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Experimentation Project

Background

Jigsaw puzzles originated in Europe during the 1700's when mapmakers cut maps into small pieces as a toy. Today puzzles range from 10 pieces to over 32,000 pieces for beautiful murals. Puzzles have been a cornerstone of entertainment, an aid for development of problem solving and critical thinking skills, and a tool to help Alzheimer and dementia patients improve short-term memory. Puzzle manufacturers estimate a 500-piece puzzle to take approximately 4-6 hours to complete, or 1.38 - 2.08 pieces solved per minute. Does age of the person or puzzle size impact the average speed at which people can solve jigsaw puzzles?

Design

This experiment measures pieces solved per minute (PPM) at which four individuals can solve a jigsaw puzzle. The experiment will be performed with the following factors[1]:

- Age of the individual (18, 27, 35, and 58)
- Puzzle Size (100, 200, and 500 pieces)

Every individual will solve each size of puzzle. The order of the individual solving the puzzle and the size of the puzzle will be randomly drawn[2]. Since puzzle size is easily randomized, and the age factor should not be random, there will be no blocking factors.[4] Only one puzzle per individual will be solved per day in order to maintain independence between runs. After every puzzle size is solved by each participant, the participants will perform an additional round of experimentation with new puzzle of each size to ensure the results are replicated.[3]

This experiment is designed as a replicated, balanced, 2 factor fixed effect ANOVA where the mean value of the PPM is evaluated. The overall goal is to asses if age or puzzle size significantly impact the PPM rate.

Measurement Evaluation & Data Collection Plan

The experiment will be performed as follows[5]:

1. The experimenter will randomly select the order of the participants each day.
2. Each participant will have a hat with each puzzle size written on individual slips of paper. One puzzle size will be randomly drawn each morning.
3. The experimenter will perform the time measurement utilizing a stopwatch and will ensure the puzzle is 100% complete. The timer will start when the individual opens the puzzle box and will stop when the final piece is in place. The time will be measured in minutes and will be rounded to the nearest integer (ex: 2:20 mins = 2 mins, 2:35 mins = 3 mins).
4. The next day, the participant order and puzzle drawing will be performed again with the previous drawings removed until all participants have completed all puzzle sizes one time.
5. One week after the conclusion of step 4, the experiment will be re-performed with a new puzzle of each size. Step 1-4 will be repeated until completion of step 4.

Results

After the experiment was performed, descriptive statistics are examined to obtain an understanding of the data[6]. Figure 1 shows that the PPM results have a mean value of 1.4376 with a minimum of ~1.33 and maximum of ~1.64. The median is 0.03 lower than the mean, so a higher value or possible outlier could exist. The Anderson- Darling Test on the PPM results in a non-normal distribution, which could impact the residuals assumptions of the model. The scatterplots of age & size vs. PPM in figure 2&3 do not show a linear correlation between the factors and the response.

