FINAL PROJECT
HAND - EYE EXPERIMENT

STAT 424: ANOVA and Design of Experiments

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Introduction

Hand-eye coordination, or eye-hand coordination, is the ability to do activities that require the simultaneous use of our hands and eyes, like an activity that uses the information our eyes perceive (visual-spatial perception) to guide our hands to carry out a movement.

Experiment Setting & Goal

In this experiment, There are two drawn adjacent circles and in a single experiment run, a person is tasked to mark dots in these two circles alternatively for a time period of 10 seconds. The response measured is the number of cycles (sets of dots) marked across both circles. This response is a measure of the level of hand-eye coordination.

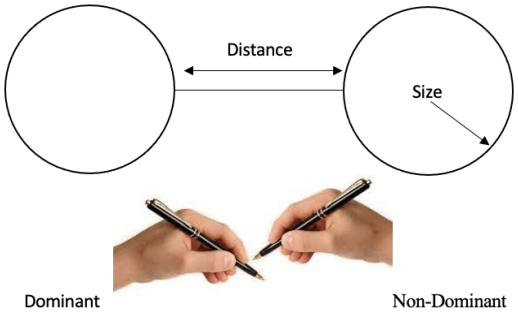

Fig 1: Experiment

The **goal** of the experiment is to investigate the effect of the hand type, size of the circle, and the distance between the circles on the response. The aim is also to determine if adjustments to either of these three factors would affect the response. Some of the research questions that can be addressed through this experiment are as follows:

- How does the type of Hand (Dominant/ Non-Dominant) affect the coordination?
- How does the distance between the two circles (small/large) affect the coordination?
- Does changing the size of the circle (small/ large) affect the coordination?

Experimental Design

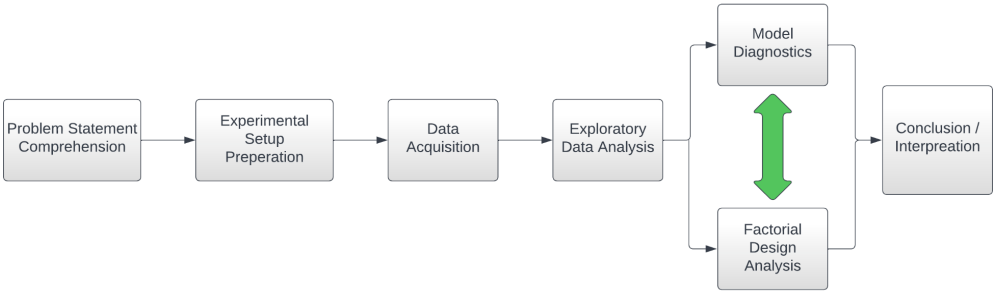

Fig 2: Experiment Process

In the above-described experiment, there are three factors each with two levels. The factors are the size of the circle, the distance between the circles, and the type of hand used. The experiment is replicated twice so there are 16 runs. The significance level chosen for the experiment is **0.05**.

Table 1: Factor Levels

S. No	Factors	Level 1	Level 2
1	Size of Circle (Radius)	Small (0.75 in)	Large (1.5 in)
2	Distance between Circle	Small (1.5 in)	Large (4.0 in)
3	Hand Type	Non-Dominant	Dominant

