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Ergonomics — Accessible design — Method for creating colour combinations taking account of age-related changes in human colour vision

Ergonomie — Conception accessible — Méthode de création de combinaisons de couleurs tenant compte des changements liés à l'âge dans la vision en couleurs humaine

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Foreword

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 159, *Ergonomics*, Subcommittee SC 5, *Ergonomics of the physical environment*.

Introduction

While the social care of older people has widely spread in many countries, the design and production of visual signs and displays do not always take into account the unique needs of older people. This International Standard presents a method for assessing and designing signs and displays in our visual environment so that they are clearly visible to older people. This International Standard includes a method and data for creating conspicuous colour combinations in visual signs and displays seen by people at any age by considering age-related change of human colour vision.

A reasonably large number of people, especially men, have defective colour vision of various types, and some smaller part of the population have suffered from medical disorders of the eye such as low vision. This International Standard is not applicable to colour combinations for people who have deficient colour vision or medical disorders affecting vision. Other International Standards are planned that will provide methods to enable the creation of colour combinations for people with widely varying visual disabilities, including those for people with normal colour vision at any age, people with colour deficiencies and people with low vision, and for general guidance on the use of the colour-combination standard.

In describing colours in this International Standard, the Munsell colour system is used, which is a colour-order system recommended by the Commission Internationale de l'Eclairage.[9]

This International Standard adopts the principles of accessible design given in Reference [3] and amplified in Reference [4].

Ergonomics — Accessible design — Method for creating colour combinations taking account of age-related changes in human colour vision

1 Scope

This International Standard provides a method for creating conspicuous colour combinations for use in visual signs and displays taking into account viewer age. It is based on the perceived similarity of colours at photopic and mesopic lighting conditions.

This International Standard applies to the design of visual signs and displays in which multiple colours are used so that the colours are conspicuous to people of any age, including older people who do not have deficient colour vision. The method and data in this International Standard are not applicable to the design of visual signs and displays for people with colour deficiencies or medical disorders affecting vision.

Basically, this International Standard applies to the reflective or object mode colours, but may apply to self-luminous mode colours if the colour coordinates are appropriately transferred to those of the object mode colours.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 3864-1, *Graphical symbols — Safety colours and safety signs — Part 1: Design principles for safety signs and safety markings*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
colour similarity
extent to which some percentage of the population judge a given colour as similar to a fundamental reference colour

EXAMPLE Colour similarity of 50 % means that half of the people judge a given colour as similar to the reference colour.

3.2
fundamental colour
set of basic colours perceived by people with normal colour vision, which are red, orange (yellow-red), yellow, green-yellow, green, blue-green, blue, purple-blue, purple, red-purple, black, grey, and white, in accordance with the Munsell colour system

3.3
mesopic vision
vision by the normal eye intermediate between photopic and scotopic vision

[SOURCE: CIE S 017/E:2011]

Note 1 to entry: In mesopic vision, both the cones and the rods are active.

3.4
photopic vision
vision by the normal eye in which cones are the principle active photoreceptors

[SOURCE: CIE S 017/E:2011]

Note 1 to entry: Photopic vision normally occurs when the eye is adapted to levels of luminance of at least 5 cd/m^2.

Note 2 to entry: Colour perception is typical of photopic vision.

3.5
scotopic vision
vision by the normal eye in which rods are the principle active photoreceptors

[SOURCE: CIE S 017/E:2011]

Note 1 to entry: Scotopic vision normally occurs when the eye is adapted to levels of luminance of less than 10^{-3} cd/m^2.

Note 2 to entry: In comparison with photopic vision, scotopic vision is characterized by the lack of colour perception and a shift of visual sensitivity towards shorter wavelengths.

3.6
span of a fundamental colour
area in a colour space in which colours are perceived as similar to a reference colour in colour appearance

Note 1 to entry: The span is definable differently according to the extent of similarity to the reference fundamental colour, such as “very similar”, “moderately similar”, or “slightly similar”.

Note 2 to entry: The Munsell colour system is used to describe the span in this International Standard.

4 Factors affecting conspicuity of colour combinations

4.1 General

Colour combinations should be conspicuous whenever colours are used for identifying, discriminating, or recognizing information in visual signs and displays. The factors given in 4.2. to 4.4 shall be taken into account in creating and using colour combinations.

For the special use of colour for safety, the selection of colours and colour combinations shall comply with ISO 3864-1.

NOTE *Conspicuity* of a colour combination is the distinctiveness between, and identification of, each colour used in the combination. In colour science, *conspicuous colour combination* applies to a combination with relatively large colour differences, whereas *colour discrimination* refers to small colour differences such as a just noticeable difference.

4.2 Luminance level

Colour appearance changes with luminance level. This effect shall be taken into consideration, particularly in choosing colours for use in low-luminance environments such as those in mesopic vision.

EXAMPLE In mesopic vision, reddish colours appear relatively darker and bluish colours appear brighter.

4.3 Ageing effect

Colour appearance changes with age. This effect shall be taken into account, particularly in choosing colours for use by older people.

NOTE Age-related change of colour perception is described in Reference [3].

EXAMPLE A bluish colour on dark background or vice versa is difficult for older people to see.

4.4 Viewing mode and condition

Colour appearance changes with the viewing mode such as the self-luminous mode or the reflective or object mode. This International Standard is based on the Munsell colour system, the colour appearance of which is the object mode. For colours of the self-luminous mode or light sources, such as electronic displays, this International Standard can be applicable when appropriate conversion of colour appearance is assured.

NOTE 1 Transformation of colour coordinates of Munsell colour system to CIE XYZ system has not been formulated yet. There are, however, some conversion methods or data for practical use which can be applied to the self-luminous mode colours (see Annex C).

NOTE 2 Some requirements for using colours in electronic visual displays are described in more detail in References [1] and [5].

NOTE 3 The light source of illumination is a factor affecting the appearance of object-mode colours. This International Standard is based on data taken under a daylight fluorescent lamp. When using other light sources, such as incandescent lamps or LEDs, it is noted that the colour appearance is shifted (see Reference [7]).

Colour appearance also changes with visual field size and surrounding colours. This International Standard is based on the field size larger than 20 min of arc of visual angle (2,9 mm from the 50 cm distance) below which colour appearance changes. Care shall be taken to ensure that the visual angle is above 20 min of arc.

This International Standard is based on dark surround where no strong contrast effect occurs. For coloured or lighter surround, the colour appearance also changes more or less with the surround, and care shall be taken not to cause strong change of the appearance.

5 Colour combinations using fundamental colours and their conspicuity

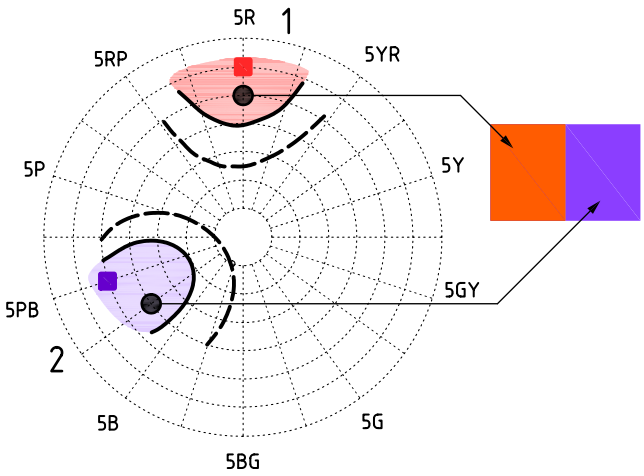
5.1 Fundamental colours and their combinations

Thirteen colours are defined as fundamental colours in this International Standard which are perceived as the most basic in human colour perception for people with normal colour vision. They are red, yellow-red (orange), yellow, green-yellow, green, blue-green, blue, purple-blue, purple, red-purple, white, grey, and black.

