Assessment of Permanent Marker Removal Methods

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Experimental Design

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Contents

1 Introduction

Permanent markers are markers that are used to create permanent markings on objects. One of the hallmark characteristics of a permanent marker is its stubbornness to being erased which makes it impervious to a multitude of removal methods. This could potentially cause unwanted defects and imprints all over undesirable locations. To combat this issue, we have decided to test multiple products that have been rumored to have some effects on removing permanent markings. In order to test the effectiveness of each product, an experiment was conducted. In this report, we thoroughly discuss the effectiveness of the different removal products using statistical analysis and make conclusions based off of those results.

1.1 Names and Descriptions of Investigational Products

In this experiment, we test the removal methods against a streak made by a black Sharpie marker. The streak will be made on 2 (two) different surface materials; white tiling and a whiteboard. We will be testing 4 (four) different removal methods. The four removal methods are:

- Dollar Store brand acetone based nail polish remover.
- Room temperature, undistilled Nestle natural spring water.
- Clorox bleach cleaner - spray variant.
- Greenworks natural all-purpose cleaner - spray variant.

In addition to the main removal products, we also used the following products to aid us in the investigation. These products were kept constant throughout the experiment. The additional products are:

- Generic brand, brown paper napkins.
- Dollar store brand, 500 mL spray bottles.

2 Study Objective and Hypothesis

2.1 Objectives

To evaluate the effectiveness of the 4 (four) different removal methods and to determine whether the surface on which the markings are made has an effect on the removal difficulty (interaction effect).

2.2 Hypothesis

Due to the chemical composition of permanent markers, they can be vulnerable to a variety of organic compounds. We believe that removal methods that contain higher concentrations of chemical will be more effective than those with lower concentrations, regardless of whether the surface is tile or the whiteboard. This leads us to hypothesize that the Nail Polish remover (99% acetone) will be more effective than Clorox bleach cleaner (1-5% bleach), Clorox Greenworks (unknown composition) and the control group water respectively.

3 Study Design and Rationale

3.1 Description of Study Design

We will begin by making identical 8cm lines on both a white board and on our tile squares. The marker line is then photographed and allowed to dry for a period of one minute. At this point, our wiper (Paven) will receive a clean paper towel that has one spritz of a cleaner (sprayed by the same person throughout the experiment) that is unknown to him. The wiper will then wipe the marker line exactly twice, starting from the bottom. We then repeat the process three times for each cleaner on each surface type. Using the two-way ANOVA sample size adjustment in figure 4 (appendix), we wish to achieve a power of 0.8 at the 0.05 significance level, so we need 48 samples. However, due to time and monetary constraints, we decided to cut the sample size in half for a total of 24 observations. Finally, we will use an image processing system to quantify the differences in marker intensity, our response variable (the higher the value the better).

This is a blinded, randomized, fully crossed and balanced two factor between-subjects design. Both the sprayer and the wiper do not know the chemical they are dealing with (blinding). Each 8 cm marker line was numbered from 1-24, and randomly assigned through a random number generator to a treatment (randomization). All treatment combinations were available in this experiment (fully-crossed) and every treatment had the same number of units (balanced), but not all sample units were able to receive all the treatments (between-subjects).

3.2 Methodology

Target Population	Permanent Marker Brands
Experimental Unit	One 8 cm ink line drawn by a permanent marker
Factor A	Removal Method: Nail Polish Remover (NP), Clorox Cleaner (CC), Water (W), Green Cleaner (GC)
Factor B	Surface Material: Tile, Whiteboard
Treatment	(NP, Tile), (NP, Whiteboard), (CC, Tile), (CC, Whiteboard), (W, Tile), (W, Whiteboard), (GC, Tile), (GC, Whiteboard)
Response	Difference in raw score based off of the app "ImageJ" (measures how much ink was wiped off)

4 Results

Before we actually looked at our models, we first applied Cook's distance to make sure we didn't have any outliers affecting our response variable in figure 6 (appendix). Because there are no values greater than 1, we know there are no outliers and we can proceed to analyze our models. Since we have a two factor design, we checked for interaction effects. We examined the interaction plot and analyzed the R output of the interaction model. The results are illustrated in figures 1 and 2(appendix).

