**Assignment 1: Database Management and Sample Size Estimation**

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**Database Management and Sample Size Estimation**

**Introduction**

The study aims to explore the relationship between superpowers and intelligence quotient (IQ) among the Avengers. Specifically, it investigates whether Avengers with superpowers exhibit a higher average IQ than those without. Given the fictional dataset, this analysis provides an opportunity to apply statistical techniques such as independent samples t-tests, database management, and sample size estimation. The study utilizes a dataset from the Avengers' final battle against Thanos, which includes variables such as IQ, agility, speed, strength, damage resistance, willpower, and battlefield location. This study will contribute to a deeper understanding of the impact of superpowers on cognitive ability while also demonstrating proficiency in data management and statistical analysis.

**Methodology**

**Data Management**

The dataset was imported and inspected for missing or unusual values. Only complete cases were retained to ensure data quality. A new variable, CombatEffectiveness, was created by summing agility, speed, strength, and willpower scores to measure overall battlefield performance. Prior to this, a copy of the dataset was created in both SPSS and csv formats that only includes the avengers who did not have a superpower and have died.

**Descriptive Statistics**

Descriptive statistics, including mean, standard deviation (SD), and range, were computed for combatEffectiveness, kills, and injuries for the overall sample. These statistics were then stratified by battlefield location (north vs. south) to assess differences in combat performance and injury rates.

**Hypothesis Testing**

To assess the relationship between superpowers and IQ, an independent samples t-test was conducted. Superpower status was converted into a factor variable (categorical) to facilitate group comparisons. The test compared the mean IQ scores of Avengers with and without superpowers to determine whether the presence of superpowers significantly influences intelligence.

**Sample Size Estimation & Power Analysis**

Before conducting the t-test, a power analysis was performed to determine whether the dataset contained a sufficient number of participants. A hypothetical effect size was selected based on prior assumptions, and power calculations were conducted to ensure adequate sensitivity to detect meaningful differences.

**Effect Size Calculation**

Upon obtaining the t-test results, an effect size (Cohen’s d) was computed along with a 95% confidence interval (CI) to assess the magnitude and precision of the observed difference.

**Results**

**Data Inspection and Cleaning**

The total sample size from the avenger’s data was 814 observations of 15 variables. After dataset inspection and cleaning for missing or unusual values, 2 incomplete cases were removed, and the new dataset called clean avenger was created with sample size of 812 observations of 15 variables. A new dataset called clean avengers1 with 812 observations of 16 variables, containing a new variable called CombatEffectiveness which consist of the sum of agility, speed, strength, and willpower.

**Descriptive Statistics**

After creating the dataset clean avengers1, and the new dataset was created from clean avengers1, named clean avengers2 with 101 observations of 16 variables which included only avengers who did not have a superpower and have died. The clean avengers 2 was then summarized to understand the properties of combatEffectiveness, kills, and injuries with their mean, SD, and range values for the overall sample as well as based on battlefield location (i.e., north vs. south).

**Overall Sample**

**Table 1** displays the means, standard deviations (SDs), and range of values the variables CombatEffectiveness, Kills and Injuries for the overall sample. The variable CombatEffectiveness represents a sum of agility, speed, strength and willpower, with a mean of 497.53 (Standard Deviation (SD)=177.56) with a range of 879.64 (67.25-946.89). Kills represents how many bad guys the avenger killed, with a mean of 2.55 (SD=8.81) and a range of 79 (0-79). Injuries represents how many injuries the avenger sustained, with a mean of 4.55 (SD=0.74) and a range of 3 (2-5).

**Battlefield Comparison**

**North Battlefield:**

**Table 2** displays the means, standard deviations (SDs), and range of values for the variables CombatEffectiveness, Kills and Injuries of North battlefield. The variable CombatEffectiveness with a mean of 499.78 (Standard Deviation (SD)= 174.07) and a range of 766.38 (130.68-897.06). Kills with a mean of 1.71 (SD=4.57) and a range of 34 (0-34) and Injuries, with a mean of 4.60 (SD=0.68) and a range of 3 (2-5).

**South Battlefield:**

**Table 3** displays the means, standard deviations (SDs), and range of values for the variables CombatEffectiveness, Kills and Injuries of South battlefield. CombatEffectiveness with a mean of 491.68 (Standard Deviation (SD)= 189.53) and a range of 879.64 (67.25-946.89). Kills with a mean of 4.75 (SD=14.99) and a range of 79 (0-79) and Injuries, with a mean of 4.43 (SD=0.88) and a range of 3 (2-5).

**Most Effective Battlefield and Most Injuries**

Based on the combat effectiveness mean scores, the most effective battlefield was North battlefield with a mean score of 499.78. The battlefield with the most injuries based on injuries mean scores was also North battlefield with a means score of 4.60 though the difference compared to South was small.

**Erroneous Variable in Mean Model**

To assess which variable was most erroneous, the coefficient of variation (CV) was calculated for CombatEffectiveness, kills, and injuries. The highest CV indicated the most erroneous variable. The coefficient of variation of CombatEffectiveness, kills, and injuries as calculated was 0.36, 3.45 and 0.16 respectively (**See table 4**).

The variable with the highest CV was Kills making it the most erroneous in the mean model. Kills has the highest CV (3.45) with a much larger SD compared to its mean, indicating high variability and potential outliers. Also, the wide range of "Kills" (0 to 79) further supports its high error potential.

**Two Justifications for Estimating the Required Sample Size**

***Effect Size Estimation from Previous Research or Pilot Data:***

Before conducting the analysis, we can look at previous studies or pilot data to estimate the expected effect size (Cohen’s d). If past studies suggest a moderate effect size (d =0.5), we can use this estimate to calculate the required sample size for an independent samples t-test. This is because, effect size helps determine how large a difference in IQ we expect between avengers with and without superpowers. Larger effect sizes require fewer participants, while smaller effect sizes need more participants to detect a meaningful difference.

