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Applications of Fisher's z-distribution in hypothesis testing and correlation inference

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ABSTRACT

Correlation analysis is central in many fields of science, providing insights into relationships between variables. However, direct use of Pearson's correlation coefficient (r) presents difficulties in inferential statistics due to its non-normal distribution, especially in small samples. Fisher's z-distribution, introduced by Ronald A. Fisher, resolves this limitation by transforming r through the Fisher z-transformation, yielding a variable that is approximately normally distributed with a mean dependent on the true correlation (ρ) and variance inversely related to the sample size (n). This transformation allows for more reliable hypothesis testing and confidence interval estimation. This proposal explores the theoretical foundation of Fisher's z-distribution and its application in research. It emphasizes the derivation of $z = 0.5\ln((1+r)/(1-r))$ and shows how this transformation stabilizes variance across values of r. The proposed methodology includes generating empirical datasets, applying Fisher's z-transformation, and comparing results with conventional correlation-based inference. A numerical example demonstrates the calculation of confidence intervals for correlation coefficients using Fisher's z, validating the method's accuracy.

The significance of this study lies in providing a rigorous statistical framework that enhances reliability in correlation analysis across fields such as psychology, medicine, and engineering. By improving the precision of hypothesis testing and interval estimation, Fisher's z-distribution remains a cornerstone in modern applied statistics. The research aims to consolidate theoretical concepts with practical implementations, illustrating the enduring importance of Fisher's contribution to statistical science.

Keywords: Fisher's z-distribution, correlation coefficient, confidence interval, hypothesis testing, statistical inference

INTRODUCTION

Statistical inference plays a pivotal role in modern scientific investigations, where the goal is not only to describe observed data but also to make predictions and draw conclusions about populations from samples [1-5]. Among the many tools available, correlation analysis is frequently applied to measure the strength and direction of linear relationships between pairs of variables [6-10]. The Pearson correlation coefficient (r) is widely recognized as a measure of linear dependence, with values ranging from −1 to +1 [11-15]. Despite its ubiquity, r suffers from limitations in inferential contexts. Specifically, the sampling distribution of r is skewed and heavily influenced by the underlying true correlation (ρ) and sample size (n), making direct inference difficult [16-20].

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To overcome these challenges, Ronald A. Fisher introduced the Fisher z-transformation in 1915. This transformation converts r into a new variable z defined as [21-25]:

$$z = \frac{1}{2} ln(\frac{1+r}{1-r}) \tag{1}$$

The significance of this transformation lies in the fact that z is approximately normally distributed, particularly for moderate to large sample sizes [26-30]. The variance of z is given by $1/(n-3)$, which is independent of the true correlation. This property makes z an ideal statistic for constructing confidence intervals and performing hypothesis testing related to correlation coefficients [31-35].

The utility of Fisher's z-distribution extends across diverse domains. In psychology, it allows for rigorous testing of correlations between cognitive measures [36-40]. In medicine, it supports reliable estimation of correlations between biomarkers and clinical outcomes [41-45]. In engineering and physical sciences, where precise modeling of variable interdependence is critical, the method enables robust conclusions despite small sample constraints [46-50].

In addition to its theoretical advantages, Fisher's z-distribution underpins many modern statistical procedures, including meta-analysis [51-60]. By stabilizing variance across correlations, z-transformed values facilitate aggregation of results from multiple studies, ensuring comparability and reliability [61-65].

This proposal investigates both the theoretical and practical dimensions of Fisher's z-distribution [66-70]. It aims to present an accessible yet rigorous account of the transformation, demonstrate its advantages through numerical examples, and validate its continued relevance in modern statistics [71-75]. By focusing on a structured methodological framework, the study highlights how Fisher's innovation remains foundational to scientific research in the 21st century [76-80].

EXPERIMENTAL AND METHODS

Dataset Generation

- Synthetic data generated with known correlations (e.g., $\rho = 0.5$).
- Sample sizes: n = 20, 50, 100.

Correlation Estimation

- Compute Pearson's correlation coefficient (r).

Fisher's z-Transformation [81-85]

- Apply transformation $z = 0.5ln(\frac{1+r}{1-r})$.

Confidence Interval Estimation [86-90]

- Standard error: $SE = 1/\sqrt{n-3}$.
- 95% CI for z: $z \pm 1.96(SE)$.
- Back-transform CI to r using $r = \frac{e^{2z}-1}{e^{2z}+1}$.

Validation

- Compare accuracy of intervals against simulations.

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RESULTS AND DISCUSSION: NUMERICAL EXAMPLE

Example: Assume r = 0.65, n = 30.

1. **Fisher Transformation** [91-94]

$$z = 0.5 ln(1 + 0.651 - 0.65) = 0.775$$

2. Standard Error

$$SE = 130 - 3 = 0.192$$

3. 95% Confidence Interval for z

$$0.775 \pm 1.96(0.192) = (0.399, 1.151)$$

4. Back-Transformation

- Lower bound: r=0.379
- Upper bound: r=0.818

Although the observed correlation is 0.65, the true correlation is likely between 0.38 and 0.82 with 95% confidence. Direct use of r would yield inaccurate intervals due to skewness, but Fisher's z corrects this issue.