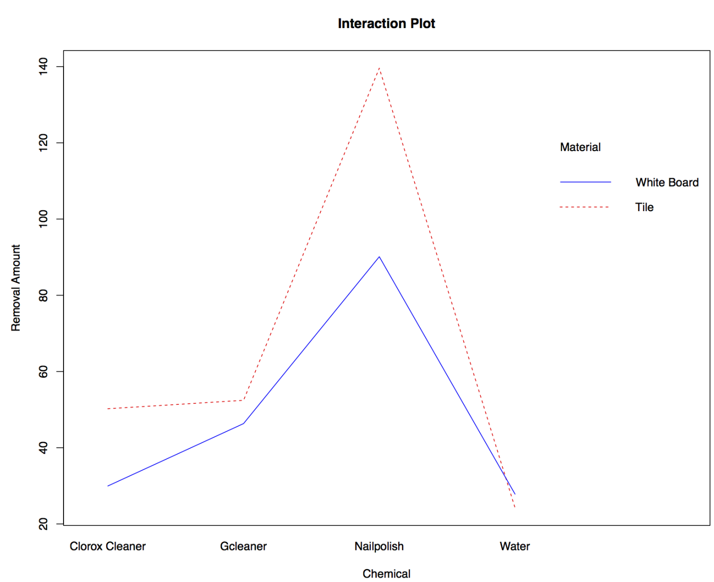

Figure 1: Interaction Plot

Notice that in the our interaction plot we observe intersecting lines. However, after analyzing the interactive model summary we see the difference in means of whiteboard material is not statistically significant. Hence, we make the assumption that there is no interaction.

We next fit an additive model to see the main effects of our factors in figure 3 (appendix).

After analyzing the additive model summary, we notice only the nail polish remover is statistically significant at the 5% level. Of all the products, we have evidence to suggest that on average, the nail polish remover performs the best when used to clean permanent markings made by permanent markers. In general, if we look at the ANOVA summaries of both the interaction and general additive model in figures 7 and 8 (appendix), we can see that the type of chemical (removal method) used is the only statistically significant factor compared to the material and the interaction between material and chemical. Through the box plot in figure 5 (appendix), we can also clearly see that the nail polish remover, on average, has the highest difference in raw removal score of the ink which confirms our hypothesis.

5 Limitations

- Chemical reaction rate: It's possible if given more time to interact with the marker, certain cleaners would be more effective.
- Spray bottle variation: Although all bottles were set to the same spray rate, variations in the amount of chemical sprayed may have affected our results. One possible fix could be using an eyedropper instead which has a set volume of liquid coming out.
- Pressure variations in wiping: Although we kept the wiper and number of wipes constant, it is possible there were variations in pressure of wipes affecting our results.
- Marker ink level: We used a single marker to make every single line that we experimented on. Markers are known to be less effective the more they're used. This could mean that the lines created earlier in the experiment might have been stronger and ultimately harder to remove.
- Sample size: As we mentioned earlier, the optimal sample size to retrieve a power of 0.8 in the experiment is 48, but because of the price of tiles and all the cleaning products, we opted to use 24 samples instead. This means the power of our experiment is below 0.8 which increases the chance of us failing to reject the null when the null is true; a type 2 error.

6 Conclusions

In conclusion, our research clearly showed that out of all the permanent marker removal methods tested, the nail polish remover is the most effective. This substantiates our hypothesis that removal methods that contain higher concentrations of chemicals will be more effective than those with lower concentrations, regardless of whether the surface is tile or the whiteboard. If we were to re-conduct this entire research to make it better, we would definitely need to control for more nuisance variables such as chemical reaction rate and spray bottle variation. The effectiveness of a removal method can have a profound effect on the daily lives of people whether its cleaning the bathroom, removing a stain off a shirt, or simply trying to get rid of a permanent marker ink. Through the results of this experiment, companies can consider making more effective removal methods; maybe a more potent form of the chemical compounds found in nail polish removers which could help make cleaning effortless.

