Games−Howell Post Hoc Test

Purpose: compare all pairs of group means without assuming equal variances.
H0 for each pair: the two group means are equal.
H1 for each pair: the two group means are different.

Group summary:

group	n	mean	standard_deviation	variance	standard_error	minimum	maximum	mean_ci95_lower	mean_ci95_upper
1	212	10.84434	3.218624	10.359541	0.2210560	0	18	10.41107	11.27761
2	305	12.09180	3.243125	10.517860	0.1857008	0	19	11.72783	12.45578
3	97	13.22680	2.502104	6.260524	0.2540502	8	18	12.72887	13.72474
4	35	13.05714	3.038410	9.231933	0.5135850	6	19	12.05052	14.06377

Welch ANOVA context:

test	f_value	df_between	df_error_welch	p_value	note
Welch ANOVA context	18.18288	3	139.1006	5.188109e−10	Included because Games−Howell is designed for unequal variances and/or unequal group sizes.

Standard one−way ANOVA context:

source	sum_of_squares	df	mean_square	f_value	p_value
Between groups	465.0778	3	155.025942	15.87627	5.705728e−10
Within groups	6298.1887	645	9.764634	NA	NA
Total	6763.2666	648	NA	NA	NA

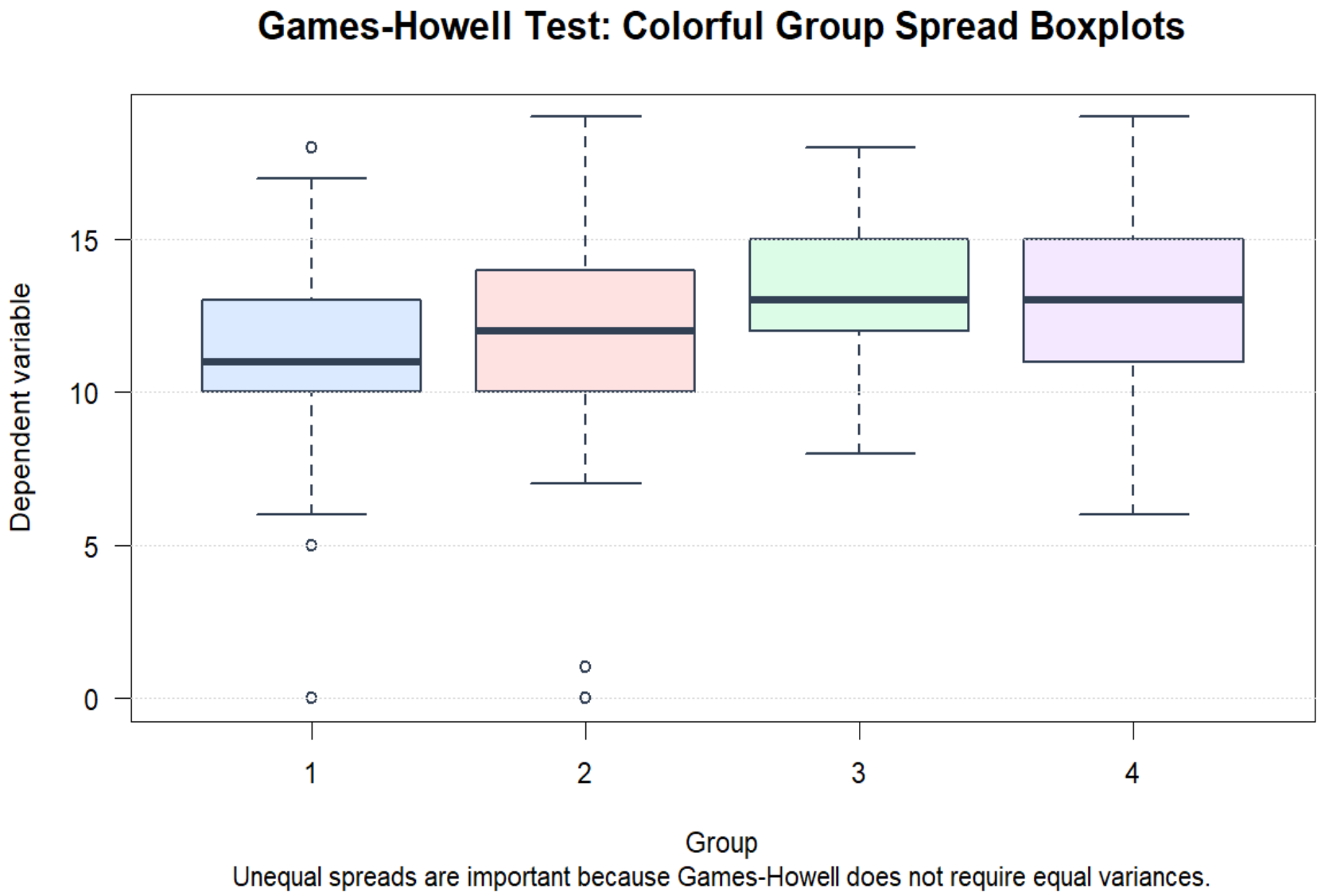
Games−Howell pairwise results:

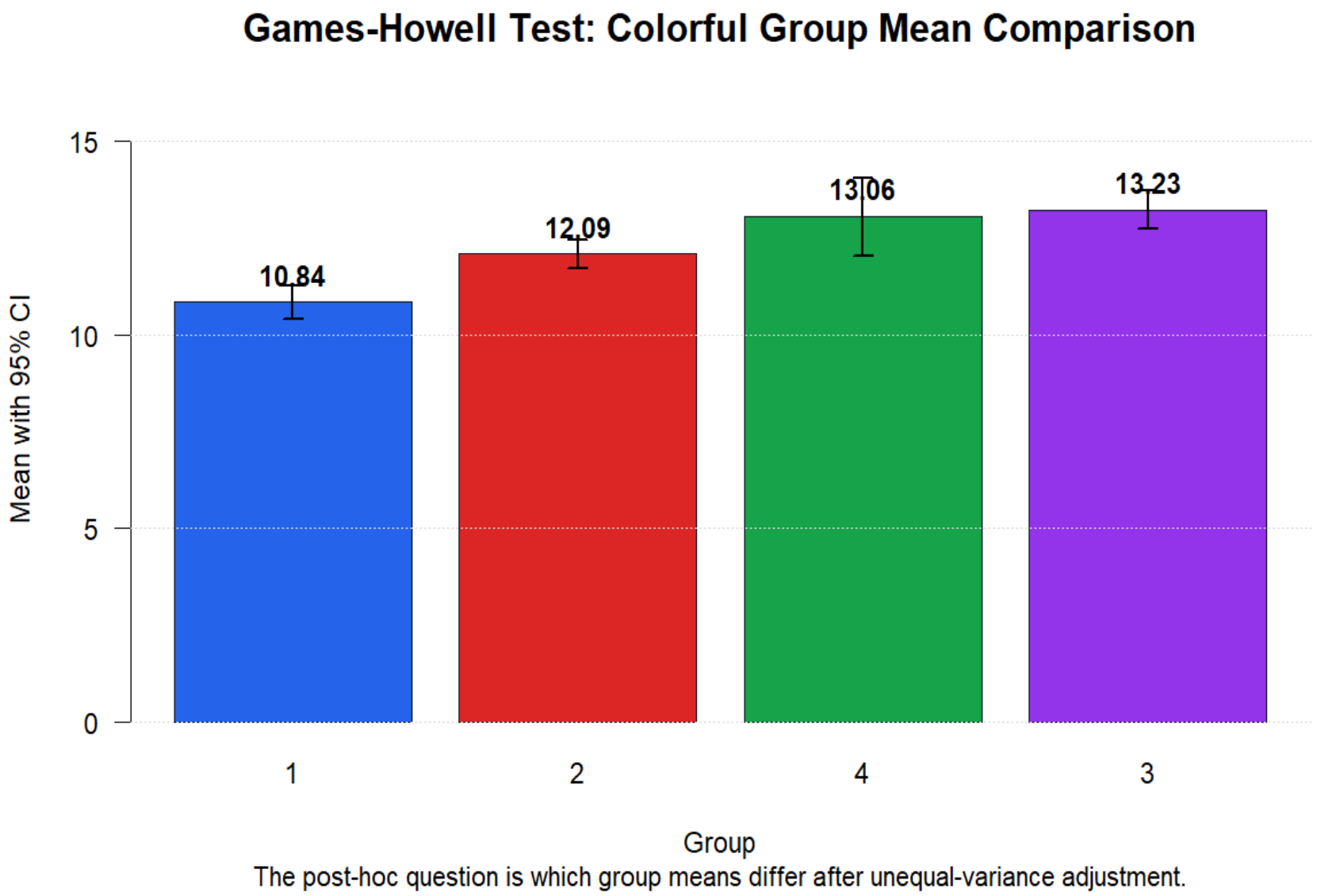
group_1	group_2	mean_group_1	mean_group_2	mean_difference_group_1_minus_group_2	absolute_mean_difference
1	2	10.84434	12.09180	−1.2474637	1.2474637
1	3	10.84434	13.22680	−2.3824645	2.3824645
1	4	10.84434	13.05714	−2.2128032	2.2128032
2	3	12.09180	13.22680	−1.1350008	1.1350008
2	4	12.09180	13.05714	−0.9653396	0.9653396
3	4	13.22680	13.05714	0.1696613	0.1696613