Each fundamental colour has a span in a colour space that consists of colours similar in appearance to each reference colour of the fundamentals. Two spans are definable with different extent of similarity: Span 1 consists of colours that are highly similar to the reference, Span 2 are colours that are somewhat or less similar to the reference.

NOTE Span 1 and Span 2, respectively, denote areas in which colours are perceived as similar to the reference fundamental colour with the 50 % and 10 % colour similarity (see 3.1 and 3.6).

The fundamental colours and their spans are used as components of colour combinations. Exact colours for a combination shall be selected respectively from the Span 1 of each fundamental colour (see Figure 1).



Key

1	red
2	purple-blue
———	Span 1
– – – –	Span 2
■	reference colour for red fundamental colour
■	reference colour for purple-blue fundamental colour

Figure 1 — Examples of Span 1 and Span 2 of fundamental colours in Munsell colour system and an example of colour combination (for value 5 plane only)

5.2 Classification of the conspicuity of colour combinations

The conspicuity of the colour combinations based on fundamental colours is classified into the following three groups depending on the geometrical relations of the Span 1 and Span 2 in a colour space.

a) **Highly conspicuous colour combinations**

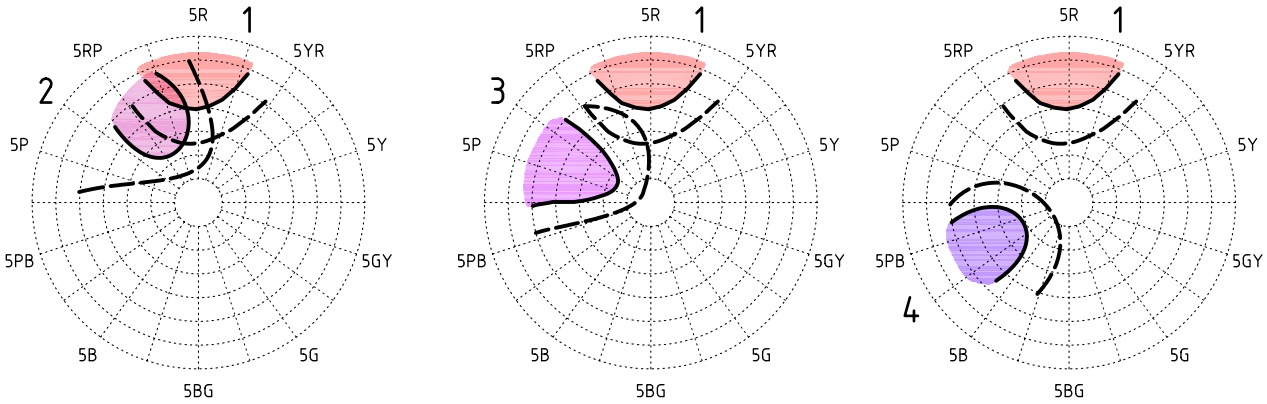
Combinations of fundamental colours for which Span 1 does not mutually overlap in the colour space and neither does Span 2. See Figure 2 c).

b) **Conspicuous colour combinations**

Combinations of fundamental colours for which Span 1 does not mutually overlap in a colour space, but Span 2 does. See Figure 2 b).

c) **Slightly conspicuous colour combination**

Combinations of fundamental colours for which Span 1 mutually overlaps in a colour space and Span 2 does as well. See Figure 2 a).



a) Slightly conspicuous (red–red-purple)

b) Conspicuous (red–purple)

c) Highly conspicuous (red–purple-blue)

Key

1	red
2	red-purple
3	purple
4	purple-blue
———	Span 1
– – – –	Span 2

Figure 2 — Colour combinations based on fundamental colours and their conspicuity with examples

5.3 Tables of two-colour combinations of fundamental colours and their conspicuity

Tables 1 to 4 show combinations of any two fundamental colours and their conspicuity evaluated based on the criterion shown in 5.2 for four different viewing conditions, respectively, i.e. younger people in the photopic condition, older people in the photopic condition, younger people in the mesopic condition, and older people in the mesopic condition.

For combinations of two or more colours, a set of fundamental colours shall be selected so that any pair in the set fulfils the lowest level of conspicuity required (see Annex B).

An exact colour for the fundamental colours in the combination shall be selected from the area of Span 1 for each of the fundamental colours (see 5.1 and Figure 3).

NOTE 1 Tables were derived from experimental data for younger people in their teens and 20s and older people in their 60s and 70s. Tables 1 and 3 for younger people are applicable to people under age 50 and Tables 2 and 4 are applicable for older people over 50.

NOTE 2 Tables were derived from experimental data at 500 lx and 0,5 lx for photopic and mesopic conditions, respectively, as their representative illuminance condition. Tables 1 and 2 are applicable to the photopic condition above 10 lx and Tables 3 and 4 are applicable for the mesopic condition below 10 lx by taking this value as a border between the photopic and mesopic condition.

NOTE 3 Some combinations in the tables show more conspicuous for older people than for younger people. It is noted that the spans for fundamental colours are generally narrower for older people and consequently, the exact colours of the combination selected from those spans will be sufficiently separated for older people.

Table 1 — Colour combinations and conspicuity of fundamental colours for younger people at the photopic level

	R	YR	Y	GY	G	BG	B	PB	P	RP	GRY	WHT	BLK
R		++	+++	+++	+++	+++	+++	+++	++	+	+++	+++	+++
YR			+	+++	+++	+++	+++	+++	+++	++	++	+++	++
Y				++	++	+++	+++	+++	+++	+++	+++	++	+++
GY					+	++	+++	+++	+++	+++	++	++	++
G						+	++	++	+++	+++	++	+++	++
BG							+	++	+++	+++	++	++	++
B								+	++	+++	++	++	++
PB									+	+++	++	++	++
P										+	+	++	++
RP											++	++	+++
GRE												++	++
WHT													+++
BLK													

Symbol legend: +++, highly conspicuous; ++, conspicuous; +, slightly conspicuous.

Abbreviations of the colour name: red (R), orange or yellow-red (YR), yellow (Y), green-yellow (GY), green (G), blue-green (BG), blue (B), purple-blue (PB), purple (P), red-purple (RP), grey (GRY), white (WHT), and black (BLK).

Table 2 — Colour combinations and conspicuity of fundamental colours for older people at the photopic level

	R	YR	Y	GY	G	BG	B	PB	P	RP	GRY	WHT	BLK
R		++	+++	+++	+++	+++	+++	+++	++	++	+++	+++	+++
YR			++	+++	+++	+++	+++	+++	+++	++	+++	+++	+++
Y				++	+++	+++	+++	+++	+++	+++	+++	++	+++
GY					+	++	+++	+++	+++	+++	++	+++	+++
G						+	++	++	+++	+++	++	+++	+++
BG							+	++	+++	+++	++	++	+++
B								+	++	+++	++	++	+++
PB									++	+++	++	++	+++
P										+	++	+++	+++
RP											++	++	+++
GRE												++	++
WHT													+++
BLK													

Symbols and colour name abbreviations are the same as those in Table 1.

Table 3 — Colour combinations and conspicuity of fundamental colours for younger people at the mesopic level

	R	YR	Y	GY	G	BG	B	PB	P	RP	GRY	WHT	BLK
R		++	+++	+++	+++	+++	+++	+++	++	+	+++	+++	++
YR			+	++	+++	+++	+++	+++	++	++	++	+++	+++
Y				++	+++	+++	+++	+++	++	++	++	+	+++
GY					+	++	++	++	++	+++	+	+++	++
G						+	++	++	+++	+++	++	+++	++
BG							+	+	++	+++	++	++	+++
B								+	++	+++	++	++	+++
PB									++	+++	++	++	++
P										+	++	++	+++
RP											++	++	+++
GRE												++	+++
WHT													+++
BLK													

Symbols and colour name abbreviations are the same as those in Table 1.

