CS 498 KA
Experimental HCI & Interactive Technologies

Text Chapter 5

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Factor Analysis

In the final optional analysis step, the effect of factors other than the independent variable can be investigated.

STEP 4: Split the data so as to investigate more specific research questions (factor analysis).

The analysis so far has focused on determining whether the set of predefined conditions (the independent variable) has had any effect on performance.

We now consider extending the definition of independent variable to include other factors . In doing so, we define the primary independent variable as the set of conditions relating to the original research question to distinguish it from other factors.

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Factor Analysis

Factor analysis allows for a more in-depth investigation of the data according to the different tasks and experimental objects.

Recall that the reason why it is a good idea to use different experimental objects and tasks is to permit generalization of the results, ensuring that any significant results do not hold for only one type of task and only one type of experimental object.

The experimental results can therefore be generalized within the definitions of all tasks and experimental objects used, making them more useful.

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Factor Analysis

However, it may be the case that the effect of the conditions is more marked for particular tasks or experimental objects; for example, the experimental conditions may not have had an overall effect, but may have an effect only on task 1 or only on the largest of the experimental objects.

This means that there are two additional factors to be investigated: the effect of the tasks and the effect of the experimental objects.

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Factor Analysis

However, it may be the case that the effect of the conditions is more marked for particular tasks or experimental objects; for example, the experimental conditions may not have had an overall effect, but may have an effect only on task 1 or only on the largest of the experimental objects.

This means that there are two additional factors to be investigated: the effect of the tasks and the effect of the experimental objects.

Any aspect of the experiment that the experimenter has had control over and that has had varied values can be considered a relevant secondary factor.

These factors may include, for example, the gender of the participants, the time of day when the data collection took place, or different computing equipment used for different participants. Any of these factors could have affected the results: we call these secondary independent variables.

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Factor Analysis

Note, however, that only those factors (and their values) that can be clearly described and differentiated are appropriate secondary independent variables.

There must be a clear qualitative difference (i.e., difference in quality) between the values that the factor can take. Examples of inappropriate factors with no qualitative difference include three randomly generated graphs of similar size, four identical experimental rooms differing only in room number, etc.

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Factor Analysis

Note, however, that only those factors (and their values) that can be clearly described and differentiated are appropriate secondary independent variables.

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In contrast, qualitative differences can be described, for example, for three data sets of different size or different structure; the interfaces for three mobile devices produced by different companies; and experimental rooms with different size windows.

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Factor Analysis

Our main research question is still focused on whether the primary independent variable (the set of conditions) has had an effect on the dependent variable (the performance). In analyzing the data further to determine whether other factors have had an effect on performance, there are two approaches:

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Factor Analysis

Our main research question is still focused on whether the primary independent variable (the set of conditions) has had an effect on the dependent variable (the performance). In analyzing the data further to determine whether other factors have had an effect on performance, there are two approaches:

1. Producing all possible statistics for all combinations of factors, and investigating those that are interesting (i.e., performing a multiway factor analysis).

This approach, which can only be used for data that are normally distributed, is the method typically favored by psychologists.

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Factor Analysis

In multiway factor analysis, other relevant factors are considered as independent variables in addition to the primary independent variable (the set of conditions) on which the research question is based.

The experimental objects often constitute relevant and interesting additional independent variables to be investigated for their possible effects on the primary dependent variable or variables.

But there are countless possibilities for additional independent variables.

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Factor Analysis

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Factor Analysis

Our main research question is still focused on whether the primary independent variable (the set of conditions) has had an effect on the dependent variable (the performance). In analyzing the data further to determine whether other factors have had an effect on performance, there are two approaches:

2. Focusing on the primary research question first, and then investigating other factors as necessary (i.e., performing a selective factor analysis).

This approach entails devising appropriate and interesting second-level research questions, and investigating each of these in turn, producing only those statistics relevant to these second-level research questions.

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Factor Analysis

Illustration of Approach 1:

Producing all possible statistics for all combinations of factors, and investigating those that are interesting (i.e., performing a multiway factor analysis). This approach, can only be used for data that are normally distributed.

Consider a within-participant experiment that aims to answer the research question, "Which visual form of an image best supports visual search?"

The independent variable is the visual form of an image with three conditions: Black and White (BW), Color (C), and Grey-scale (GS).

