Tukey HSD / Tukey-Kramer Post Hoc Analysis

Workflow:
1. Run one-way ANOVA for the dependent variable across the selected factor.
2. Use pooled ANOVA MSE and Studentized Range q critical value.
3. Apply Tukey-Kramer standard error when sample sizes are unequal.
4. Interpret simultaneous confidence intervals and adjusted p-values.

ANOVA result:

target_variable	group_variable	number_of_groups	total_n	grand_mean	ss_between_groups	df_between_groups	ms_between_groups	ss_within_error	df_within_error	ms_within_error	f_statistic	p_value	eta_squared	omega_squared	alpha	anova_decision_alpha_0_05	posthoc_not
G3	studytime	4	649	11.906009	465.077825	3	155.025942	6298.188739	645	9.764634	15.876268	5.705728e-10	0.068765	0.064341	0.05	Reject equal means Tukey HSD pairwise results should be interpreted after the omnibus ANOVA context

Levene/Brown-Forsythe variance context:

	context_test	statistic	p_value	alpha	decision_alpha_0_05	interpretation
Median-centered Levene / Brown-Forsythe	context	1.026312	0.380358	0.05	Equal variance assumption looks reasonable	Tukey HSD is an equal-variance post hoc method; use Games-Howell or Tamhane when variances are clearly unequal.

Group summary:

group	n	mean	standard_deviation	standard_error	variance	minimum	maximum	ci95_low	ci95_high
1	212	10.844340	3.218624	0.221056	10.359541	0.0	18.0	10.411070	11.277609
2	305	12.091803	3.243125	0.185701	10.517860	0.0	19.0	11.727830	12.455777
3	97	13.226804	2.502104	0.254050	6.260524	8.0	18.0	12.728866	13.724742
4	35	13.057143	3.038410	0.513585	9.231933	6.0	19.0	12.050516	14.063769

Homogeneous subset letters:

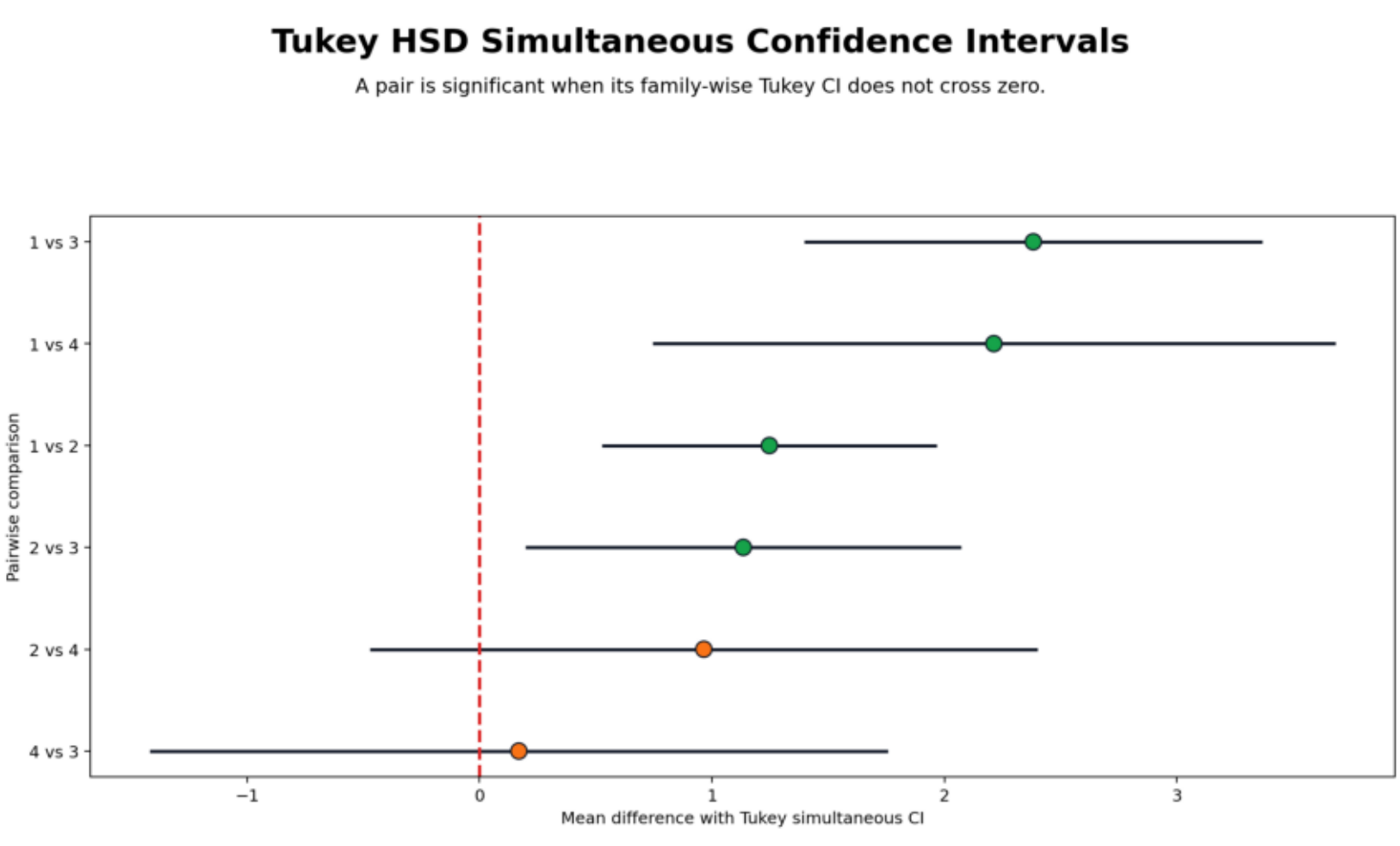
group	mean	tukey_hsd_homogeneous_subset_letters	letter_rule
3	13.226804	A	Groups sharing a letter are not significantly different by Tukey HSD at alpha .05.
4	13.057143	A	Groups sharing a letter are not significantly different by Tukey HSD at alpha .05.
2	12.091803	B	Groups sharing a letter are not significantly different by Tukey HSD at alpha .05.
1	10.844340	C	Groups sharing a letter are not significantly different by Tukey HSD at alpha .05.