Table 4 — Colour combinations and conspicuity of fundamental colours for older people at the mesopic level

	R	YR	Y	GY	G	BG	B	PB	P	RP	GRY	WHT	BLK
R		+++	+++	+++	+++	+++	+++	+++	++	++	+++	+++	+++
YR			++	+++	+++	+++	+++	+++	++	+	+++	+++	+++
Y				+++	+++	+++	+++	+++	++	++	++	++	+++
GY					+	++	++	++	++	+++	+	+++	++
G						++	++	++	+++	+++	++	+++	++
BG							++	++	+++	+++	++	+++	+++
B								+	+++	+++	++	+++	+++
PB									++	+++	++	+++	++
P										+	++	+++	+++
RP											+++	+++	+++
GRE												+++	+++
WHT													+++
BLK													

Symbols and colour name abbreviations are the same as those in Table 1.

5.4 Span 1 of fundamental colours

Figures 4 to 7 show Span 1 for the 13 fundamental colours expressed in the Munsell colour system for four different viewing conditions such as younger people in photopic vision, older people in photopic vision, younger people in mesopic vision, and older people in mesopic vision, respectively.

NOTE When other colour systems aside from the Munsell colour system are applied, a conversion system from the Munsell system to the other one is required. The conversion system might be supplied by those systems with assumption of a given viewing condition. A guide is given in Annex C.

In each figure, spans of 13 fundamental colours are shown as coloured areas at four different constant value planes (lightness) of values 3, 5, 7, and 9. To avoid overlaps of the areas, some areas are expressed on separate colour charts at the same value plane. In such a case, only the contours of all the areas are shown in every figure so that their spatial relationships are visible.

For other value planes, such as values 2, 4, 6, and 8, linear interpolation along with the value axis is applicable assuming that the colour space is continuous and smoothly changing which indicates that the span of each fundamental colour forms a 3D shape similar to an elliptical solid in the colour space. Any colour in this elliptical solid can be selected for the colour combinations.

Similar figures for Span 2 are given respectively in Annex A for confirmation of the colour combination classification in 5.2 of the four viewing conditions: younger people in photopic vision, older people in photopic vision, younger people in mesopic vision, and older people in mesopic vision.

6 Procedures to create a colour combination

The following procedures shall be used to create colour combinations of particular colours based on fundamental colours and their conspicuity levels described in Clause 5.

a) Select a combination table according to the required viewing condition.

   EXAMPLE Table 2 for older people at the photopic level.

b) Select a two-colour combination from the table according to the required conspicuity level.

   EXAMPLE Green-yellow and red-purple for a highly conspicuous combination for older people at the photopic level from Table 2.

c) In case of a colour combination of three or more colours, select fundamental colours from the table so that any two-colour combination among those colours meets the lowest level of conspicuity necessary.

   EXAMPLE 1 Selection of green-yellow, blue, and red-purple, for a highly conspicuous combination to older people at the photopic level from Table 2.

   — Green-yellow and blue: highly conspicuous

   — Green-yellow and red-purple: highly conspicuous

   — Blue and red-purple: highly conspicuous

   EXAMPLE 2 Selection of green-yellow, blue-green, and red-purple for a conspicuous combination to older people at the photopic level from Table 2.

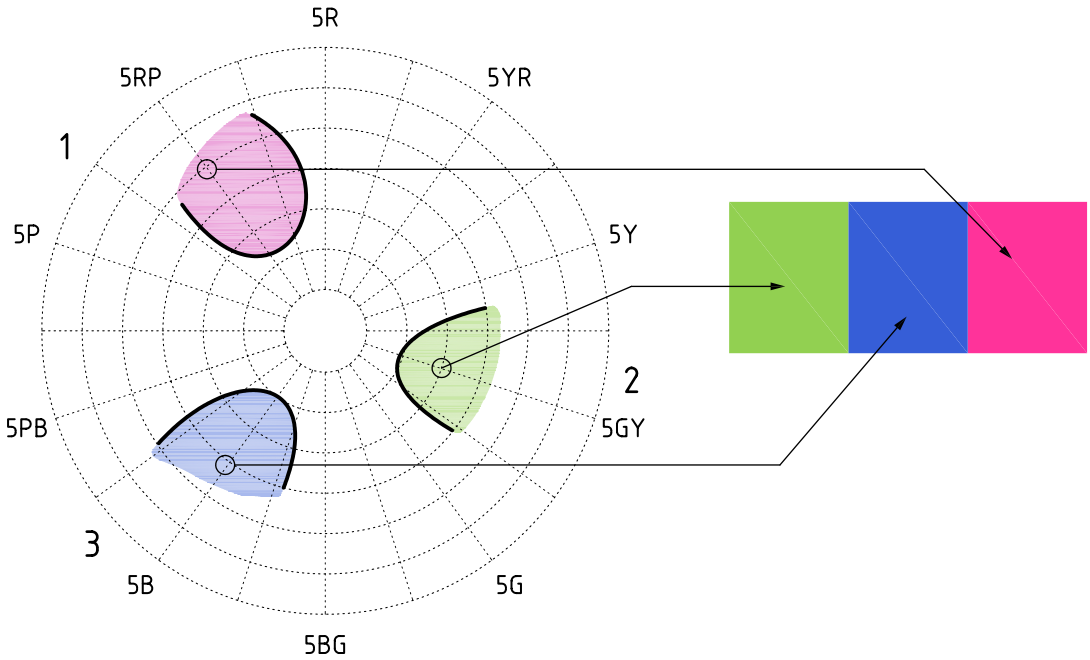
   — Green-yellow and blue: conspicuous

   — Green-yellow and red-purple: highly conspicuous

   — Blue-green and red-purple: highly conspicuous

d) Select a colour from the span of each fundamental colour at the corresponding condition referring to Figures 4 to 7 and make a combination (see Figure 3).

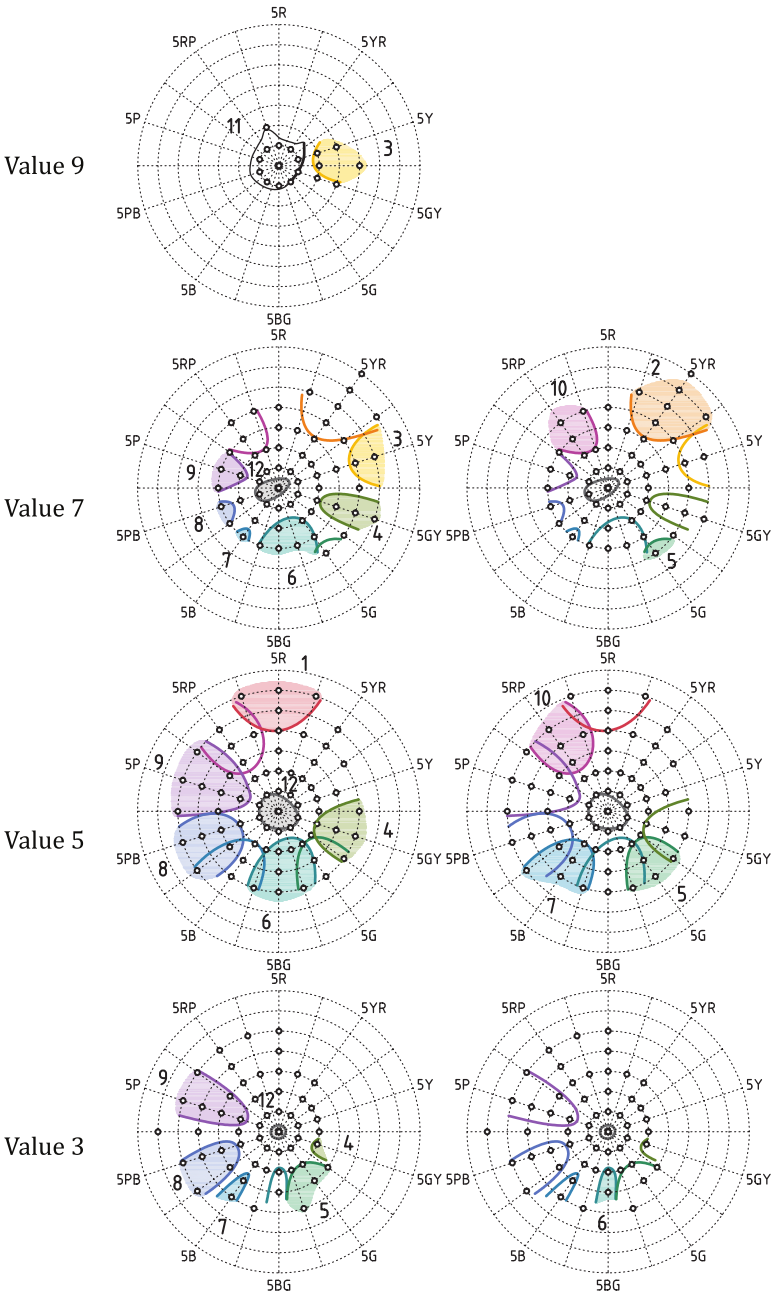
   NOTE Spans of fundamental colours in Figures 4 to 7 are specified as coloured areas in the Munsell colour system in one or more colour charts at a constant lightness (value) level to avoid overlaps. These data are taken from collaborative experimental works of China, Germany, Japan, Korea, Thailand, and USA using a method described in Reference [11].