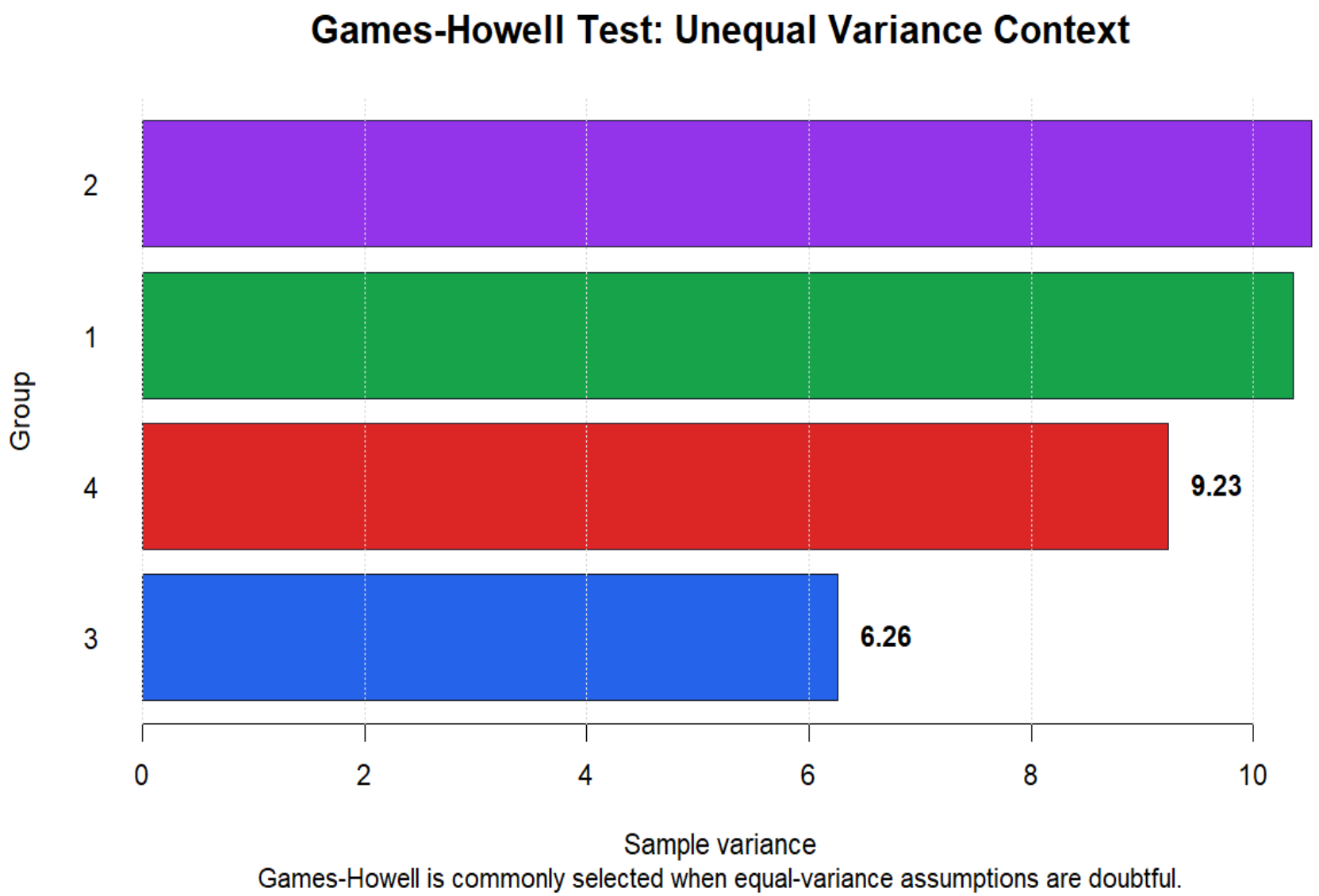
n_group_1	n_group_2	variance_group_1	variance_group_2	welch_standard_error	games_howell_standard_error
212	305	10.359541	10.517860	0.2887050	0.2041452
212	97	10.359541	6.260524	0.3367599	0.2381252
212	35	10.359541	9.231933	0.5591380	0.3953702
305	97	10.517860	6.260524	0.3146844	0.2225155
305	35	10.517860	9.231933	0.5461266	0.3861698
97	35	6.260524	9.231933	0.5729843	0.4051611