Tukey HSD pairwise comparisons

comparison_order	group_1_lower_mean	group_2_higher_mean	mean_1	mean_2	mean_difference_2_minus_1	standard_error_tukey_kramer	q_statistic	q_critical_tukey	hsd_threshold	simultaneous_ci_low	simultaneous_ci_high	df_error	family_number_of_groups	adjusted_p_value_tukey_hsd	decision_alpha_0_05	method_note
1	1	2	10.844340	12.091803	1.247464	0.197579	6.313752	3.642648	0.719710	0.527754	1.967174	645	4	5.590361e-05	Significant	Tukey-Kramer HSD uses one family-wide q critical value based on all groups and the ANOVA error df.
2	1	4	10.844340	13.057143	2.212803	0.403143	5.488874	3.642648	1.468509	0.744294	3.681312	645	4	6.612043e-04	Significant	Tukey-Kramer HSD uses one family-wide q critical value based on all groups and the ANOVA error df.
3	1	3	10.844340	13.226804	2.382465	0.270856	8.796057	3.642648	0.986633	1.395832	3.369097	645	4	5.367514e-09	Significant	Tukey-Kramer HSD uses one family-wide q critical value based on all groups and the ANOVA error df.
4	2	4	12.091803	13.057143	0.965340	0.394338	2.448001	3.642648	1.436434	-0.471094	2.401774	645	4	3.083885e-01	Not significant	Tukey-Kramer HSD uses one family-wide q critical value based on all groups and the ANOVA error df.
5	2	3	12.091803	13.226804	1.135001	0.257567	4.406624	3.642648	0.938226	0.196775	2.073227	645	4	1.031067e-02	Significant	Tukey-Kramer HSD uses one family-wide q critical value based on all groups and the ANOVA error df.
6	4	3	13.057143	13.226804	0.169661	0.435692	0.389406	3.642648	1.587074	-1.417413	1.756735	645	4	9.927036e-01	Not significant	Tukey-Kramer HSD uses one family-wide q critical value based on all groups and the ANOVA error df.