Key

1 red-purple
2 green-yellow
3 blue

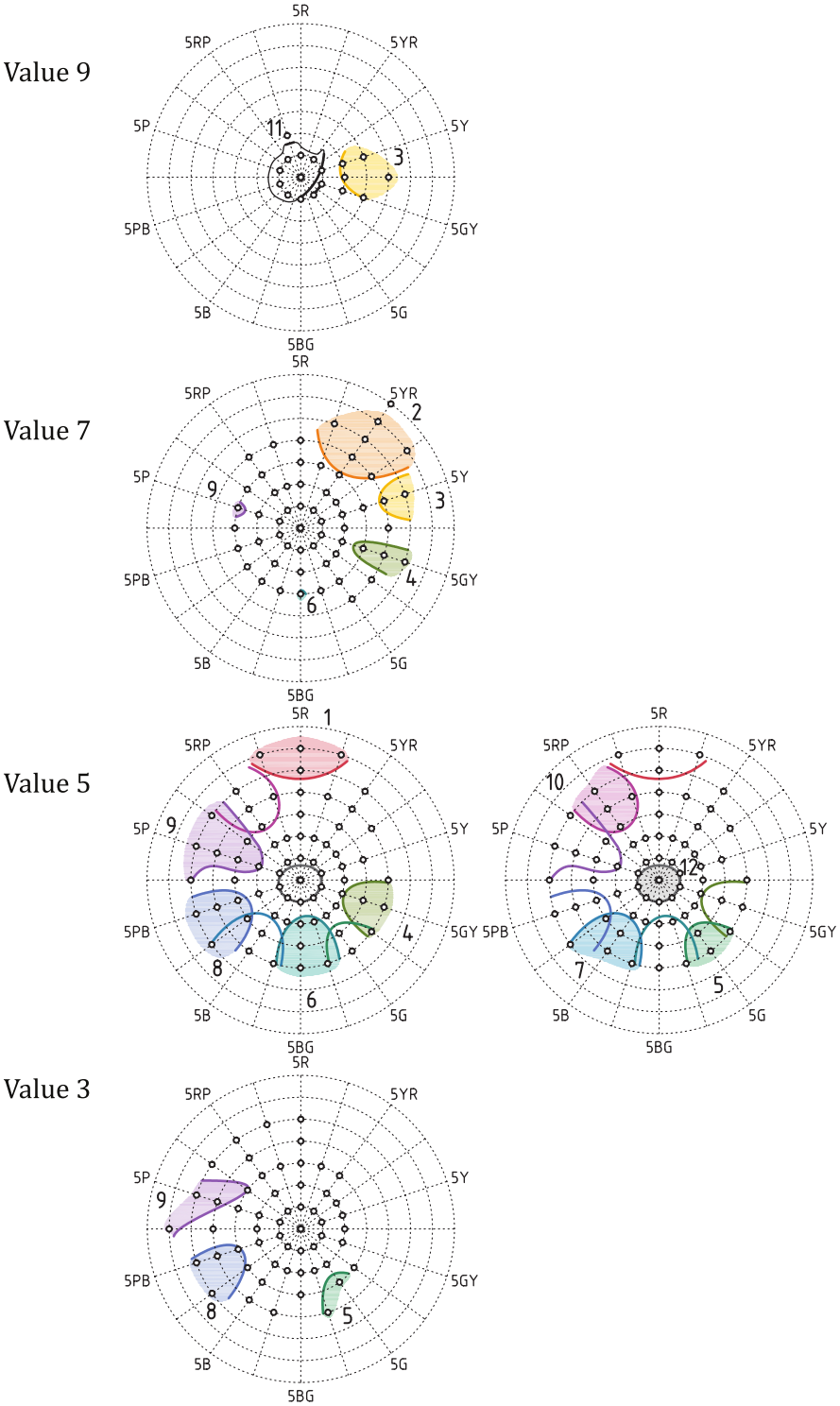
Figure 3 — Example of highly conspicuous colour combination to older people in photopic vision to illustrate a selection of colours from fundamental colours for creating a combination
(data taken from the value 5 plane of Figure 5)



Key

1	red	4	green-yellow	7	blue	10	red-purple
2	yellow-red	5	green	8	purple-blue	11	white
3	yellow	6	blue-green	9	purple	12	grey

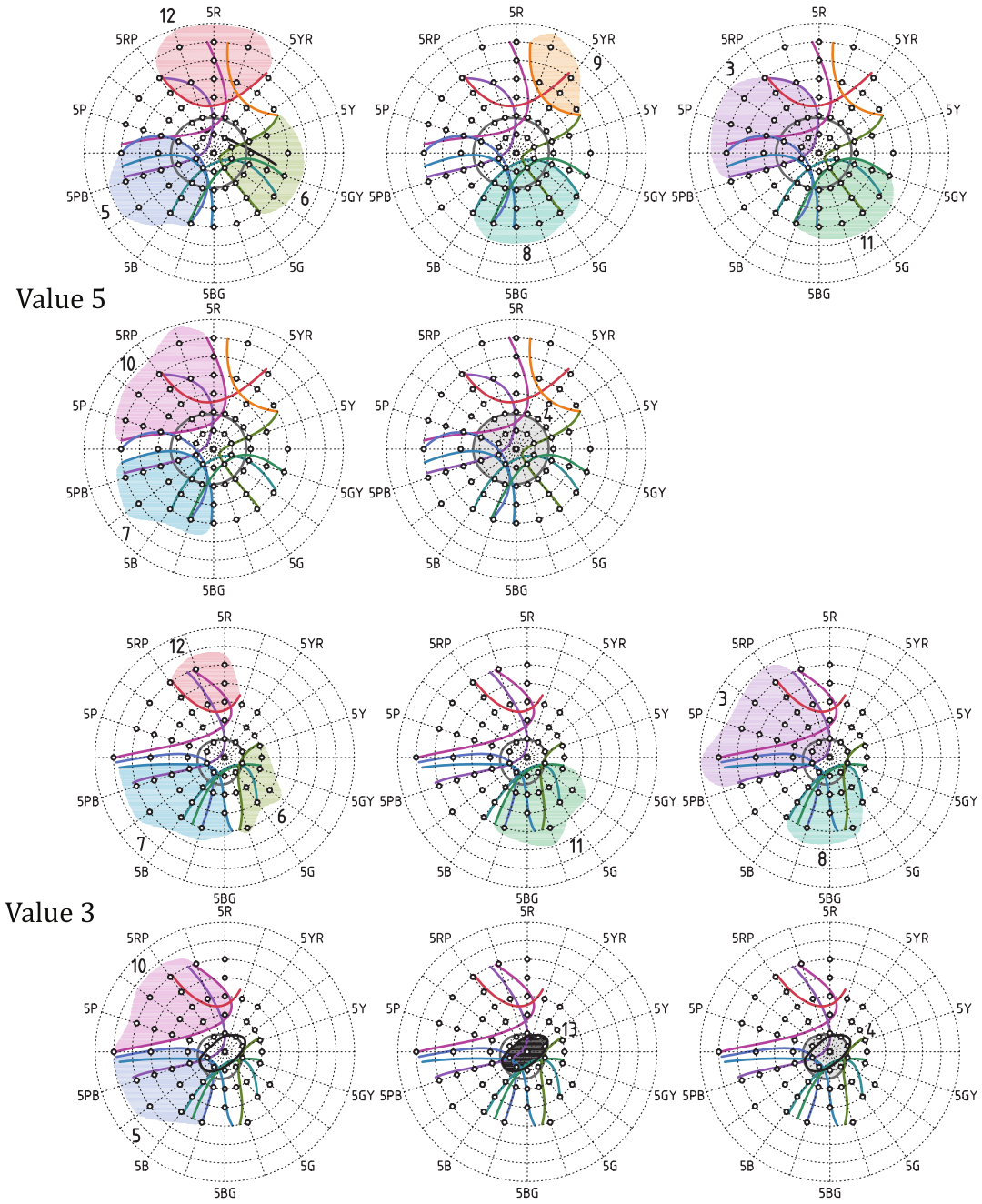
Figure 4 — Spans of fundamental colours for younger people in photopic vision (Span 1)