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Factor Analysis

Illustration of Approach 1:

In the experiment, each screen presents forty items, and there is only one task – identify the largest image.

To ensure generalizability of the results, there are three experimental objects, each using a different form of image: images of the environment (photographs, P), paintings (photographs of paintings, PP), and graphics (images created using a digital imaging tool, G).

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Factor Analysis

Illustration of Approach 1:

In the experiment, each screen presents forty items, and there is only one task – identify the largest image.

To ensure generalizability of the results, there are three experimental objects, each using a different form of image: images of the environment (photographs, P), paintings (photographs of paintings, PP), and graphics (images created using a digital imaging tool, G).

Error and response time data are collected, but only error data are considered here. Data for this experiment (fabricated for the purposes of illustration) are shown next. The primary independent variable is visual form (BW, C, GS) because this is directly related to the research question. A secondary independent variable is image type (with three secondary conditions, P, PP, G).

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Table A3.1: *Data used for demonstrating two approaches to factor analysis*

	Black and white			Colour			Grey scale		
	P	PP	G	P	PP	G	P	PP	G
p1	0.69	0.59	0.07	0.36	1.00	0.55	0.64	0.38	0.40
p2	0.40	0.20	0.43	0.27	0.51	0.79	0.53	0.34	0.42
p3	0.76	0.50	0.39	0.34	0.80	0.60	0.67	0.33	0.35
p4	0.76	0.03	0.76	0.27	0.48	0.58	0.59	0.33	0.57
p5	0.72	0.74	0.00	0.33	0.63	0.92	0.63	0.56	0.07
p6	0.69	0.08	0.75	0.36	0.95	0.91	0.37	0.52	0.75
p7	0.72	0.67	0.05	0.42	0.64	0.96	0.77	0.40	0.25
p8	0.70	0.04	0.67	0.51	0.83	0.95	0.53	0.36	0.39
p9	0.43	0.75	0.21	0.55	0.70	0.96	0.15	0.60	0.60
p10	0.23	0.02	0.51	0.42	0.63	0.96	0.47	0.58	0.35
p11	0.39	0.76	0.54	0.43	0.80	0.90	0.20	0.51	1.00
p12	0.53	0.55	0.55	0.40	0.61	0.92	0.46	0.51	0.37
p13	0.08	0.87	0.74	0.56	1.00	0.87	0.74	0.54	0.67
p14	0.10	0.55	0.90	0.25	0.66	0.94	0.65	0.52	0.06
p15	0.09	0.52	0.33	0.26	0.82	0.57	0.48	0.52	0.73
p16	0.69	0.01	0.53	0.38	0.81	0.71	0.59	0.52	0.10
p17	0.59	0.58	0.22	0.40	0.67	0.76	0.63	0.52	0.34
p18	0.39	0.19	0.55	0.35	0.43	0.60	0.65	0.56	0.09
p19	0.18	0.57	0.22	0.54	1.00	0.55	0.03	0.57	0.72
p20	0.22	0.18	0.53	0.50	0.97	0.60	0.63	0.40	0.22