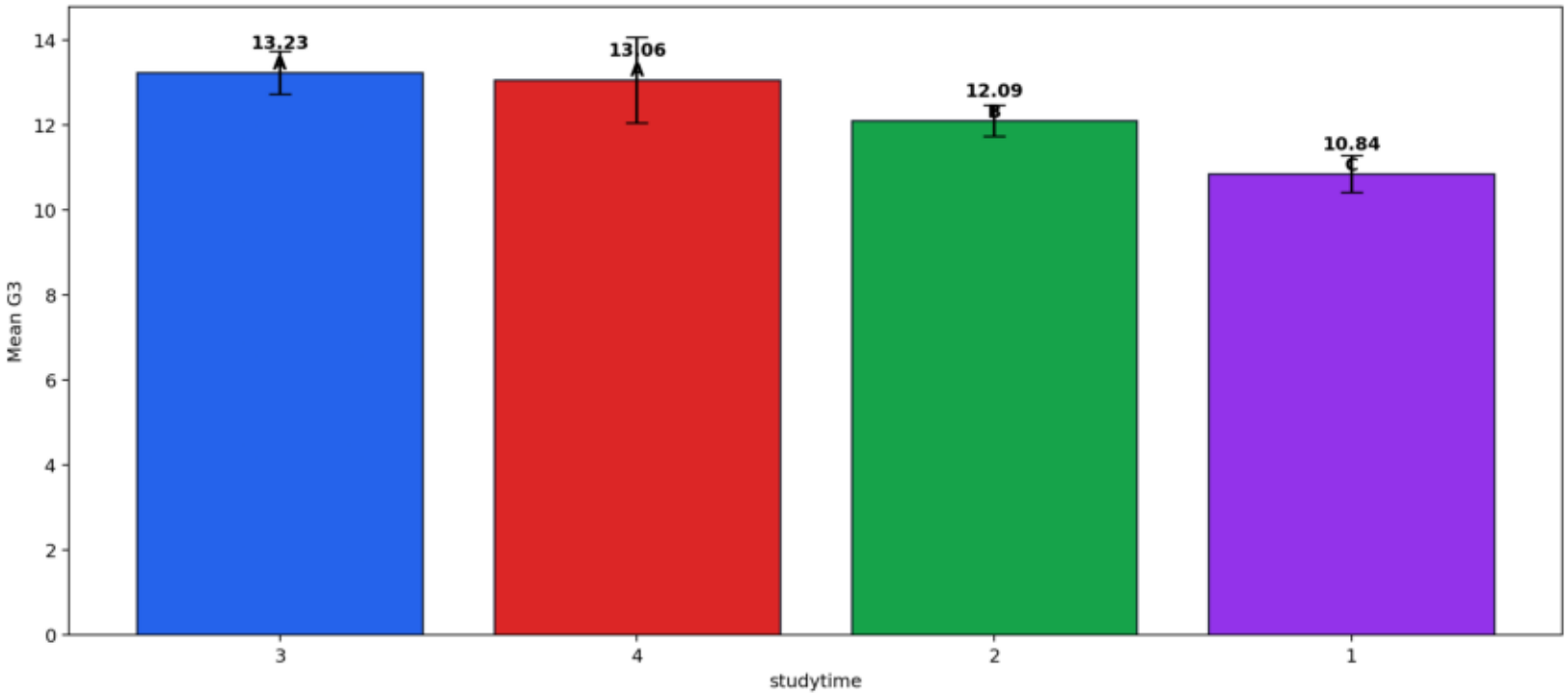
Interpretation summary

section	finding	interpretation
Method	Tukey HSD / Tukey-Kramer post hoc test	Used when comparing all pairs of group means after one-way ANOVA under an equal-variance context.
Omnibus ANOVA	ANOVA p-value = 0.000000	Proceed with pairwise Tukey interpretation when the overall group mean difference is meaningful.
Variance context	Levene/Brown-Forsythe p-value = 0.380358	Tukey HSD assumes equal variances. If this is violated, compare with Games-Howell or Tamhane's T2.
Pairwise result	4 of 6 Tukey comparisons were significant at alpha .05	Significant pairs have simultaneous confidence intervals that exclude zero and q statistics above the Tukey critical q.
Subsets	3: A; 4: A; 2: B; 1: C	Groups sharing a letter belong to the same Tukey homogeneous subset.