Key

1	red	7	blue
2	yellow-red	8	purple-blue
3	yellow	9	purple
4	green-yellow	10	red-purple
5	green	11	white
6	blue-green	12	grey

Figure 5 — Spans of fundamental colours for older people in photopic vision (Span 1)

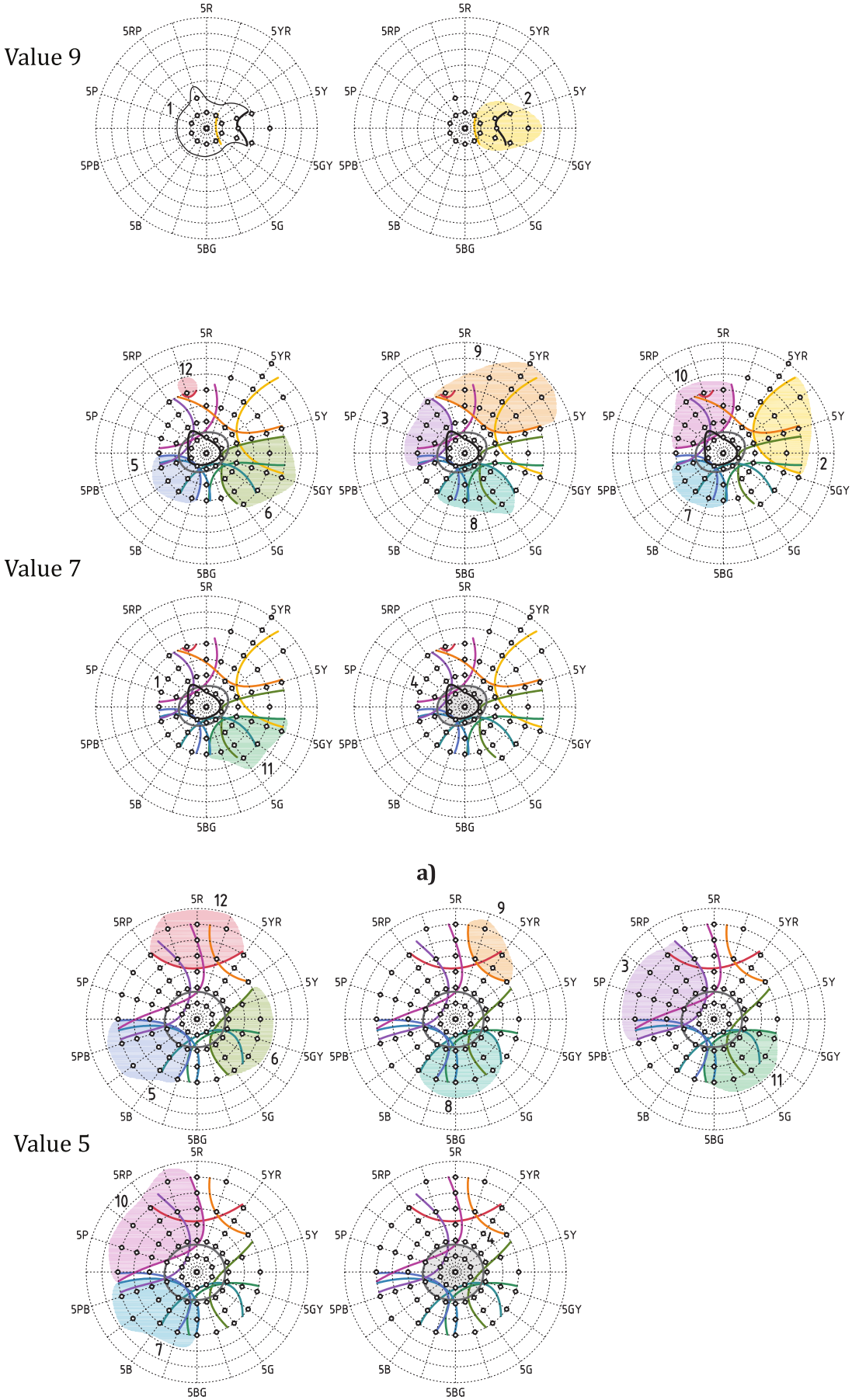


b)

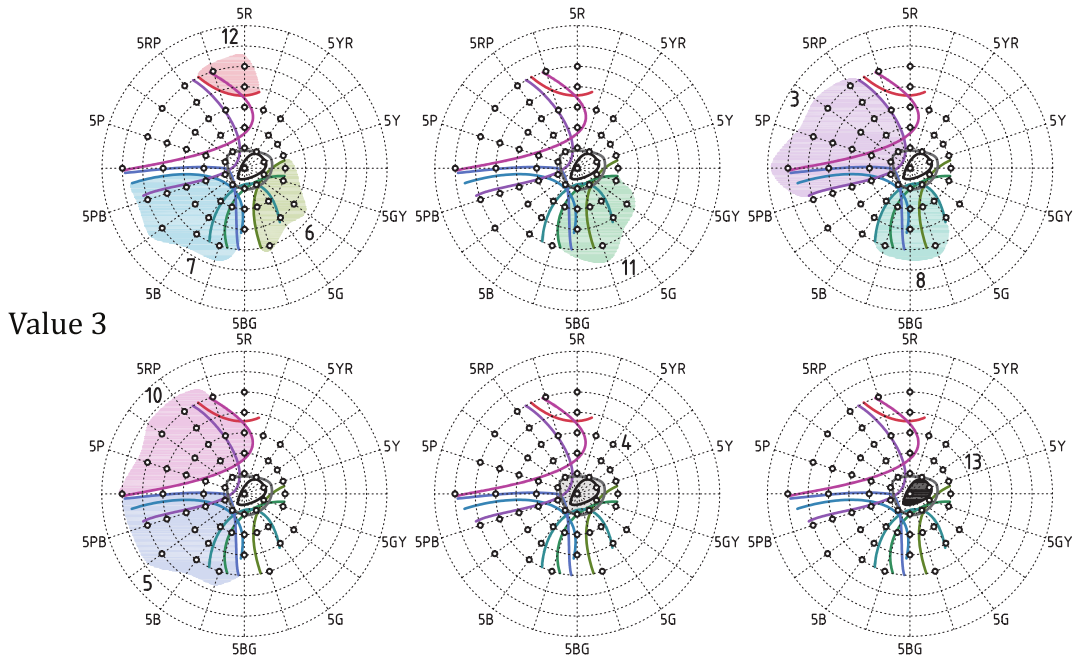
Key

1	white	7	blue
2	yellow	8	blue-green
3	purple	9	yellow-red
4	grey	10	red-purple
5	purple-blue	11	green
6	green-yellow	12	red