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Factor Analysis

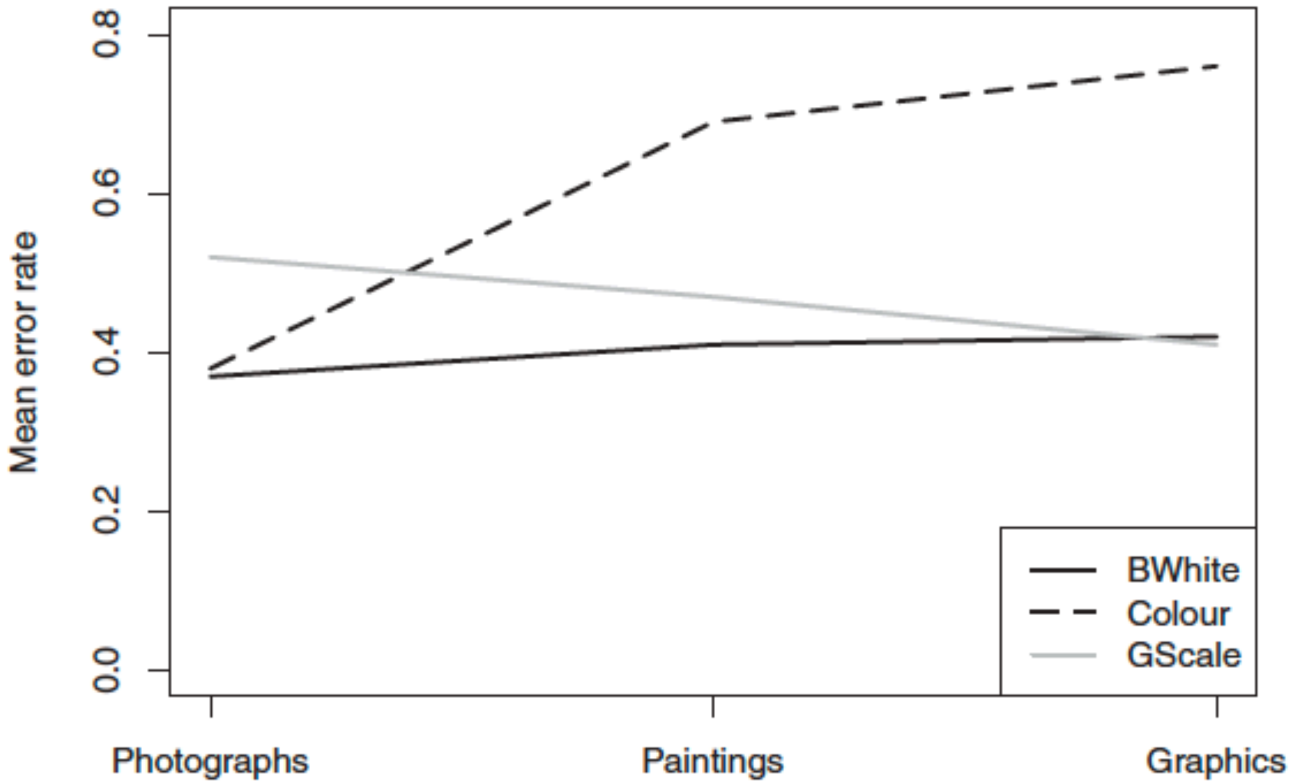

Figure A3.1: Line chart showing the interaction between Visual Form and Image Type.

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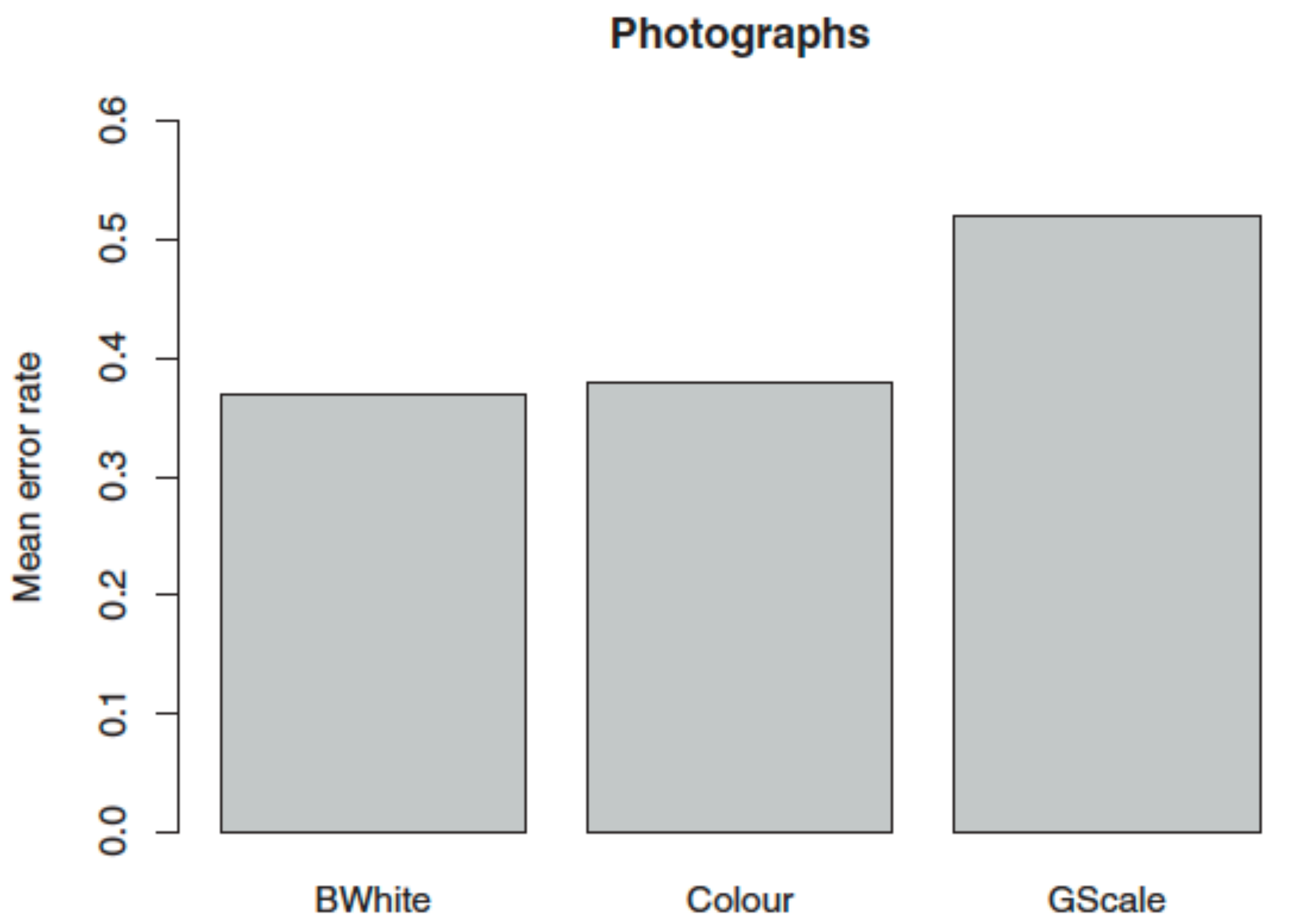