**Power Analysis Using Statistical Software:**

Power analysis ensures that we have enough participants to detect a true difference in IQ while minimizing Type II errors (failing to detect a true effect). Standard settings for power analysis: Power = 0.80 or 0.90 (80%–90% chance of detecting a true effect), Significance level (α) = 0.05 (5% chance of a Type I error) and an Effect size which can be estimated from previous studies or Cohen’s benchmarks. This approach provides an exact minimum sample size needed for our t-test, preventing an underpowered (weak) or overpowered (wasteful) study.

**Hypothesis Testing: Superpowers and IQ**

An independent samples t-test was conducted to examine the difference in IQ between Avengers with and without superpowers. The test statistic was **t = 4.25**, indicating a statistically significant difference. The effect size was calculated as **Cohen’s d = 0.62 (95% CI: 0.32, 0.90)**.

**Hypothetical Effect Size and Justification**

**Justification for Choosing d = 0.2:**

A small effect size (Cohen’s d = 0.2) was chosen for this study based on Cohen’s conventions which classify effect sizes as small (0.2), medium (0.5), and large (0.8). In combat-related research, factors like weather, leadership, and team coordination influence combat effectiveness, kills, and injuries. A small effect size allows detection of subtle yet meaningful differences between groups, which can inform training and resource allocation. While smaller effect sizes require larger sample sizes, they offer a more realistic and conservative estimate given the variability in combat data. Choosing d = 0.2 helps avoid exaggerated findings and prevents misleading strategic decisions, ensuring a more accurate and reliable analysis of battlefield effectiveness.

**Power Analysis**

A power analysis was conducted using the hypothetical effect size (Cohen’s d = 0.2). A significance level (α) of 0.05, a standard threshold in hypothesis testing, ensuring a 5% probability of committing a Type I error (falsely rejecting the null hypothesis), total sample size of 812 participants. And a two-sample t-test (two-tailed), as it is appropriate for comparing the IQ of two independent groups—Avengers with and without superpowers. The estimated Power = **0.81 or 81%,** indicated that the study has sufficient participants to detect the hypothesized effect.

**Ensuring Power for Zero Effect**

To determine if there is truly no difference between the two groups, a power analysis for equivalence testing was performed using the ‘TOSTER’ package. The calculated required sample size to achieve this ‘zero effect’ with equivalence bounds of -0.2 and 0.2 is 429 per group, estimating the power required for detecting a zero effect at 83**%** power.

**Interpretation of Effect Size and Precision**

With test statistic of 4.25 from the independent t-test analysis, the estimated effect size is Cohen’s d = 0.41, with a 95% Confidence Interval (CI) of (0.22, 0.60).

**Precision of the Estimate**

The estimated effect size is Cohen’s d = 0.41, with a 95% Confidence Interval (CI) of (0.22, 0.60). The confidence interval has a width of 0.38 (0.22 - 0.60), which is relatively narrow, indicating a **moderately precise estimate**. This suggests that while the estimate is reasonably reliable, there is still some variability in the effect size.

**Qualitative Label (Cohen’s Conventions)**

According to Cohen’s conventions—small (d = 0.2), medium (d = 0.5), and large (d = 0.8)—the estimated Cohen’s d = 0.42 falls between small and medium, it indicates a **moderate effect**, suggesting a meaningful but not large difference between groups. This indicates that the effect of superpowers on IQ is moderate, suggesting the effect could be as low as small (0.22) or as high as medium (0.60), so while the estimate is **moderately stable**, there is still some uncertainty.

**Conclusion**

**Table 1:**

*Descriptive Statistics of Means, Standard Deviations, and range values for overall sample.*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Variables** | **Mean** | **Standard Deviation (SD)** | **Minimum range of values** | **Maximum range of values** | **Range** |
| CombatEffectiveness | 497.53 | 177.56 | 67.25 | 946.89 | 879.64 |
| Kills | 2.55 | 8.81 | 0 | 79 | 79 |
| Injuries | 4.55 | 0.74 | 2 | 5 | 3 |

**Table 2:**

*Descriptive Statistics of Means, Standard Deviations, and range values for North Battlefield.*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Variables** | **Mean** | **Standard Deviation (SD)** | **Minimum range of values** | **Maximum range of values** | **Range** |
| CombatEffectiveness | 499.78 | 174.07 | 130.68 | 897.06 | 766.38 |
| Kills | 1.71 | 4.57 | 0 | 34 | 34 |
| Injuries | 4.60 | 0.68 | 2 | 5 | 3 |

**Table 3**:

*Descriptive Statistics of Means, Standard Deviations, and range values for South Battlefield.*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Variables** | **Mean** | **Standard Deviation (SD)** | **Minimum range of values** | **Maximum range of values** | **Range** |
| CombatEffectiveness | 491.68 | 189.53 | 67.25 | 946.89 | 879.64 |
| Kills | 4.75 | 14.99 | 0 | 79 | 79 |
| Injuries | 4.43 | 0.88 | 2 | 5 | 3 |

**Table 4:**

*Coefficient of Variation (CV) of CombatEffectiveness, kills, and Injuries*.

|  |  |  |  |
| --- | --- | --- | --- |
| **Variable** | **Mean** | **Standard Deviation (SD)** | **CV (Relative Error)** |
| CombatEffectiveness | 497.53 | 177.56 | 0.36 |
| Kills | 2.55 | 8.81 | 3.45 |
| Injuries | 4.55 | 0.74 | 0.16 |

CV=Coefficient of Variation