Figure A.1 — Spans of fundamental colours for younger people in photopic vision (Span 2)



a)

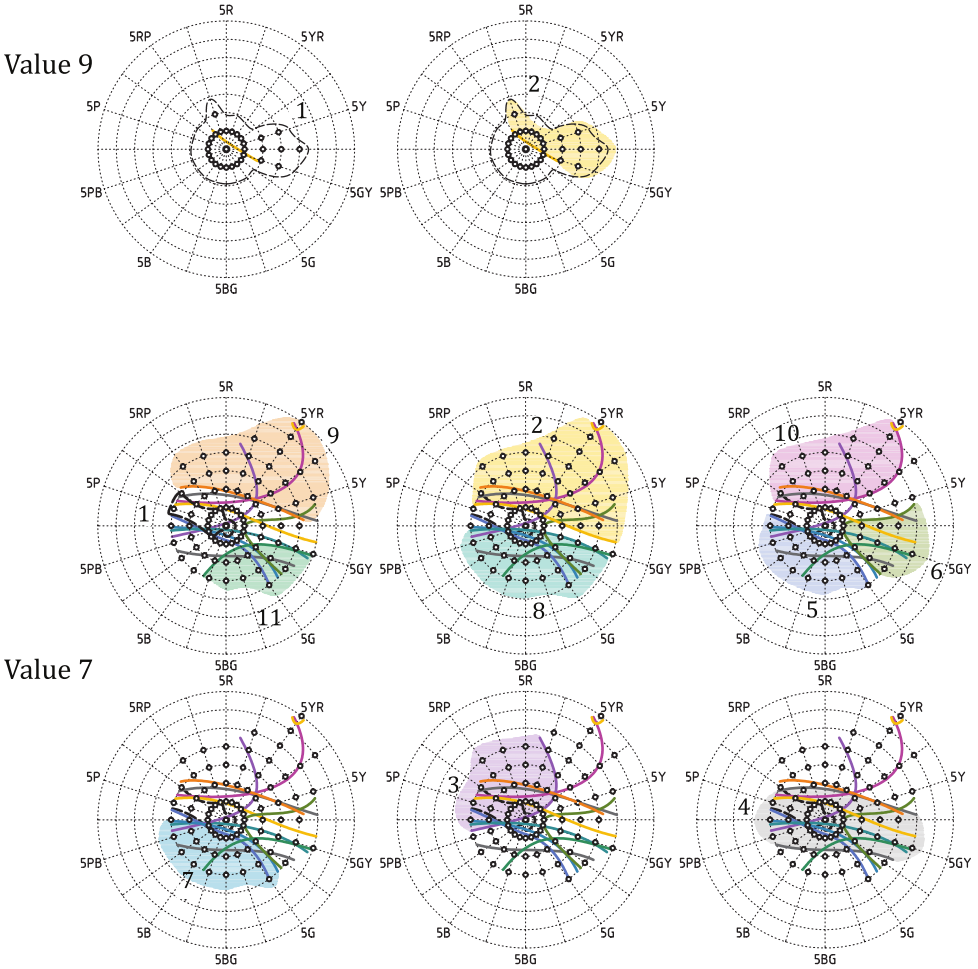


b)

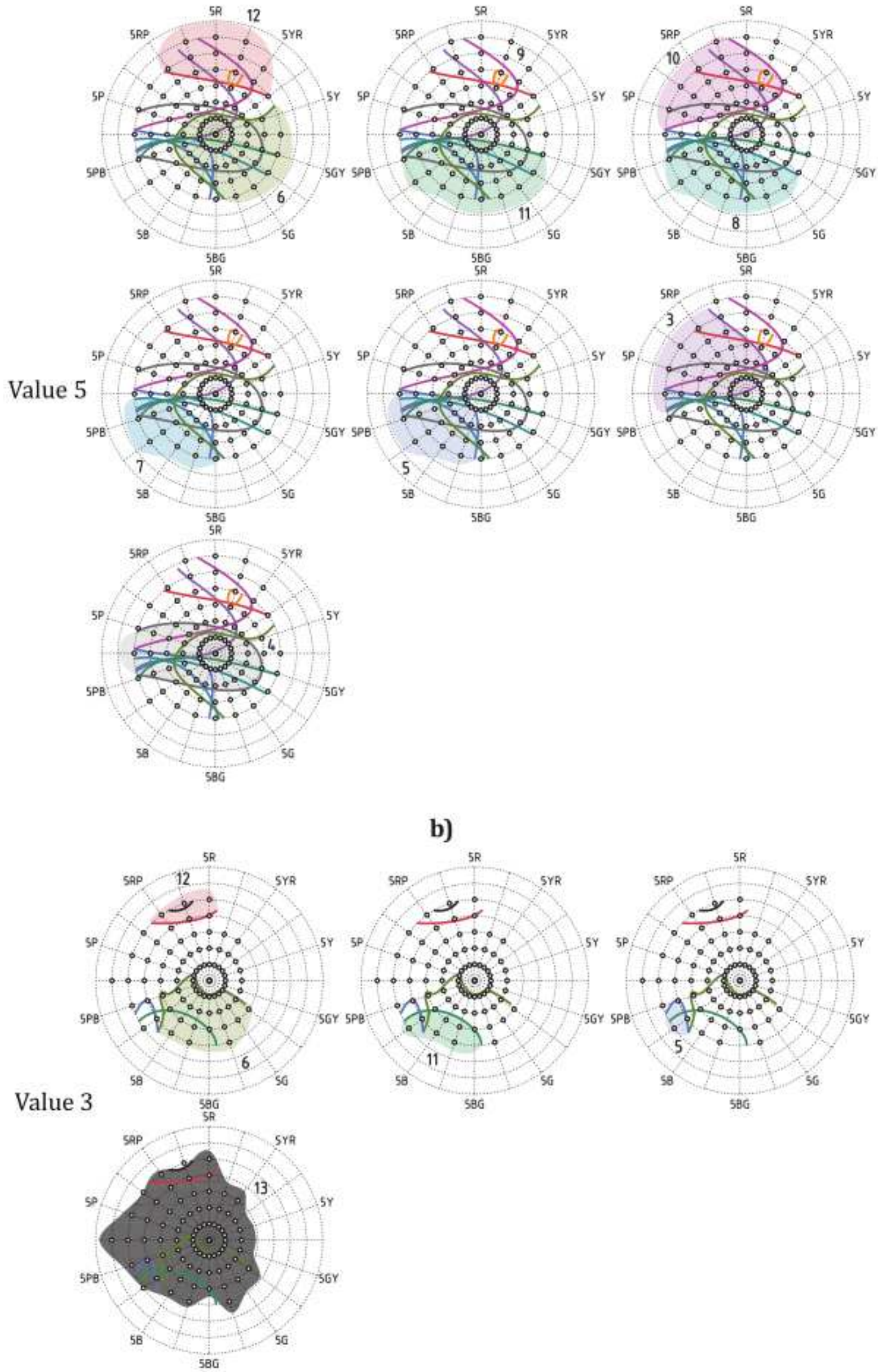
Key

1	white	7	blue
2	yellow	8	blue-green
3	purple	9	yellow-red
4	grey	10	red-purple
5	purple-blue	11	green
6	green-yellow	12	red