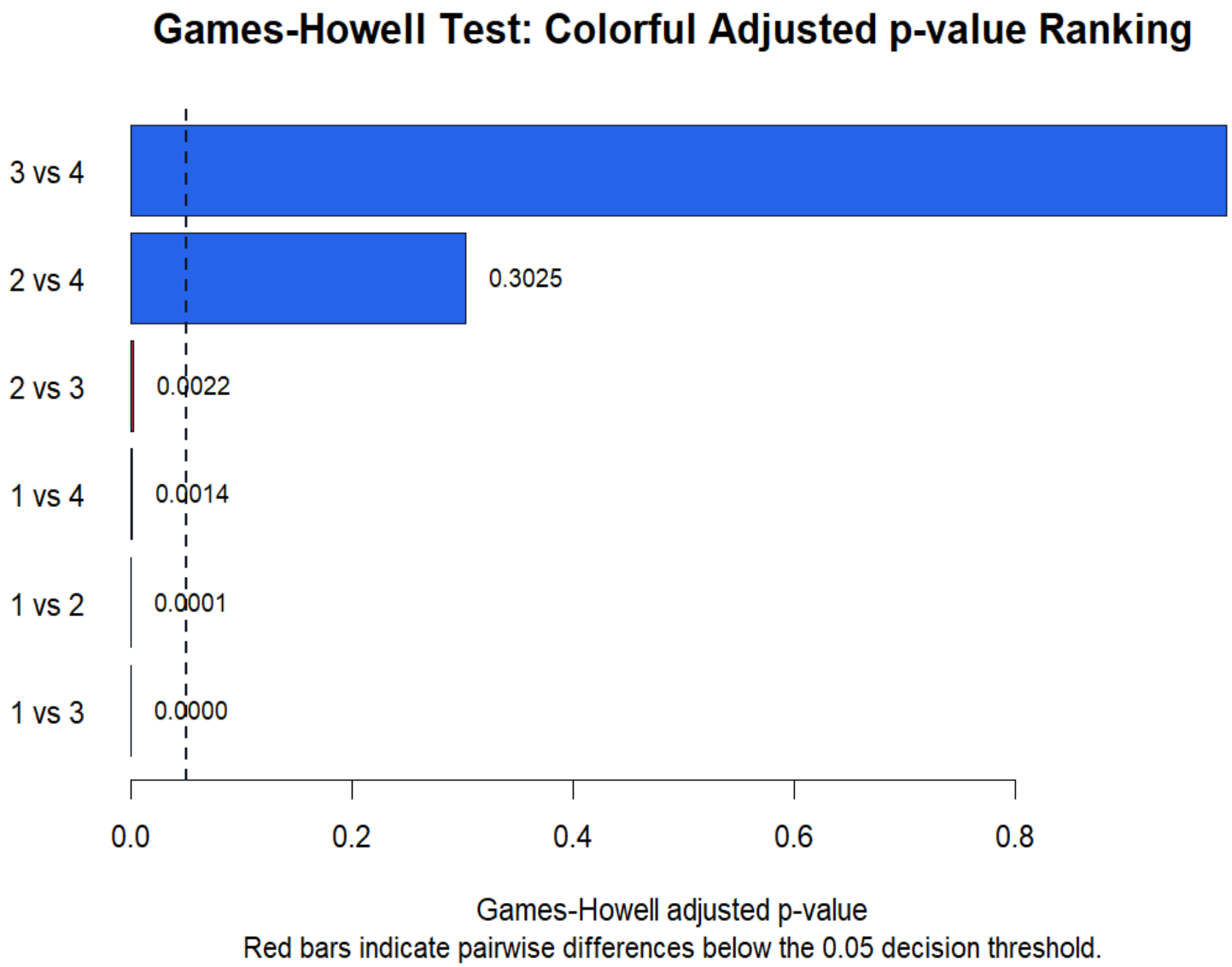
q_statistic	welch_degrees_of_freedom	adjusted_p_value_games_howell	q_critical_alpha_0_05	ci95_lower_difference
6.1106677	456.19790	1.120671e−04	3.646585	−1.991897
10.0050908	235.08565	1.023753e−10	3.659279	−3.253831
5.5967874	47.50184	1.395448e−03	3.765154	−3.701433
5.1007726	207.30376	2.183915e−03	3.662801	−1.950031
2.4997798	43.38841	3.025455e−01	3.778029	−2.424300
0.4187502	51.58075	9.908627e−01	3.754464	−1.351501