7 References

https://www.rdocumentation.org/

8 Appendix

```
Call:
lm(formula = Difference ~ Chemical * Material)

Residuals:
    Min      1Q  Median      3Q     Max 
-40.237 -12.774   2.071  17.865  46.673 

Coefficients:
                                        Estimate Std. Error t value Pr(>|t|)    
(Intercept)                               24.222     15.003   1.615   0.1260    
ChemicalClorox Cleaner                    26.005     21.217   1.226   0.2381    
ChemicalGcleaner                          28.223     21.217   1.330   0.2021    
ChemicalNailpolish                       115.387     21.217   5.438 5.47e-05 ***
MaterialWhite Board                        3.601     21.217   0.170   0.8674    
ChemicalClorox Cleaner:MaterialWhite Board -23.871   30.005  -0.796   0.4379    
ChemicalGcleaner:MaterialWhite Board      -9.708     30.005  -0.324   0.7505    
ChemicalNailpolish:MaterialWhite Board   -53.085     30.005  -1.769   0.0959 .  
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 25.99 on 16 degrees of freedom
Multiple R-squared:  0.7492,	Adjusted R-squared:  0.6394 
F-statistic: 6.827 on 7 and 16 DF,  p-value: 0.000742
```

Figure 2: Interactive Model Summary

```
Call:
lm(formula = Difference ~ Chemical + Material)

Residuals:
    Min      1Q  Median      3Q     Max 
-41.436 -19.034  -1.868  12.338  45.571 

Coefficients:
                       Estimate Std. Error t value Pr(>|t|)    
(Intercept)               35.05      12.04   2.913  0.00893 ** 
ChemicalClorox Cleaner    14.07      15.22   0.924  0.36697    
ChemicalGcleaner          23.37      15.22   1.535  0.14126    
ChemicalNailpolish        88.84      15.22   5.836 1.27e-05 ***
MaterialWhite Board      -18.07      10.76  -1.678  0.10968    
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 26.37 on 19 degrees of freedom
Multiple R-squared:  0.6933,	Adjusted R-squared:  0.6287 
F-statistic: 10.74 on 4 and 19 DF,  p-value: 0.0001009
```

Figure 3: Additive Model Summary

```
     Balanced two-way analysis of variance sample size adjustment 

              a = 4
              b = 2
      sig.level = 0.05
          power = 0.8
              n = 6

NOTE: n is number in each group, total sample = 48
```