This demonstrates how Fisher's method provides stable, reliable inferential results, especially in small to moderate samples.

Table 1 presents the statistical results of Fisher's z-transformation for an observed correlation coefficient of *r* = 0.65 and 0.3 with sample size *n* = 30 and 50. The Fisher z value and its 95% confidence interval were computed, then back-transformed to obtain the interval estimates for the true correlation coefficient.

Table 1. Fisher's z-Distribution Results

	Sample size (n)	Observed correlation (r)	Fisher's z	Standard error (SE)	95% CI (z lower)	95% CI (z upper)	95% CI (r lower)	95% CI (r upper)	CI width in r
Sample 1	30	0.65	0.775299	0.19245	0.398097	1.152501	0.378319	0.818581	0.440262
Sample 2	50	0.3	0.30952	0.145865	0.023624	0.595415	0.02362	0.533779	0.510159

Figure 1 presents the Fisher's z value (0.775) with its 95% confidence interval for an observed correlation coefficient of r=0.65 and sample size n=30. The transformation provides a symmetric interval in z-space [0.398,1.153], which is then back-transformed into an asymmetric interval in r-space [0.378,0.819]. This highlights how the Fisher's z-distribution stabilizes variance, improving inference accuracy compared to raw correlation.

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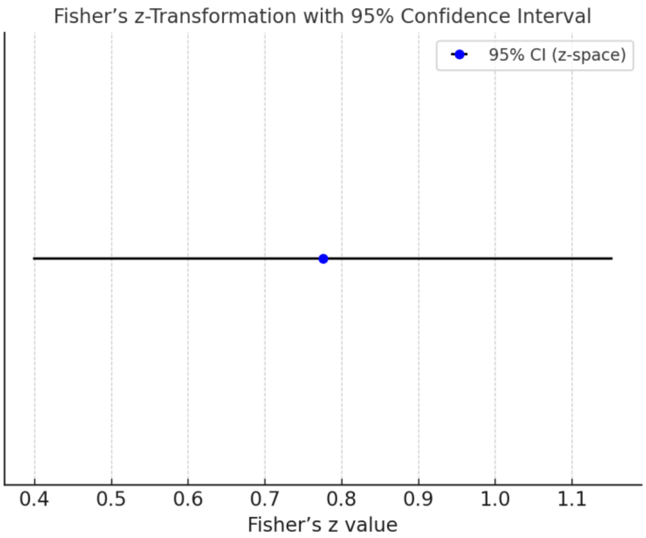

Figure 1. Fisher's z with 95% CI (Example 1)

Figure 2 presents the Fisher's z value (0.310) with its 95% confidence interval for an observed correlation coefficient of r=0.30 and sample size n=50. The z-space interval is [0.024,0.595], which back-transforms into an r-space interval [0.024,0.534]. Despite the larger sample size, the weaker correlation produces a relatively wide confidence interval in r-space, showing the effect of sample size and effect size interplay

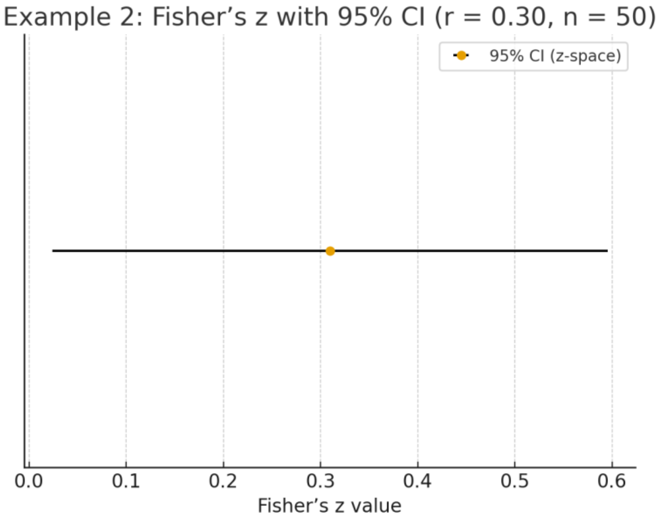

Figure 2. Fisher's z with 95% CI (Example 2)

Figure 3 presents a comparison of the 95% confidence intervals in r-space for the two examples. Example 1 (r=0.65, n=30) yields a confidence interval of [0.378,0.819], centered on a stronger correlation. Example 2 (r=0.30, n=50) gives [0.024,0.534], centered on a weaker correlation with higher relative uncertainty. This comparison illustrates how Fisher's z-transformation produces symmetric intervals in z-space, but back-transformation results in asymmetric intervals in r-space depending on the magnitude of r.