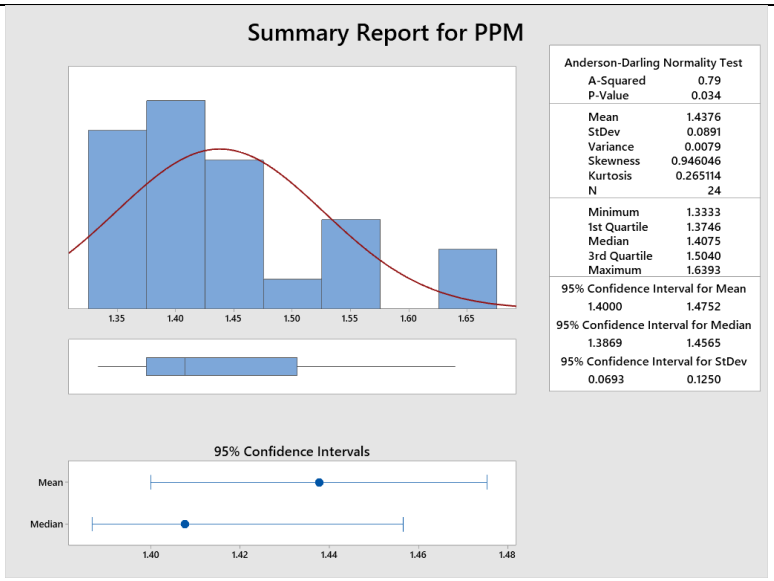

Figure 1: Descriptive Statistics

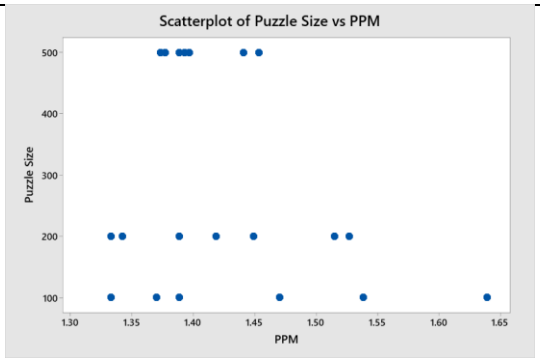

Figure 2: Size vs. PPM

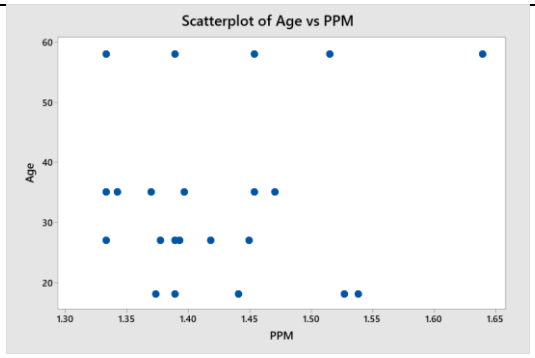

Figure 3: Age vs. PPM

Once the basic statistics of the data is examined, the following hypothesis can be tested:

H_0 = All group's mean PPM rates are equal

H_A = At least one group's mean PPM rate is not equal

α= 0.05

ANOVA was performed on the PPM rate by Age, Puzzle Size, and the Age*Puzzle Size interaction in table 1.

- Puzzle size, age, and the interaction were significant (P = 0.026, 0.019, and 0.042, respectively). Therefore, the null hypothesis should be rejected; there is at least one group of PPM rates has a different mean value.
- Since the interaction is significant, it cannot be pooled[8].
- The sigma, or experimental error, is the square root of MSE, or 0.0032.
- The model summary in table 2 shows an R^2 of 78.51%, which means that out model explains 78.51% of the variability between PPM rates.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Puzzle Size	2	0.03271	0.016355	5.00	0.026
Age	3	0.04817	0.016056	4.91	0.019
Puzzle Size*Age	6	0.06250	0.010417	3.19	0.042
Error	12	0.03924	0.003270		
Total	23	0.18262			

Table 1: ANOVA Results

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0571860	78.51%	58.81%	14.05%

Table 2: Model Summary

Since both main effects are significant, they should be assessed using Tukey's comparison in table 3 to determine which group(s) are significantly different.

- Starting with puzzle size, the 100-piece puzzle's PPM was significantly different than the 200 and 500-piece puzzles, and the 100 had the highest mean PPM at 1.48979.
- Next, the age of 58 years was significantly different than 35 and 27 years, but not significantly different than the 18 years, and the 58 years had the highest mean PPM at 1.49493.
    - The 18 years was not significantly different than the 35 and 27 years either.

Puzzle Size	N	Mean	Grouping
100	8	1.48979	A
200	8	1.41343	B
500	8	1.40965	B

Age	N	Mean	Grouping
58	6	1.49493	A
18	6	1.46785	A B
35	6	1.39437	B
27	6	1.39335	B

Table 3: Tukey's Comparison of PPM

Tukey's comparison in table 3 also shows that while age was a significant factor in this experiment, there was not a correlation between age and PPM. The PPM didn't increase with age, but there were random differences between the individuals. However, puzzle size did correlate with PPM; as puzzle size increased, PPM decreased. This could be from loss of focus as the puzzle size increased, or the individuals paced themselves slower to maintain focus for longer.

The residual analysis below shows there is nothing unusual, which indicates the residual assumptions are met[7].

a) Normality of residuals assumption is met by the AD test in figure 1 (P=0.727)

b) The factor plots show similar patterns in figure 2 & 3. Common range of variation suggests that homogeneity of variance is validated. The residuals appear to be mirrored, which is caused by the replicated runs.

c) The largest residual ±2.25 in figure 1 is not large enough to be a concern, which indicates there are no outliers in the data.

d) The run order plot in figure 3 shows a random pattern around zero, which indicates that independence is a reasonable assumption.