Figure 4: Sample Size Prediction for Experiment

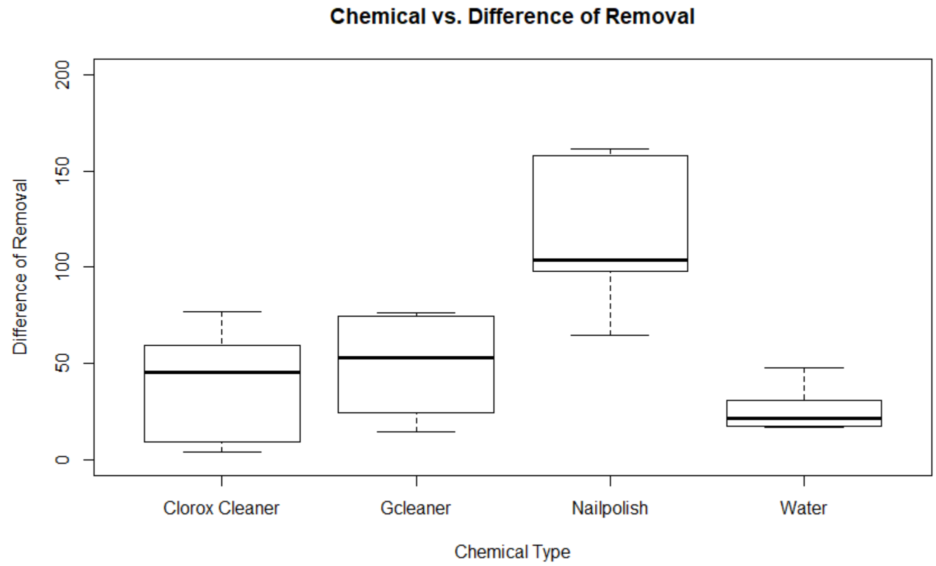

Figure 5: Chemical Type vs. Score Difference Boxplot

```
          15           18            4           16           14           23           19            9           22 
4.385205e-05 1.278052e-03 1.779771e-03 2.420083e-03 5.683368e-03 6.249322e-03 7.340161e-03 8.975640e-03 1.235165e-02 
          11            7            5           17            3            2           21           20            1 
1.349988e-02 1.423242e-02 4.343031e-02 4.702129e-02 5.545492e-02 5.960694e-02 6.618871e-02 7.816990e-02 9.189341e-02 
           6           24           12            8           13           10 
9.351741e-02 1.080984e-01 1.127128e-01 1.428195e-01 2.247856e-01 3.024466e-01 
```

Figure 6: Cook's Distance for Interaction Model

```
Analysis of Variance Table

Response: Difference
                  Df  Sum Sq Mean Sq F value    Pr(>F)    
Chemical           3 27903.3  9301.1 13.7746 0.0001066 ***
Material           1  1958.1  1958.1  2.8999 0.1079276    
Chemical:Material  3  2406.6   802.2  1.1881 0.3456851    
Residuals         16 10803.7   675.2                      
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Figure 7: Figure 7: ANOVA for Interaction Model

```
Analysis of Variance Table

Response: Difference
          Df  Sum Sq Mean Sq F value    Pr(>F)    
Chemical   3 27903.3  9301.1 13.3774 6.296e-05 ***
Material   1  1958.1  1958.1  2.8163    0.1097    
Residuals 19 13210.4   695.3                      
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Figure 8: Figure 8: ANOVA for General Additive Model

```r
setwd("D:\\School Work\\STA305\\Data Analysis") #Set my directory

install.packages("pwr2")
library(pwr2)

chem <- read.csv("Chemical Data.csv") #read the data
chemicaldata <- chem[0:24,0:3] #Clean the dataset
chemicaldata <- droplevels(chemicaldata)

attach(chemicaldata)

#Changing Reference Group
chemicaldata = relevel(chemicaldata, ref="Water")

#Interaction Model
model <- lm(Difference ~ Chemical*Material)
summary(model)
anova(model)

#Residual graph for IM
plot(model, main= "Chemical/Material Interaction vs. Difference of Removal", which = 2)
hist(model$residuals, main= "Chemical/Material Interaction vs. Difference of Removal", xlab = "Interaction Model Residuals")

#Calculating cook's distance and influential points
inf = sort(cooks.distance(model))
inf

#General Additive Model
model2 <- lm(Difference ~ Chemical + Material)
summary(model2)
anova(model2)

#Residual graph for GAM
plot(model2, main= "Chemical and Material vs. Difference of Removal", which = 2)
hist(model2$residuals,  main= "Chemical and Material vs. Difference of Removal", xlab = "General Additive Model Residual")

#Calculating cook's distance and influential points
inf = sort(cooks.distance(model2))
inf

#Boxplots
boxplot(Difference~Chemical, xlab="Chemical Type", ylab="Difference of Removal", ylim=c(0, 200), main="Chemical vs. Difference of Removal")
boxplot(Difference~Material, xlab="Material", ylab="Difference of Removal", ylim=c(0, 200), main="Material vs. Difference of Removal")

#Two Sample t-test + Barplot for Material
means = c(mean(Difference[Material == "White Board"]), mean(Difference[Material == "Tile"]))
Differences.Material = data.frame(means, c("White Board", "Tile"))
t.test(Difference[Material == "White Board"], Difference[Material == "Tile"], var.equal = FALSE)

#Sample Size Prediction
ss.2way(a=4, b=2, alpha=0.05, beta=0.2, f.A=0.5, f.B=0.5, B=100)
```

Figure 9: R Code