Figure A3.2: Mean error rate for Photographs.

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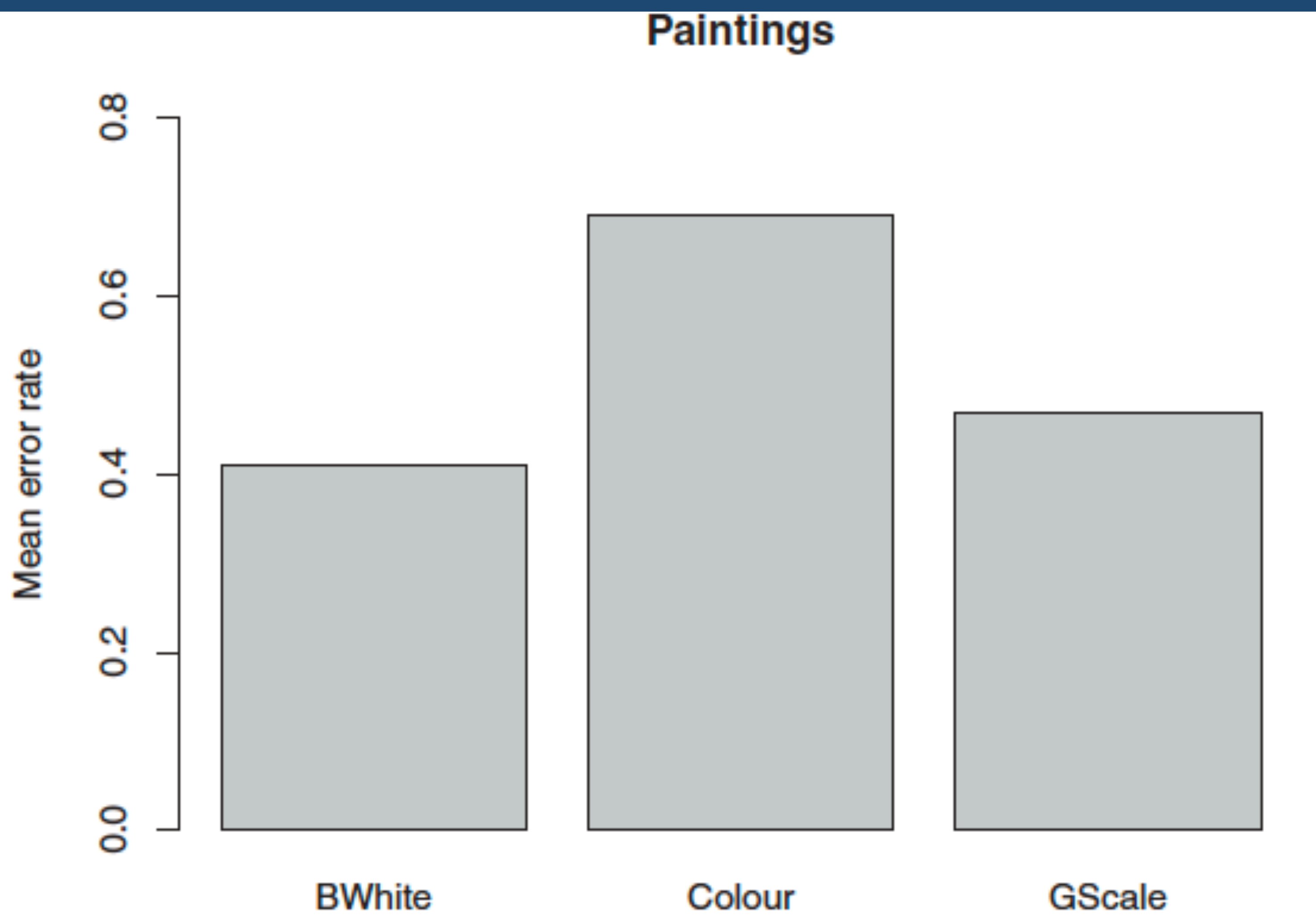