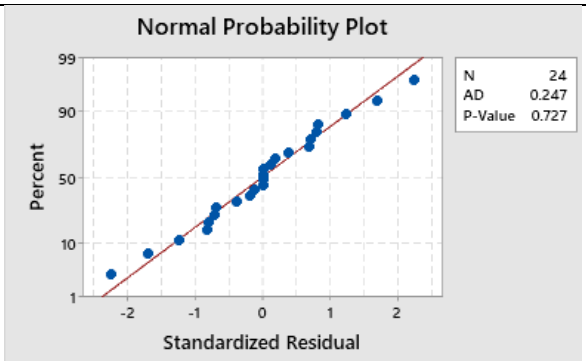

Figure 1: Residual Analysis

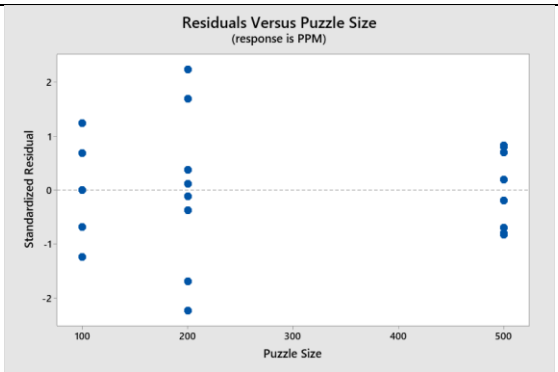

Figure 2: Puzzle Size Factor Plot

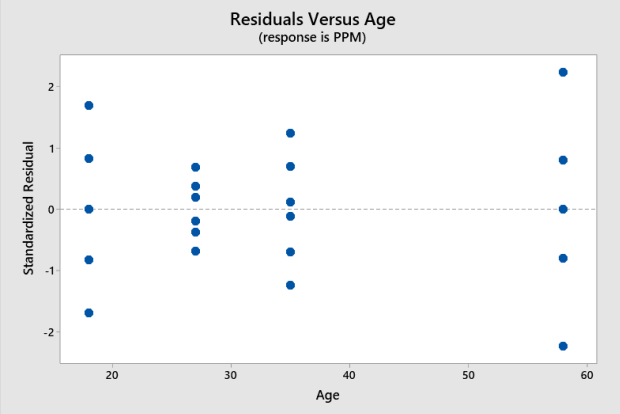

Figure 3: Age Factor Plot

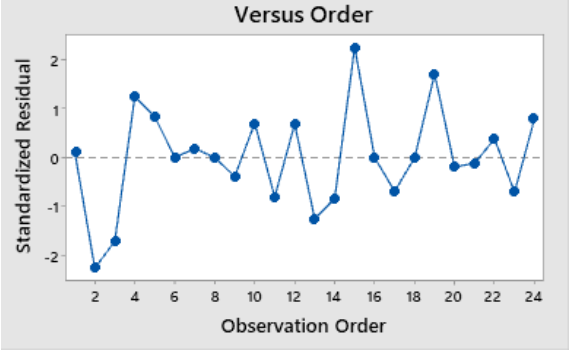

Figure 4: Residuals vs. Run Order

Conclusion

A population of 4 individuals ranging in age from 18 – 58 were tasked with completing a 100, 200, and 500-piece puzzle in a random order. A week later, the individuals completed a new set of the same sized puzzles in a random order. The time to complete the puzzles was measured in minutes and a piece solved per minute (PPM) rate was determined. The overall goal was to asses if age or puzzle size significantly impacted the PPM rate. The experiment resulted with the following:

- While age was a significant factor there was not a correlation between age and PPM; age 58 had the highest PPM and age 27 had the lowest PPM.
- Puzzle size was a significant factor, and there was a correlation between puzzle size and pieces per minute. As the puzzle size increased the PPM decreased.
- The mean PPM was 1.4376, which was slightly lower expected mean of the manufacturer of 1.67 PPM.

Improvement points for future iterations of this experiment:

- A larger sample size of different ages and puzzle sizes may show a stronger correlation between PPM and the factors.
- A more diverse sample of participants may provide differing data points (ex: education level, demographics, etc.).
- Would teamwork double the PPM, or just slightly increase it?