Tukey HSD Simultaneous Confidence Intervals
A pair is significant when its family-wise Tukey CI does not cross zero.
1 vs 3
1 vs 4
1 vs 2
2 vs 3
2 vs 4
4 vs 3
Pairwise comparison
−1
0
1
2
3
Mean difference with Tukey simultaneous CI

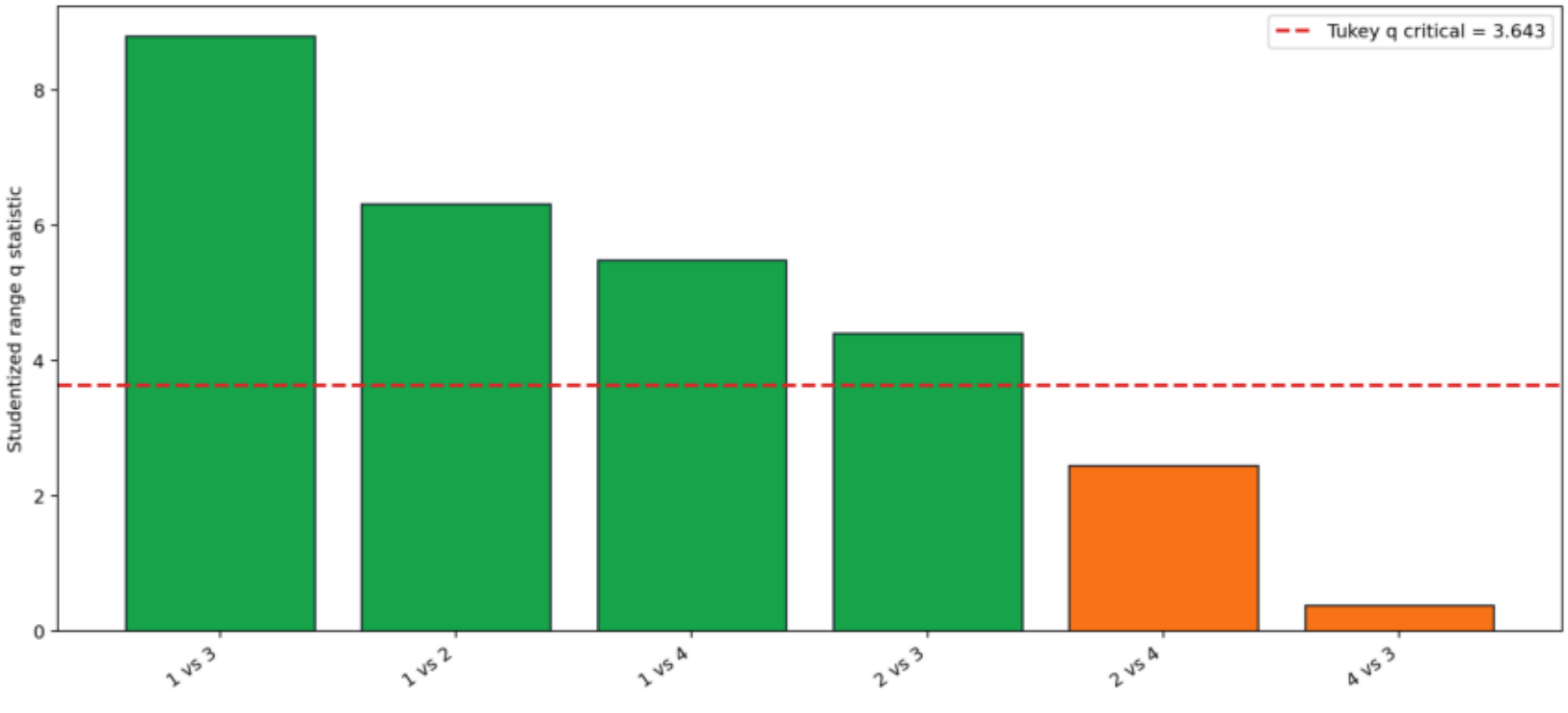
Tukey HSD Group Means with Homogeneous Letters

Groups sharing the same letter are not significantly different by Tukey HSD.