Figure A.2 — Spans of fundamental colours for older people in photopic vision (Span 2)



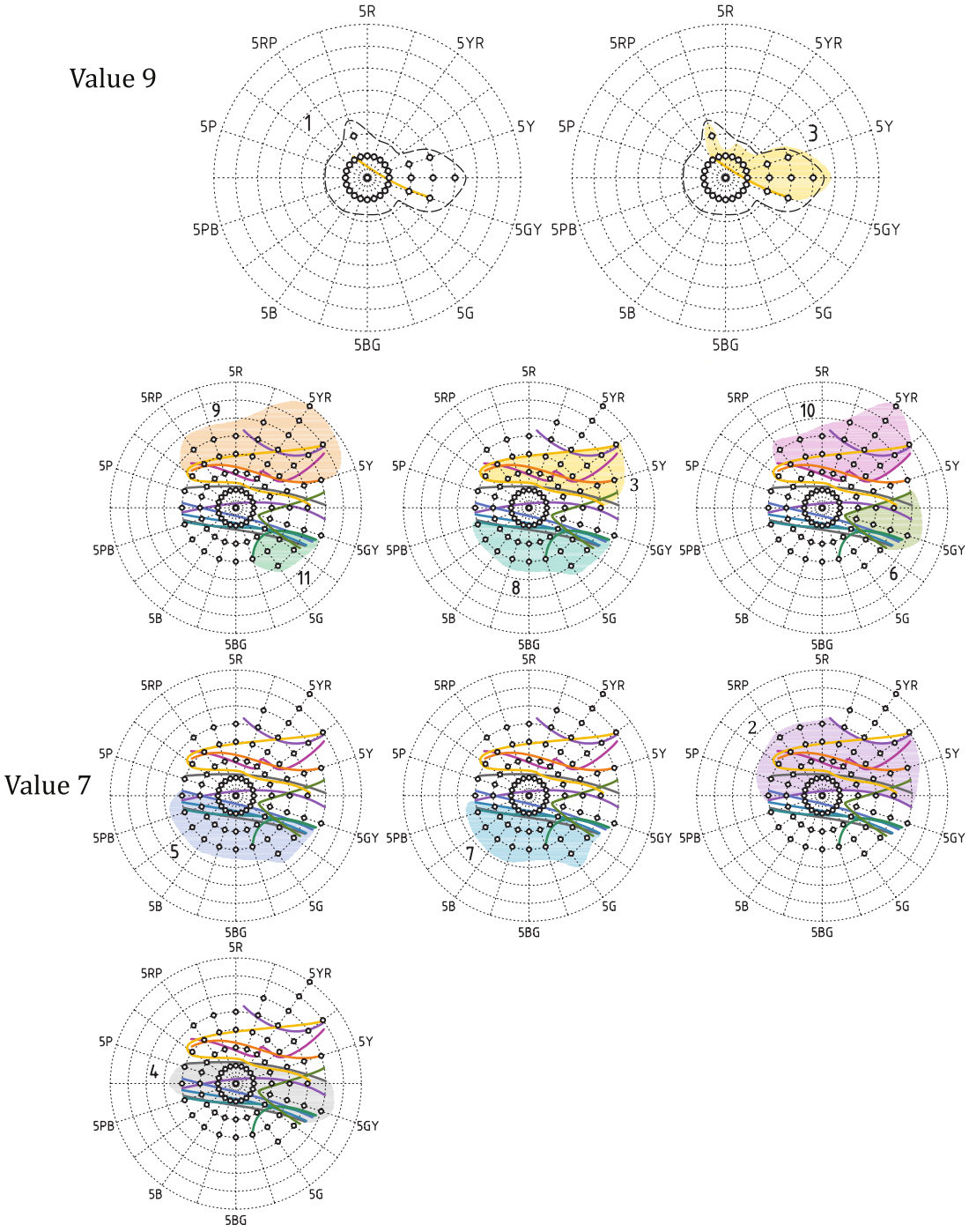
a)



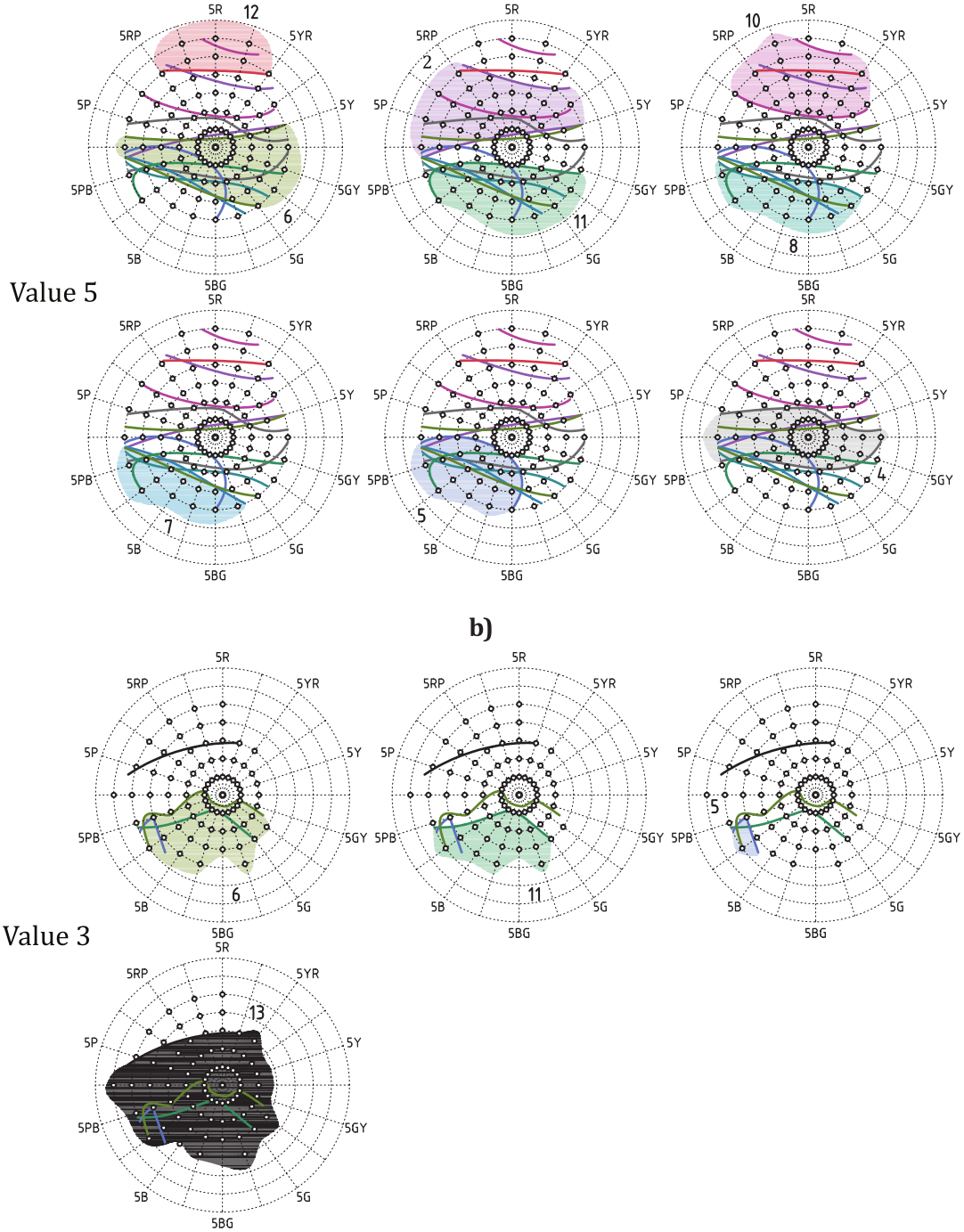
Key

1	white	4	grey	7	blue	10	red-purple	13	black
2	yellow	5	purple-blue	8	blue-green	11	green		
3	purple	6	green-yellow	9	yellow-red	12	red		

Figure A.3 — Spans of fundamental colours for younger people in mesopic vision (Span 2)



a)



Key

1	white	8	blue-green
2	purple	9	yellow-red
3	yellow	10	red-purple
4	grey	11	green
5	purple-blue	12	red
6	green-yellow	13	black
7	blue		

Figure A.4 — Spans of fundamental colours for older people in mesopic vision (Span 2)

Annex B
(informative)

Colouring example: A train network

B.1 General

Annex B provides an example of how the method of creating colour combinations is applied to a practical case. Colouring a map of train network is taken as an example.