Figure A3.3: Mean error rate for Paintings.

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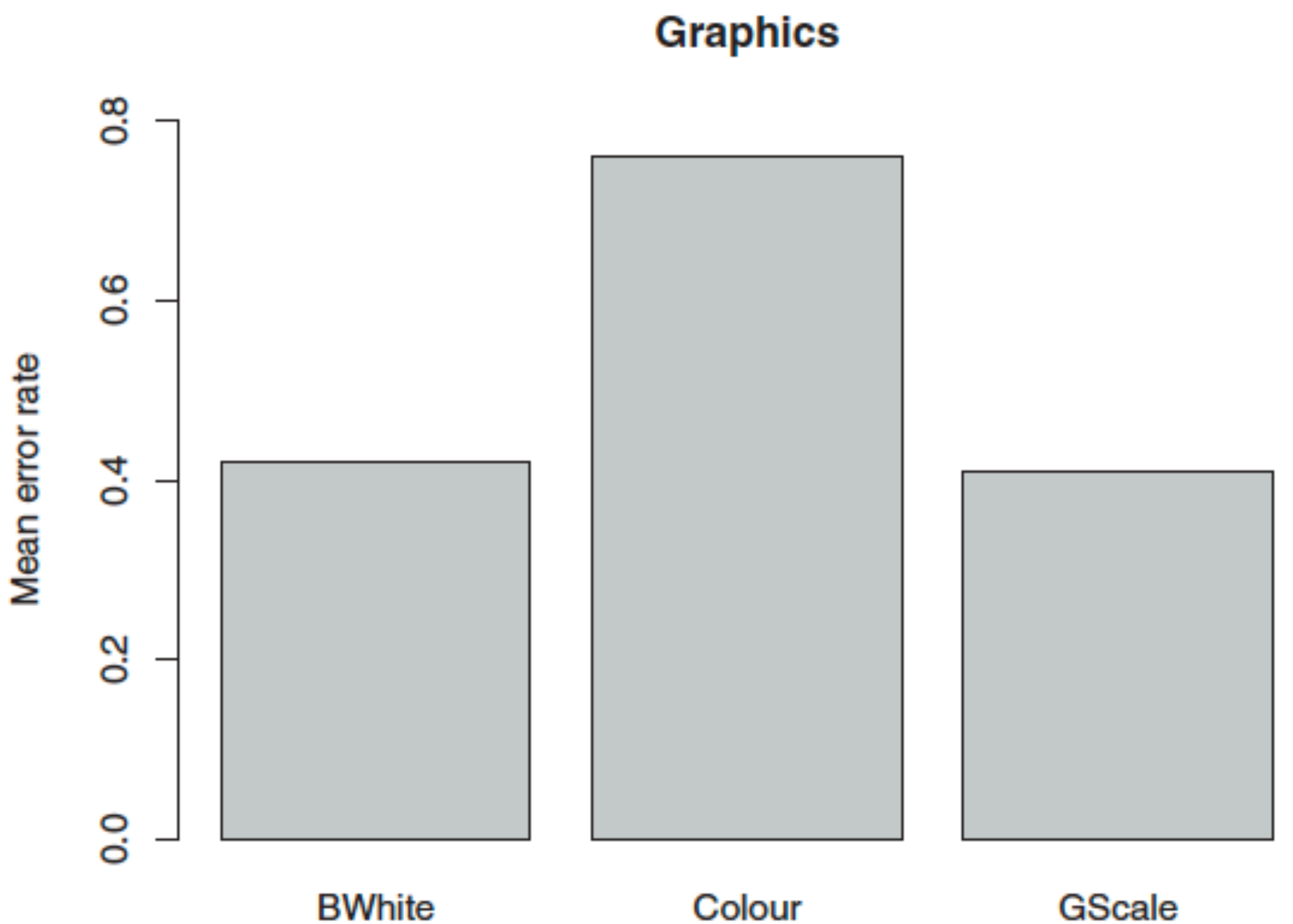