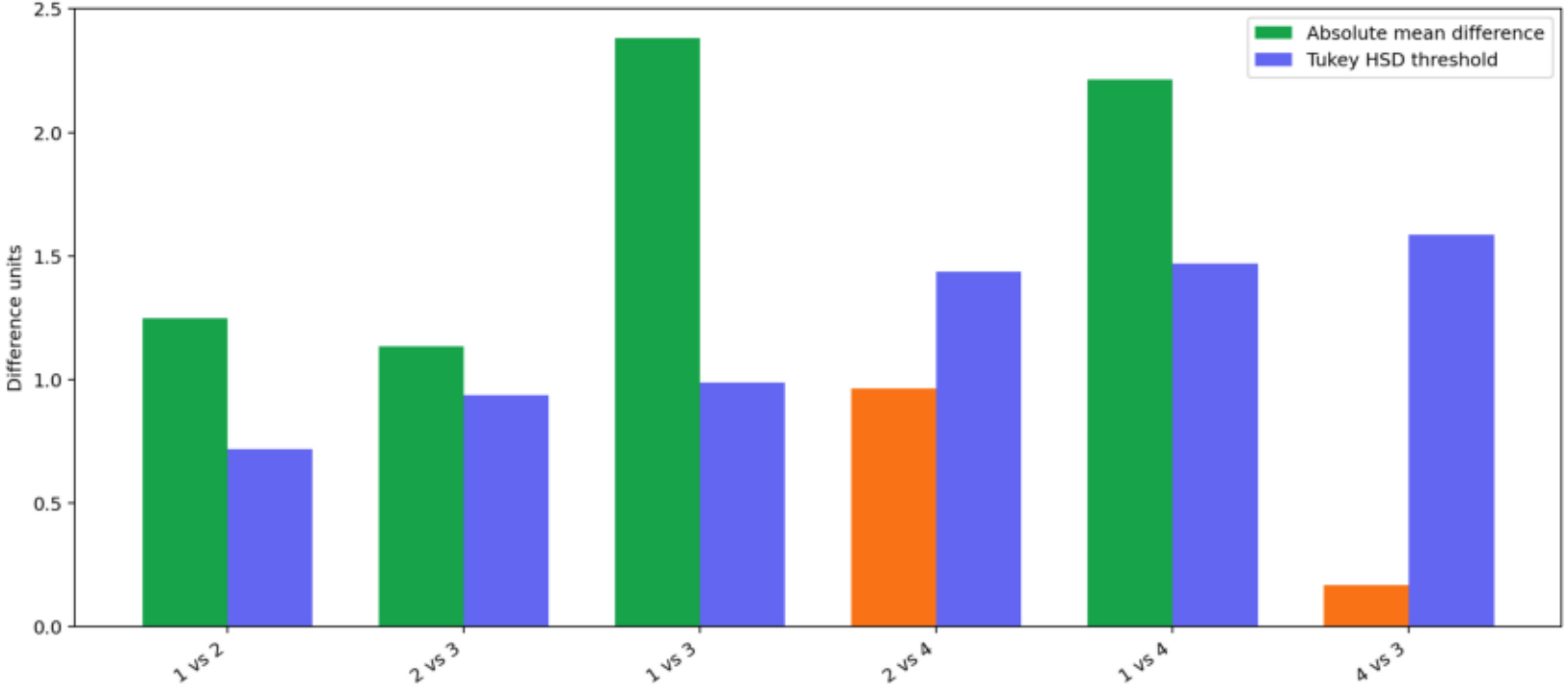
Tukey HSD q Statistic Ranking

Observed q must exceed the single family-wise Tukey critical q to be significant.