B.2 Selection of fundamental colours

When a traffic network map which has five lines is depicted in five different colours, five fundamental colours can be selected by referring to one of the Tables 1 to 4, depending on the user and the condition in which the map is intended to be used. Table 2 is selected if the map is assumed to be viewed by older people in photopic vision.

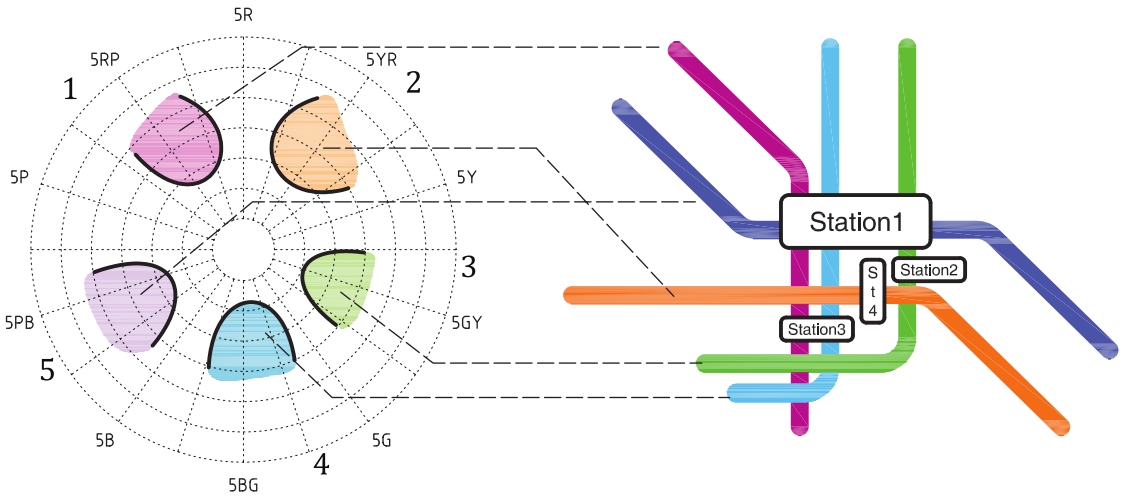
After the conspicuity level is defined, five fundamental colours are selected so that any two-colour combination among the five colours satisfies the minimum required level of the conspicuity. If the level is set at "conspicuity" for example, then the five colours of yellow-red, green-yellow, blue-green, purple-blue, and red-purple are selected to meet the conspicuity level. Table B.1 shows the five colours and their cross colour combinations marked in the table to show the conspicuity level.

Table B.1 — Colour combination table (copied from Table 2) for the condition for older people in photopic vision, with the selection of fundamental colours for colouring five traffic lines as an example

	R	YR	Y	GY	G	BG	B	PB	P	RP	GRY	WHT	BLK
R		++	+++	+++	+++	+++	+++	+++	++	++	+++	+++	+++
YR			++	+++	+++	+++	+++	+++	+++	++	++	+++	+++
Y				++	+++	+++	+++	+++	+++	+++	+++	++	+++
GY					+	++	+++	+++	+++	+++	++	+++	+++
G						+	++	++	+++	+++	++	+++	+++
BG							+	++	+++	+++	++	++	+++
B								+	++	+++	++	++	+++
PB									++	+++	++	++	+++
P										+	++	+++	+++
RP											++	++	+++
GRE												++	++
WHT													+++
BLK													

B.3 Selection of particular colours of the combination from fundamental colours

Exact colours can be chosen from each span of fundamental colours, i.e. a green-yellow colour from the Span 1 of the green-yellow fundamental colour area. In Figure B.1, five specific colours (yellow-red, green-yellow, blue-green, purple-blue, and red-purple) are shown as an example. Another choice of colours is possible as long as the colours are selected from each respective area. Any five-colour combination chosen in this manner will make the traffic lines conspicuous to older people in photopic vision.



Key

1 red-purple
2 yellow-red
3 green-yellow
4 blue-green
5 purple-blue

NOTE All the colours used here are at value 5 (moderate lightness level). Alternatively, other darker or brighter colours may be chosen from the value 3, 7, and 9 planes.

Figure B.1 — Example of colour combination for older people under photopic conditions

Annex C
(informative)

Guidance for transformation of Munsell colour system to CIE XYZ system and to sRGB system in monitor displays

C.1 General

While this International Standard is based on Munsell colour system, which is one of the recommended colour order system by CIE, other systems such as CIE XYZ or sRGB in monitor displays are widely used. This Annex provides a simple guidance on how to transfer colour coordinates of Munsell system to CIE XYZ and to sRGB system of monitor displays for the application of the present colour combination method to other colour systems.

C.2 Transformation of Munsell colour system to CIE XYZ and sRGB system

Figure C.1 shows a flow of transforming colour coordinates of Munsell colour system to those of CIE XYZ system and also to those of sRGB system used for monitor displays.

For the transformation between Munsell colour system and CIE XYZ system, no standard method or data have been proposed yet. However, practical conversion tables between H, V, C coordinates in the Munsell system and the x, y, Y values in the XYZ system exist under the condition of illuminant C or D_{65} and these tables can be used for the transformation between these two systems.[12] It is noted that x, y, Y values differ for different light sources, and CIE 1976 LAB system (L^*, a^*, and b^* values) can be used to approximately compensate these differences when using different light sources.

For the transformation from the XYZ system to sRGB system of monitor displays, there is a standard method recommended for use by IEC which is used to transfer the x, y, Y values to the R, G, B values of sRGB system for the defined condition of reference D_{65}. These R, G, B values can be transferred to R', G', B' values of the colour system of a particular monitor display system by using the method offered by display manufacturers. Inverse transformation is also possible for these processes.

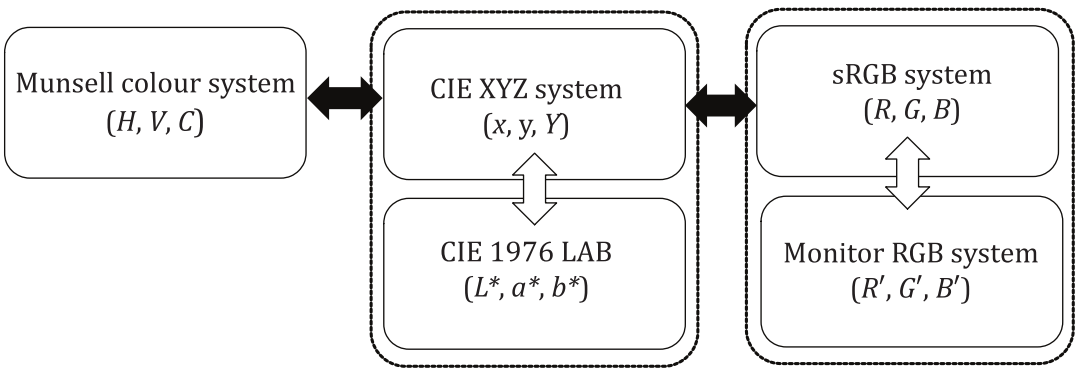


Figure C.1 — Transformation of Munsell system to CIE XYZ system and sRGB system

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