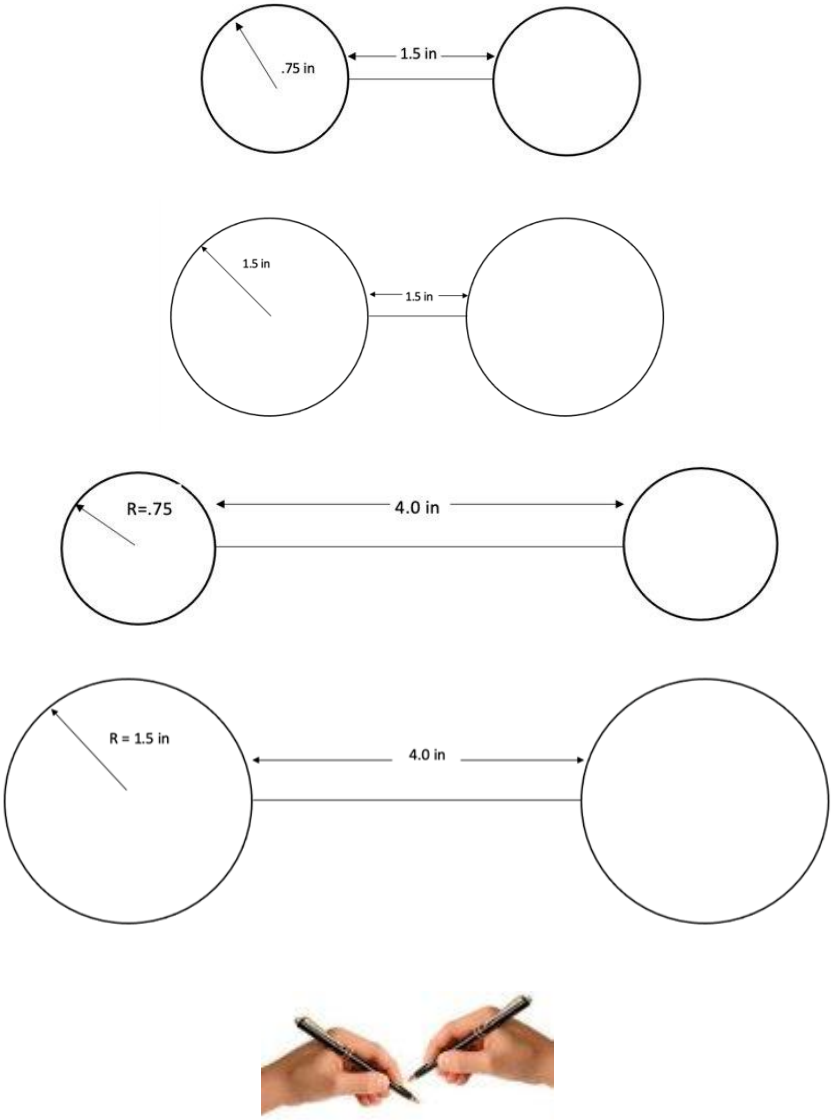

Fig 3: Treatment Combinations

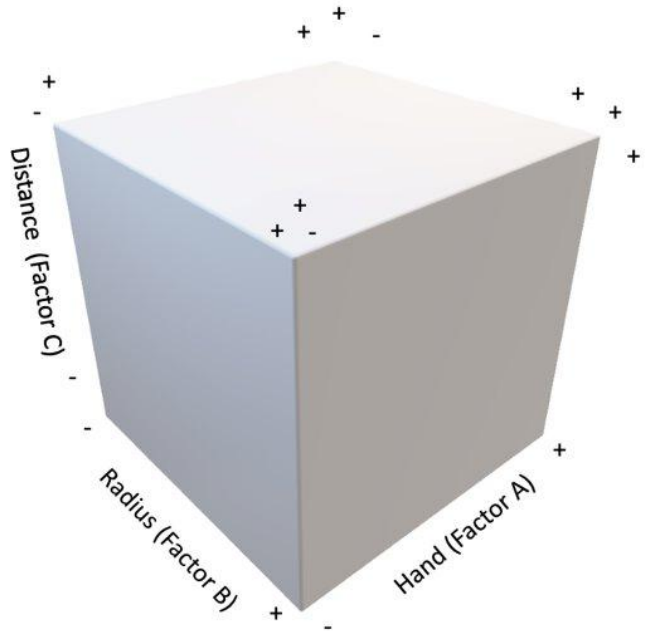

Fig 4: Model Illustration

Since there are two levels of each factor, the experiment has been implemented with a 2^3 Factorial design. The model is as below:

Null Hypothesis: The response i.e. number of cycles completed should be independent of hand, circle radius, and distance between two circles

$$Y_{ijkl} = \mu + \alpha_i + \beta_j + \gamma_k + (\alpha\beta)_{ij} + (\beta\gamma)_{jk} + (\alpha\gamma)_{ik} + (\alpha\beta\gamma)_{ijk} + e_{ijkl}$$

Where

Y_{ijkl} is the lth measurement for level i of factor A, level j of factor B, and level k of factor C

μ is the overall mean

α_i is the main effect of level i of factor A (difference with μ)

β_j = main effect of level j of factor B (difference with μ)

γ_k = main effect of level k of factor C (difference with μ)

$(\alpha\beta)_{ij}$ = interaction effect of level i of factor A and level j of factor B

$(\beta\gamma)_{jk}$ = interaction effect of level j of factor B and level k of factor C

$(\alpha\gamma)_{ik}$ = interaction effect of level i of factor A and level k of factor C

$(\alpha\beta\gamma)_{ijk}$ = interaction effect of level i of factor A, level j of factor b and level k of factor C

e_{ijkl} = error in the l th measurement for level i of factor A and level j of factor B and level k of factor C

Random Sampling

The experiment is replicated twice so there are 16 runs. The order in which the runs are made is also random, so this is a completely randomized experiment. To achieve randomization, Each

treatment combination was indexed from 1 to 8 and similarly, indexing was also done on small pieces of paper (chits) that were placed in a container. For each experiment run, the container was given a good shake and then a chit is picked from it. The index of that chit is noted and treatment combination with that index is run.

Table 2: Indexing of Treatment Combination

	Treatment 1	Treatment 2	Treatment 3	Treatment 4	Treatment 5	Treatment 6	Treatment 7	Treatment 8
Index	1	2	3	4	5	6	7	8

Fig 5: Sampling

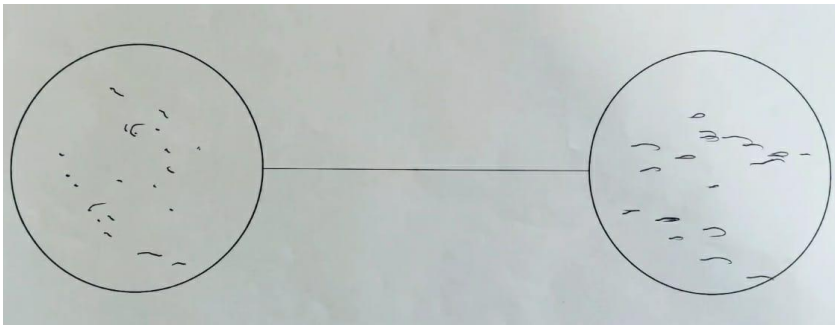

Fig 6: Sample Experiment Run

To ensure the validity of the experimental conditions, the following points were ensured:

1. The experiment was performed with single subject (Human)
2. The experiment runs were performed in the same environment i.e. location, marker, observer, and posture.
3. Individual runs were performed over a period of 3 days after every 3 hours to remove the "Warm-Up Effect" or "Muscle Memory"
4. Observations records were concealed from the subject to reduce human bias

Observed Data

Below is the table of observations that were obtained through the experiment.

Table 3: Data

	Circle (Big-1)	Distance (Large - 1)	Hand (Dominant - 1)	#Cycles Run - 1	#Cycles Run - 2
1	1	1	1	20	21
2	1	1	-1	18	17
3	1	-1	1	22	23
4	1	-1	-1	20	21
5	-1	1	1	12	15
6	-1	1	-1	14	14
7	-1	-1	1	15	16
8	-1	-1	-1	17	18