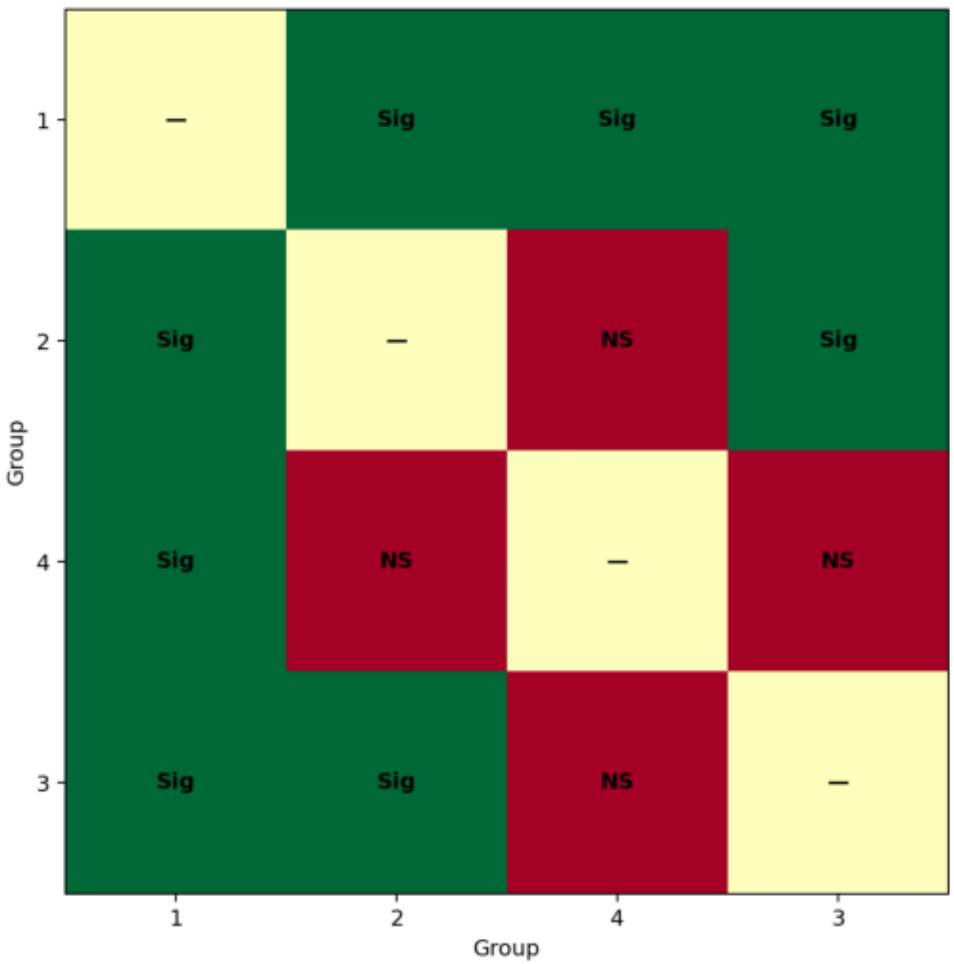
Tukey Mean Difference vs HSD Threshold

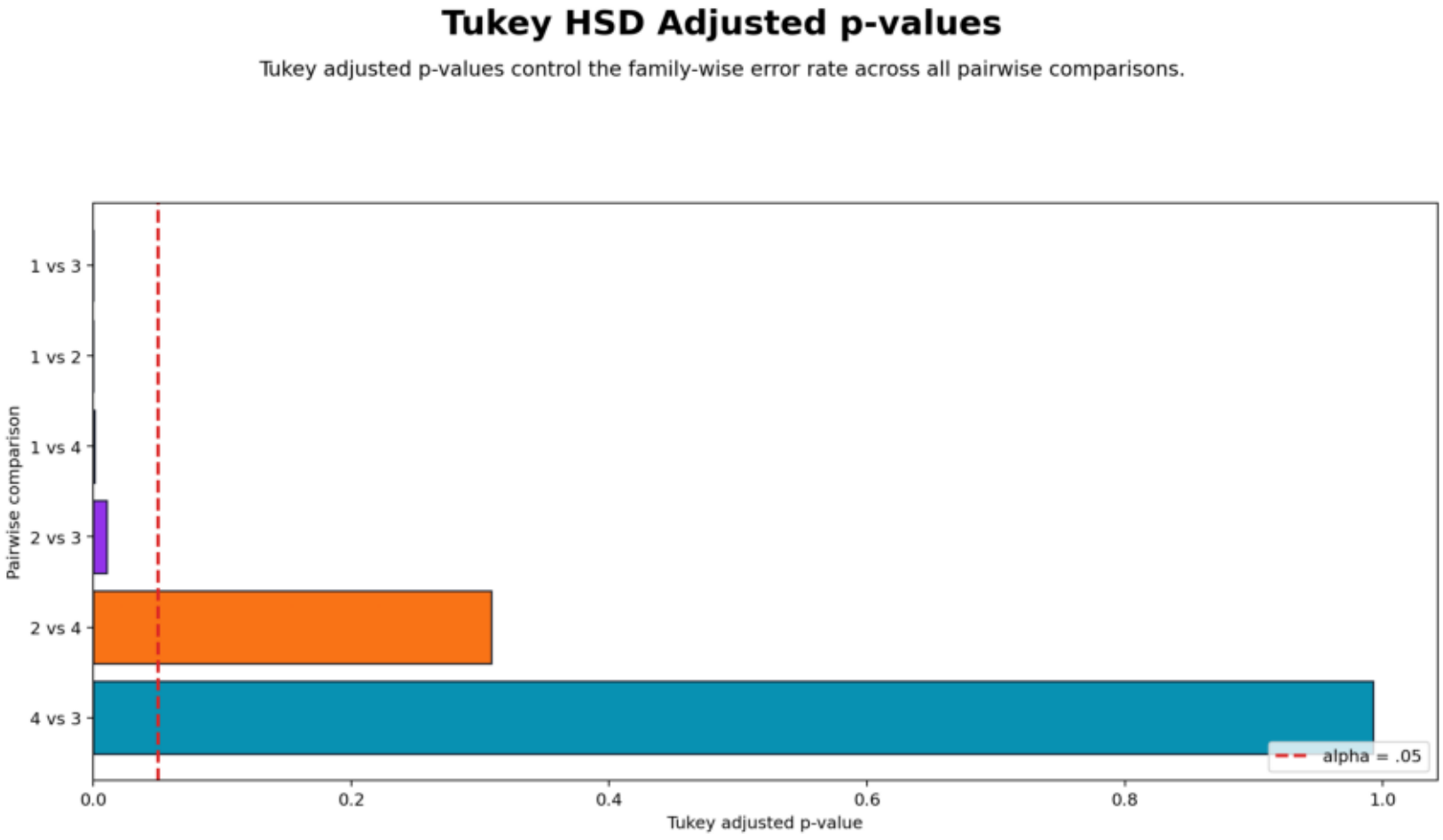
A comparison is significant when the absolute mean difference exceeds its Tukey-Kramer HSD threshold.



