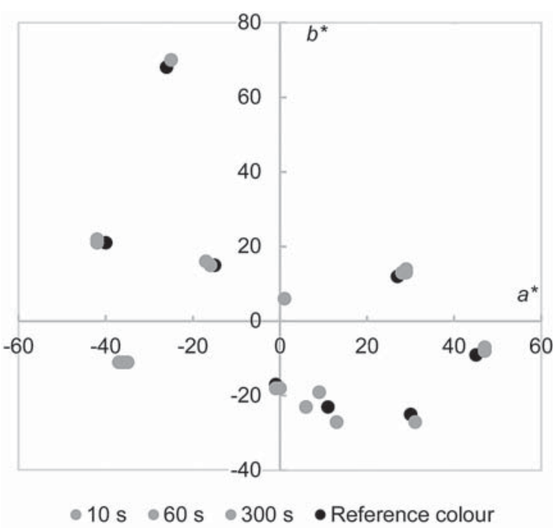
Analysis of change in lightness

The results showed that our memory for lightness is relatively accurate and comparable to our memory for hue. This is in accordance with previous investigations [12]. We also established that a similar deviation in lightness can be found for colours with similar original lightness.

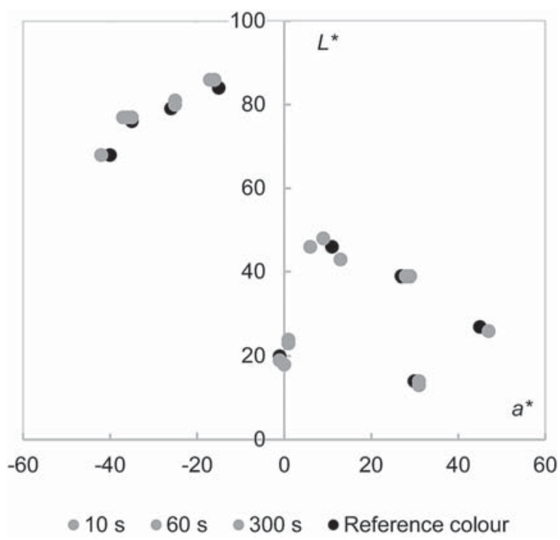
When recalling colour after a certain period of time, a deviation in lightness can occur. According to the results in Figure 3b, the difference in lightness, ΔL^*, can be either positive or negative. The colours with higher lightness were positioned above its original position; thus, the colours with higher lightness are remembered as even lighter. In contrast, the colours with moderate or lower lightness were positioned lower; hence, dark colours are remembered as even darker.

In some cases, when colours were connected with a certain object, the authors reported only the changes in the direction of lower lightness [4, 18]. The majority of researches which include independent colours confirm that colours with higher lightness are remembered as slightly lighter and those with lower lightness as considerably darker. Colours with medium lightness are remembered relatively accurately or slightly darker [3, 12].

A comparison of the average change in lightness $|\Delta L^*|$ with the original lightness of a colour (cf. Table 4) shows that the biggest changes were observed at the samples with higher lightness, i.e. samples II ($L^* = 79$) and VII ($L^* = 84$), and at a darker sample VI ($L^* = 20$). On the other hand, the samples with medium lightness, i.e. samples I ($L^* = 39$), VIII ($L^* = 68$) and IX ($L^* = 46$) were remembered very accurately, exhibiting very small values ΔL^* with time. The differences in colour memory between the colours of different lightness are not as evident as at colours of different chroma; nevertheless, the results show that very dark and very light colours are more difficult to remember.



a)



b)

*Figure 3: Reference colours I–X and colour samples, selected after different time delays (10 s, 60 s, 300 s), in CIEa*b* plane (a) and in CIEa*L* plane (b) of CIELAB colour space*

Analysis of change in hue

According to our results, the hue of a colour is the characteristic which is remembered the most accurately. The biggest differences in hue were observed at highly saturated samples, but no correlation was found between the difference in hue and the difference in chroma. Only small, barely noticeable differences in hue were reported with time also by other authors [3, 4, 12, 21]. As explained by Pérez-Carpinell *et al* [18], we quickly forget or neglect less important information and properties. The hue, however, is a basic characteristic which enables distinguishing the colours; therefore, the probability for it to be kept in our memory is increased.

Figure 3 shows the reference samples and the memorized colours after a certain time delay in the CIEa^*b^* plane. Generally, a slight shift towards an adjacent axis can be noticed. Sample X (scarlet) shifted towards the positive a^* axis, meaning that the scarlet colour is remembered as more reddish. Samples III (light blue), VII (light green) and VIII (green) moved to the negative a^* axis; thus, they are remembered as greener. Samples V (dark violet) and VI (dark blue) moved to the negative b^* axis, meaning that they are set in our memory as bluer. Similar shifts towards the axis which is closer and appropriate basic colours of the CIELAB colour space were reported by other authors [4]. An exception was noticed at sample IX (light purple), which did not show any systematic deviations, but rather random shifts. Our assumption is that this sample resembled to a colour of lavender (plant), which was also remarked by most subjects. According to the examined literature, if a reference colour resembles strongly to any known object, shape or texture, the colour sensation can be compared to our long-term memory which can potentially lead to a deviation of colour memory [1, 8].

4 Conclusion

Several investigations show that our colour memory is not reliable and that it depends on the observed colour. This can present a serious obstacle when selecting or buying an item which is meant to be of a defined colour or to be matching a certain hue, for example, when buying a garment. Namely, our perception of colour depends on several physical, physiological and psychological factors and our colour memory depends also on the former experience of individual. The purpose of our research was to focus on the properties of colour to discover which colours are remembered more accurately and how the basic parameters of colour influence our ability to preserve the colour sensation. The research was focused on colours, which were presented independently, without any connotation to shapes, textures or environment.

The results confirmed that our colour memory is rather poor. With no exception, for all samples tested, a simultaneous comparison of colours was more accurate than the recalling of a colour after a certain period of time. As soon as after 10 s, our impression of a colour is changed and the deviations increase with time. According to the results, the perceived colour difference includes the change in all three basic parameters of a colour.

The hue of a colour is the property which is remembered the best. We can conclude that the properties which are considered as less important are neglected or forgotten sooner. Hue, on the other hand, is a basic property which enables distinguishing and naming colours, and is therefore more likely to be preserved in our memory. The deviation in hue with time depends on the colour. According to our study, it is very likely that a colour shift will occur towards the closest axis of the CIEa^*b^* plane.

The ability to remember the lightness of a colour is relatively good and comparable to that of remembering its hue. The biggest errors were observed for the colours with extremely low or high lightness; lighter colours were remembered as even lighter and dark colours as darker. Our colour memory functions most accurately for the samples with medium lightness; these are usually remembered as only slightly darker or even identical to the original.

The saturation of a colour is a property which is the most difficult to be preserved in the memory. Regardless the colour, it is remembered as more saturated than it originally was. The increase in saturation is less obvious for the colours with higher chroma. According to the results, colours with lower saturation are remembered more accurately. On the other hand, the colours with higher saturation, which are also more problematic to be distinguished, are recalled from our memory with a significant deviation.

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