Exploratory Data Analysis

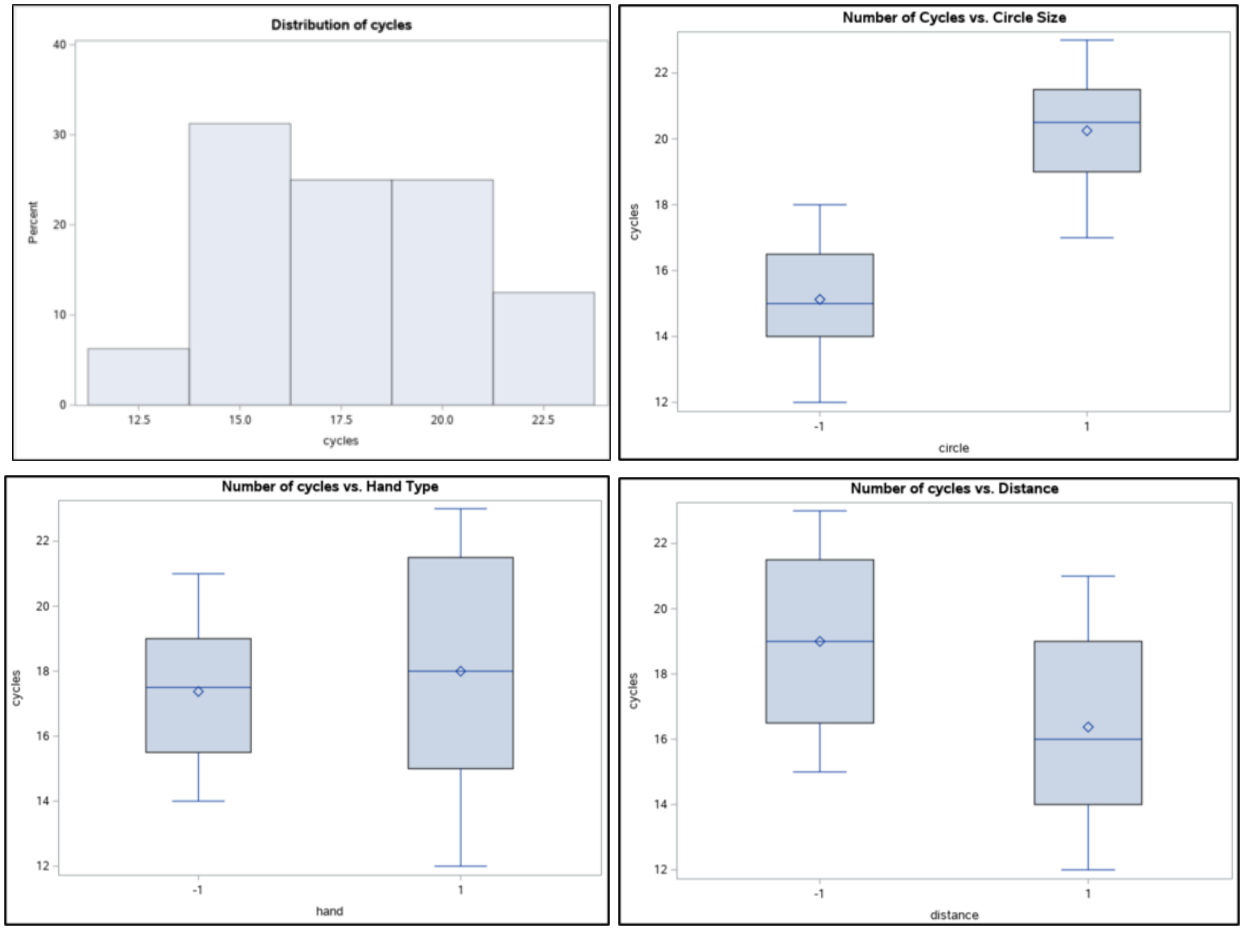

Fig 7: Univariate & Bivariate Analysis

The following observations can be interpreted from the above plots:

1) No. of cycles have a distribution similar to that of Normal Distribution
2) The number of completed cycles are more in bigger circles as compared to smaller circles.
3) More cycles were completed when the distance between circles is less
4) Similarly, more cycles are observed when the dominant hand is used. Though there is very minimal difference. We do observe a higher variance in the cycles when dominant is being used in the experiment.