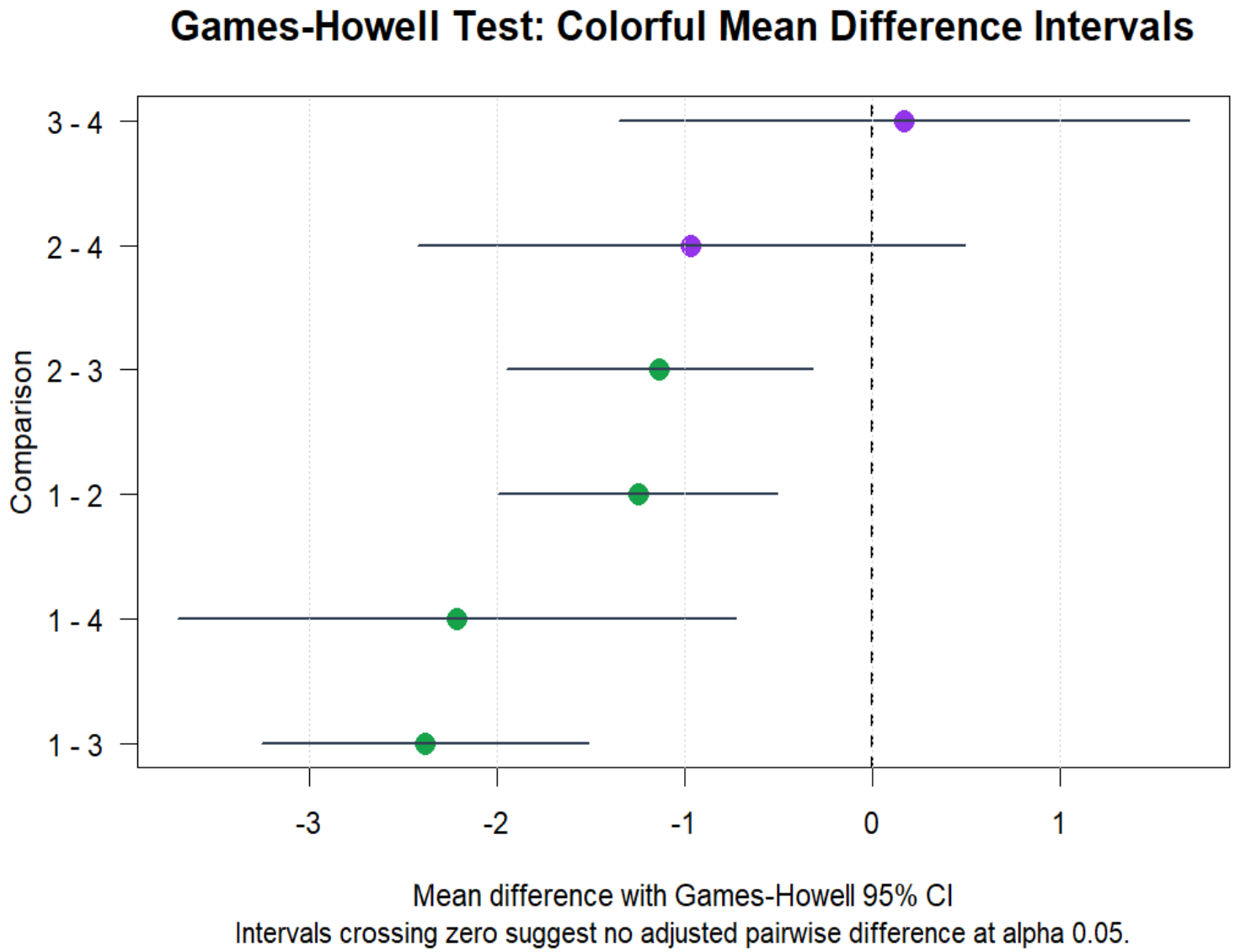
ci95_upper_difference	decision_alpha_0_05	interpretation
−0.5030307	Significant	Group means differ after Games−Howell adjustment.
−1.5110978	Significant	Group means differ after Games−Howell adjustment.
−0.7241732	Significant	Group means differ after Games−Howell adjustment.
−0.3199711	Significant	Group means differ after Games−Howell adjustment.
0.4936213	Not significant	No statistically significant adjusted difference.
1.6908239	Not significant	No statistically significant adjusted difference.