Figure A3.4: Mean error rate for Graphics.

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Factor Analysis

We investigate the interactions by splitting the data into three separate data sets according to image type, and then perform three separate ANOVA/ single-step pairwise analyses (each using p= .05), one for each image type, and report a separate result for each image type.

The results of the analysis for this experiment would be reported as four separate results:

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1. A repeated measures two-way ANOVA revealed a significant interaction between visual form and image type, $F(4,116) = 11.29$, $p < .001$.
2. **For Photographs** (Figure A3.2), there were significant differences in performance as represented by the error data according to visual form: $F(2,58) = 6.152$, $p = .004$. A single-step pairwise comparison test ($p = .05$) revealed where the differences lie: the Grey-scale condition produced significantly worse performance than both Black and White ($p = .021$) and Colour ($p = .005$).
3. **For Paintings** (Figure A3.3), there were significant differences in performance as represented by the error data according to visual form: $F(2,58) = 20.525$, $p < .001$. A single-step pairwise comparison test ($p = .05$) revealed where the differences lie: the Colour condition produced significantly worse performance than both Black and White ($p < .001$) and Grey-scale ($p < .001$).
4. **For Graphics**, (Figure A3.4) there were significant differences in performance as represented by the error data according to visual form: $F(2,58) = 26.316$, $p < .001$. A single-step pairwise comparison test ($p = .05$) revealed where the differences lie: the Colour condition produced significantly worse performance than both Black and White ($p < .001$) and Grey-scale ($p < .001$).

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SELECTIVE Factor Analysis

Illustration of Approach 2:

Focusing on the primary research question first, and then investigating other factors as necessary (i.e., performing a selective factor analysis).

This approach entails devising appropriate and interesting second-level research questions, and investigating each of these in turn, producing only those statistics relevant to these second-level research questions.

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SELECTIVE Factor Analysis

First, we look at the independent variable in which we are interested (the three visual forms) and perform an ANOVA/single-step pairwise test. We then report our primary result:

1. There were significant differences in performance as represented by the error data according to visual form: $F(2,58) = 46.067$, $p < .001$. Single-step pairwise comparison tests ($p = .05$) revealed pairwise differences: the Black and White condition resulted in fewer errors than Color ($p < .001$) and Grey-scale ($p = .028$), and Grey-scale resulted in fewer errors than Colour ($p < .001$).

The visual form conditions can therefore be ranked in order best to worst: Black and White, Grey-scale, and Color.

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SELECTIVE Factor Analysis

Having answered our main research question with respect to the primary independent variable, we may be interested to see if the image type affected the relative performance of the different visual forms.

This may be because of our own intuition as to the different nature of the image type, observation of the participants while they did the different tasks, or comments made by the participants in the post-experiment interviews.

We can therefore investigate further to see if there was any effect of image type on the performance, as shown next.