Statistical Analysis Procedure

- **Model 1:** ANOVA model of cycles vs all other factors with interactions, i.e, a full model

cycles ~ circle + distance + hand +circle*distance + distance*hand + circle*hand + circle*distance*hand

Source	DF	Type III SS	Mean Square	F Value	Pr > F
circle	1	105.0625000	105.0625000	112.07	<.0001
distance	1	27.5625000	27.5625000	29.40	0.0006
circle*distance	1	0.0625000	0.0625000	0.07	0.8028
hand	1	1.5625000	1.5625000	1.67	0.2328
circle*hand	1	14.0625000	14.0625000	15.00	0.0047
distance*hand	1	1.5625000	1.5625000	1.67	0.2328
circle*distance*hand	1	0.0625000	0.0625000	0.07	0.8028

Fig 8: P-values for each variable in the full model

Since the 3-way interaction is not significant, it is removed while fitting the next model.

- **Model 2:** ANOVA model of cycles vs all 3 factors (without 3-way interactions)

cycles ~ circle + distance + hand +circle*distance + distance*hand + circle*hand

Source	DF	Type III SS	Mean Square	F Value	Pr > F
circle	1	105.0625000	105.0625000	125.03	<.0001
distance	1	27.5625000	27.5625000	32.80	0.0003
hand	1	1.5625000	1.5625000	1.86	0.2058
circle*distance	1	0.0625000	0.0625000	0.07	0.7912
circle*hand	1	14.0625000	14.0625000	16.74	0.0027
distance*hand	1	1.5625000	1.5625000	1.86	0.2058

Fig 9: P-values for each variable in model 2

Since circle*distance and distance*hand terms are not significant, they are removed while fitting the next model.

- **Model 3:** Final ANOVA model

cycles ~ circle + distance + hand + circle*hand

Source	DF	Type III SS	Mean Square	F Value	Pr > F
circle	1	105.0625000	105.0625000	125.79	<.0001
distance	1	27.5625000	27.5625000	33.00	0.0001
hand	1	1.5625000	1.5625000	1.87	0.1987
circle*hand	1	14.0625000	14.0625000	16.84	0.0017

Fig 10: P-values for each variable in final model

Model Diagnostics

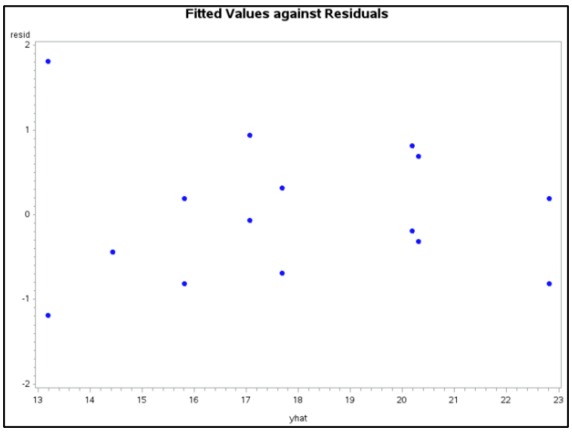

Fig 11: Residual vs Fitted Plot

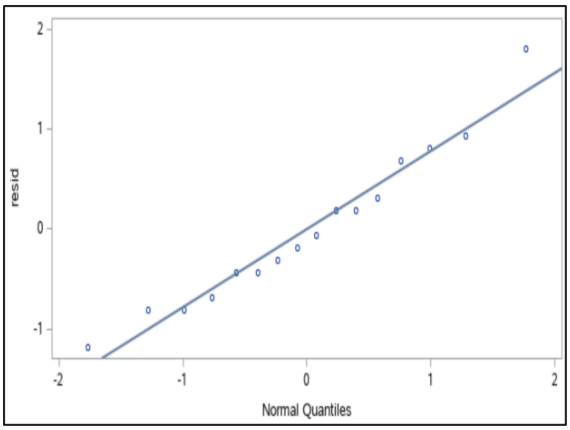

Fig 12: Q-Q Plot

➔ Since residual vs fitted plot is randomly scattered, the assumption of constancy of variance of residuals is being satisfied.
➔ From the Q-Q plot, the points are very close to the line. Thus, it can be concluded that the residuals are normally distributed.
➔ From the sequence plot in Fig 13, it can be observed that there is no auto-correlation
➔ The training effect was extremely limited as can be observed in Fig 14.