Tukey HSD Pairwise Decision Matrix

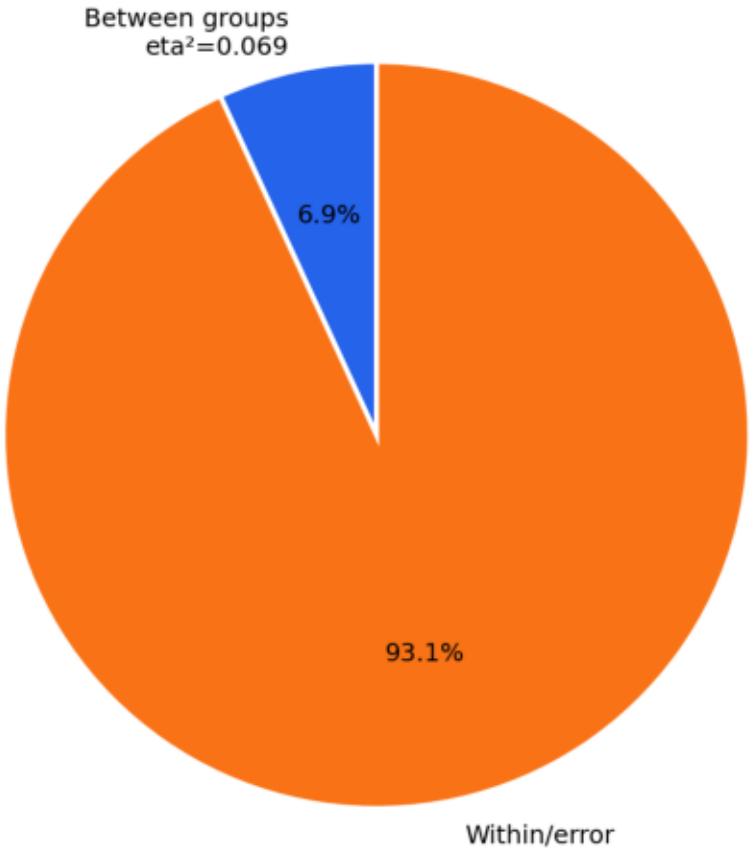
Green cells indicate significant Tukey HSD differences; red cells indicate non-significant differences.




Tukey HSD Adjusted p-values
Tukey adjusted p-values control the family-wise error rate across all pairwise comparisons.
Pairwise comparison
1 vs 3
1 vs 2
1 vs 4
2 vs 3
2 vs 4
4 vs 3
0.0
0.2
0.4
0.6
0.8
1.0
Tukey adjusted p-value
alpha = .05

ANOVA Sum-of-Squares Context Before Tukey HSD

Tukey HSD explains which group pairs differ after checking the omnibus ANOVA context.



Tukey HSD Distribution and Equal-Variance Context

Violin and box overlays help inspect spread, outliers, and group distribution shape before Tukey interpretation.