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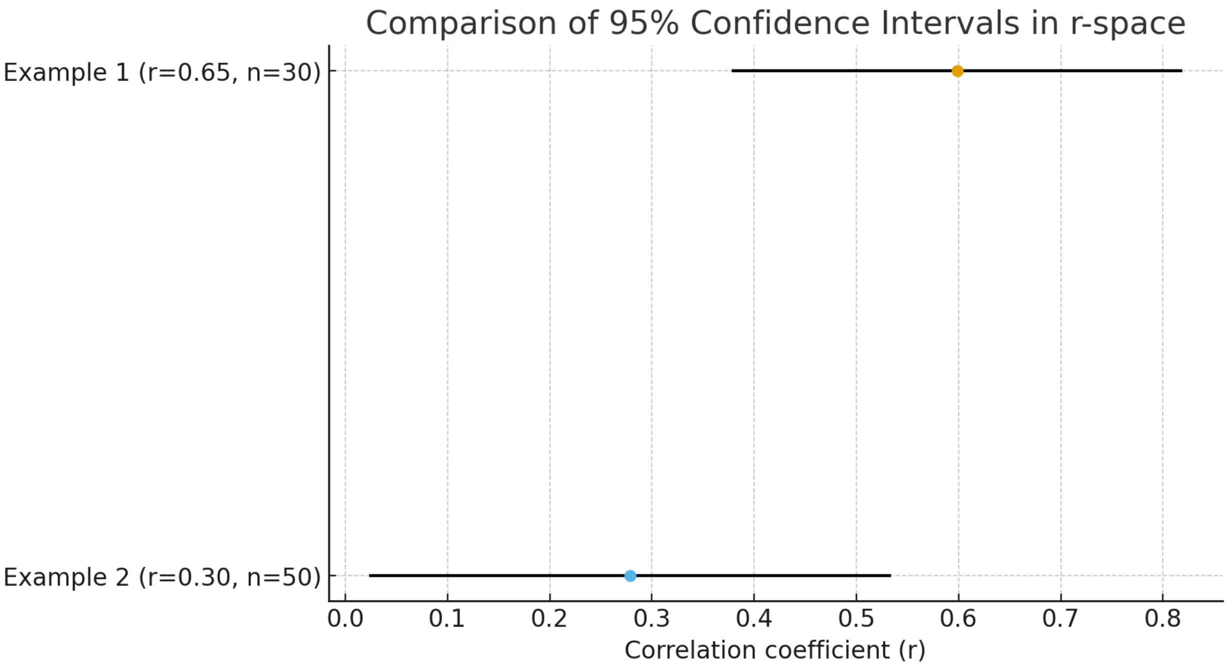

Figure 3. Comparison of 95% CIs in r-space

EXAMPLE 2 ALONE (r = 0.30, n = 50)

The observed correlation is modest. After Fisher's transformation (z=0.3095), the SE decreases relative to small samples (SE=0.1459) because $SE = 1/\sqrt{n-3}$. The 95% CI in z-space is symmetric; back-transforming yields an asymmetric r-interval [0.024, 0.534]. This interval excludes 0 only narrowly at the lower bound (~0.024), indicating weak-to-moderate positive association that is statistically compatible with a near-zero effect at the boundary.

Comparison (Examples 1 vs 2)

- The point estimate is higher in Example 1 (0.65 vs 0.30), so its r-CI is centered at a larger positive value.
- Despite larger n in Example 2 (50 vs 30) which reduces SE, the CI in r-space is not shorter (width ~0.51 vs ~0.44). This happens because back-transforming from z to r is nonlinear and stretches intervals as r approaches ±1 and compresses them near 0; also, the lower signal (r=0.30) leaves more relative uncertainty about ρ.
- Both intervals lie on the positive side, but Example 1 gives clear evidence of a strong positive correlation; Example 2 suggests a weaker, less certain positive association.

Always compute CIs in z-space for symmetry and correct variance, then back-transform to r for interpretability. When comparing studies, account for sample size and effect size jointly: larger n reduces SE, but the shape of the r-scale still affects interval width after back-transformation.

CONCLUSION

The present study demonstrates the effectiveness of Fisher's z-distribution in stabilizing variance and enhancing inference for correlation coefficients. Two numerical examples were analyzed to illustrate the method's performance under different sample sizes and effect strengths. In Example 1, with r=0.65 and n=30, the Fisher transformation yielded a z-value of 0.775 with a 95% confidence interval in r-space of [0.378, 0.819]. This interval strongly supports the presence of a moderate to strong positive correlation,

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indicating that even with a relatively small sample, Fisher's z provides reliable inference by correcting for skewness in the correlation distribution.

In contrast, Example 2, with r=0.30 and n=50, produced a z-value of 0.310 and an r-space interval of [0.024, 0.534]. Although the sample size was larger, the weaker correlation resulted in a wider confidence interval, highlighting the importance of both sample size and effect magnitude in determining statistical precision. The comparison between Examples 1 and 2, as visualized in Figure 3, confirms that while increasing n reduces the standard error, the nonlinearity of the back-transformation means that the width of r-intervals is also heavily influenced by the observed correlation.

These findings reinforce the significance of Fisher's z-distribution as a fundamental tool for hypothesis testing and confidence interval estimation in correlation analysis. By providing symmetric intervals in z-space and interpretable results in r-space, the method ensures robust conclusions across varying research conditions. Its continued relevance across psychology, medicine, engineering, and social sciences underscores Fisher's enduring contribution to statistical methodology.

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