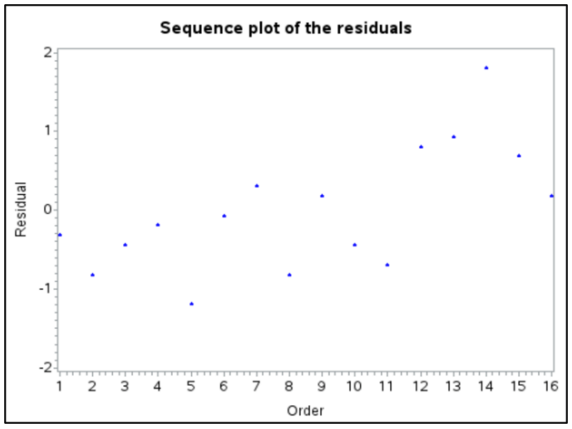

Fig 13: Residual vs Sequence Plot

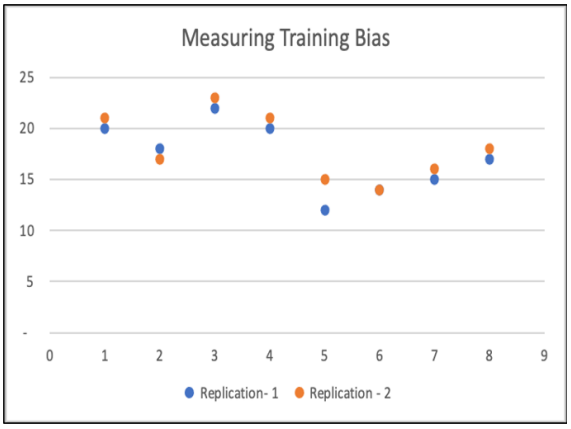

Fig 14: Training Bias Plot

Conclusion

Parameter	Estimate	Standard Error	t Value	Pr > |t|	95% Confidence Limits	
circle	5.12500000	0.45695385	11.22	<.0001	4.11925136	6.13074864
distance	-2.62500000	0.45695385	-5.74	0.0001	-3.63074864	-1.61925136
hand	0.62500000	0.45695385	1.37	0.1987	-0.38074864	1.63074864

Fig 15: Contrast between the 2 levels of every factor

circle	hand	cycles LSMEAN	Standard Error	Pr > |t|	LSMEAN Number
-1	-1	15.7500000	0.4569538	<.0001	1
-1	1	14.5000000	0.4569538	<.0001	2
1	-1	19.0000000	0.4569538	<.0001	3
1	1	21.5000000	0.4569538	<.0001	4

Least Squares Means for Effect circle*hand
t for H0: LSMean(i)=LSMean(j) / Pr > |t|

Dependent Variable: cycles

i/j	1	2	3	4
1		1.934295 0.2694	-5.02917 0.0019	-8.89776 <.0001
2	-1.93429 0.2694		-6.96346 0.0001	-10.8321 <.0001
3	5.029167 0.0019	6.963461 0.0001		-3.86859 0.0119
4	8.897756 <.0001	10.83205 <.0001	3.86859 0.0119	

Fig 16: Analysis of circle*hand effect using Tukey method

- From our statistical analysis in Fig 10, circle size and distance between the circles is significant at 5% level. Thus, the effect of these factors on the number of cycles

completed is statistically significant. This supports our initial data analysis, where we observed these factors affecting the cycles.

- The difference in number of cycles between larger and smaller circles is +5.12 cycles (Fig 15).

- The difference in number of cycles between larger and smaller distances is – 2.62 cycles (Fig 15).

- Hand Type (Dominant vs. Non-Dominant) does not affect the number of cycles at 5% level (Fig 10).

- Interaction of circle size and hand type is significant. With smaller circles, choice of hand does not affect the number of cycles (Fig 16), whereas with larger circles the choice of hand affects the number of cycles.