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SELECTIVE Factor Analysis

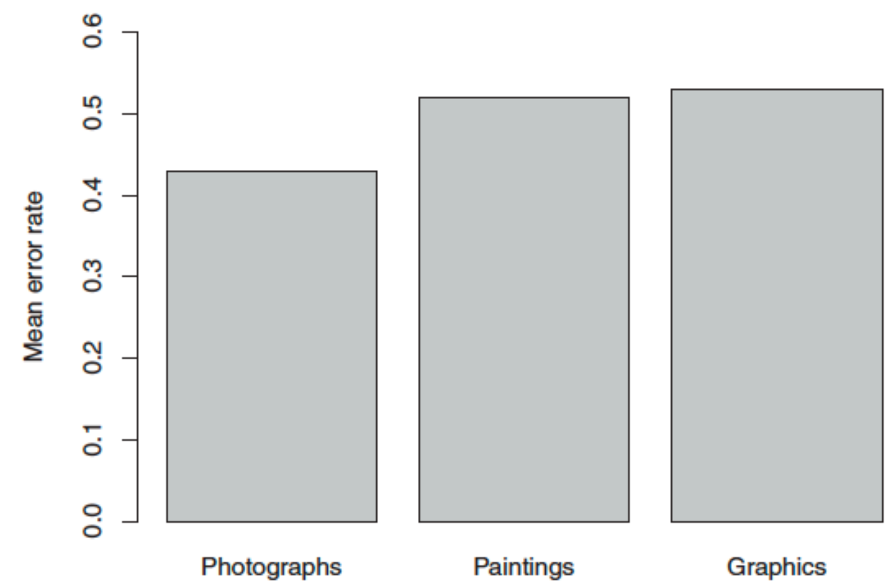

Figure A3.6: Mean errors for the three different types of image, where Image Type is a secondary factor in the experiment.

There were significant differences in performance as represented by the error data according to image type: $F(2,58) = 6.576$, $p = .003$. There are pairwise differences between the Photograph condition and Paintings ($p = 0.021$) and between the Photographs and Graphics conditions ($p = .008$). This result confirms any intuition that it might be useful to investigate each type of image separately.

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SELECTIVE Factor Analysis

We can then pose three second-level research questions:

- "Which visual form of an image best supports visual search for photographs?"
- "Which visual form of an image best supports visual search for paintings?"
- "Which visual form of an image best supports visual search in graphics?"

Answering these questions requires performing a selective factor analysis on the data, with respect to the image type secondary factor. We use a Bonferroni adjustment to reduce the *p*-value according to the number of separate data sets analysed; that is, $p = .05/3 = .0167$.

We split the data into three sets according to image type, perform three separate ANOVA/Tukey analyses (each using $p = .0167$), one for each image type, and report a separate result for each image type. Note that this is exactly the same process followed in the preceding multiway factor analysis, except that we are required to use a reduced *p*-value.

We can then report these three results:

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SELECTIVE Factor Analysis

For Photographs, there were significant differences in performance as represented by the error data according to visual form: $F(2{,}58) = 6.152$, $p = .004$. A single-step pairwise comparison test (with adjusted $p = .0167$) revealed that the Grey-scale condition produced significantly worse performance than Colour ($p = .005$).

For Paintings, there were significant differences in performance as represented by the error data according to visual form: $F(2{,}58) = 20.525$, $p < .001$. A single-step pairwise comparison test (with adjusted $p = .0167$) revealed where the differences lie: the Colour condition produced significantly worse performance than both Black and White ($p < .001$) and Grey-scale ($p < .001$).

For Graphics, there were significant differences in performance as represented by the error data according to visual form: $F(2{,}58) = 26.316$, $p < .001$. A single-step pairwise comparison test ($p = .0167$) revealed where the differences lie: the Colour condition produced significantly worse performance than both Black and White ($p < .001$) and Grey-scale ($p < .001$).

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SELECTIVE Factor Analysis

Note that we have lost one of the significant results that we reported in the two-way factor analysis: the result that the Grey-scale condition produced significantly worse performance than Black and White for photographs. This is because the *p*-value for this pairwise difference (.021) is greater than the Bonferroni-adjusted probability that we need to use for this second-level analysis (.0167).

These are deliberately extreme data designed to illustrate a subtle interaction effect; for more realistic data, the reduced *p*-value used in selective factor analysis might have a more radical effect on the number of secondary-level analyses that can be reported.