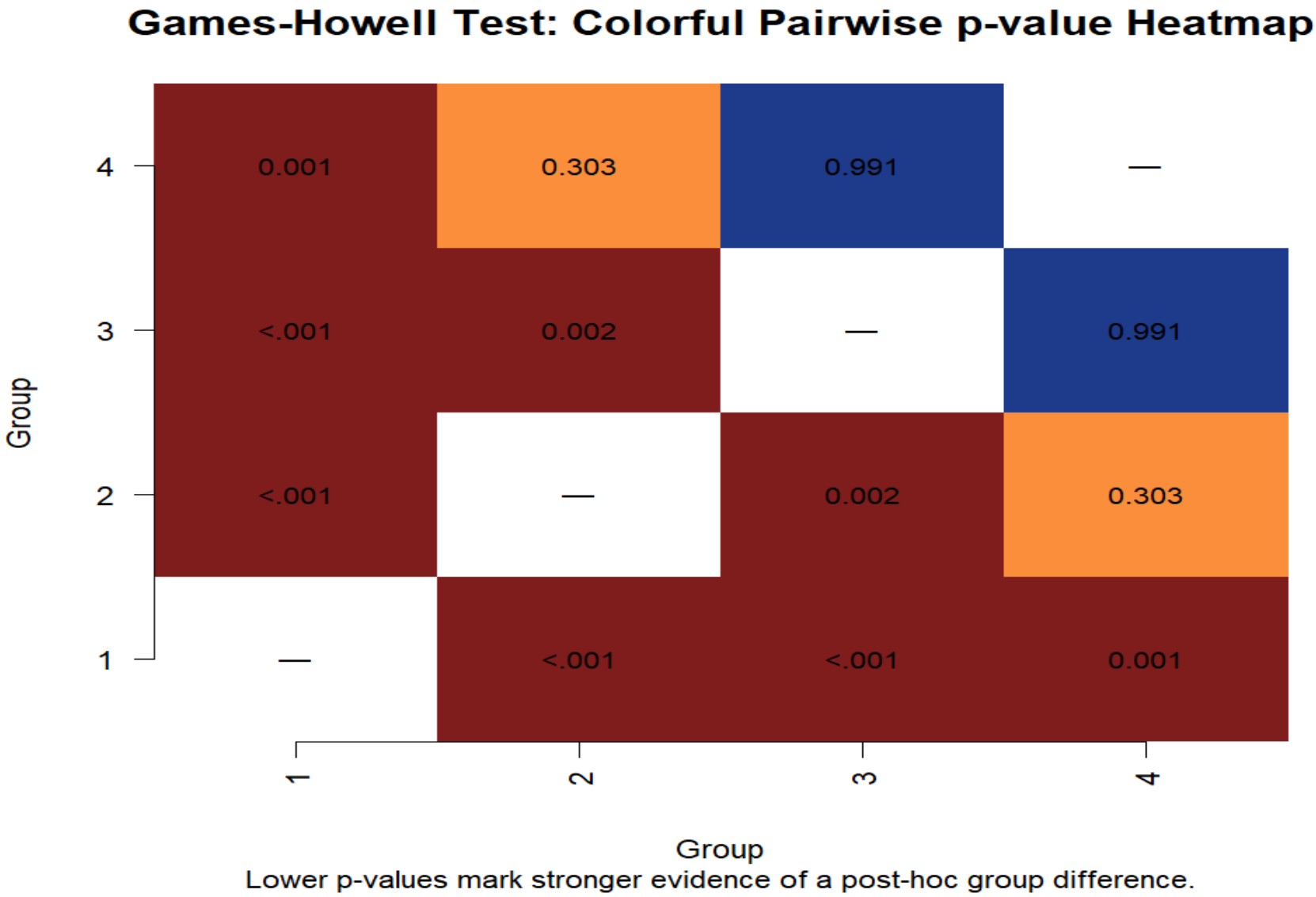

Games-Howell Test: Colorful Group Spread Boxplots
Dependent variable
0
5
10
15
1
2
3
4
Group
Unequal spreads are important because Games-Howell does not require equal variances.

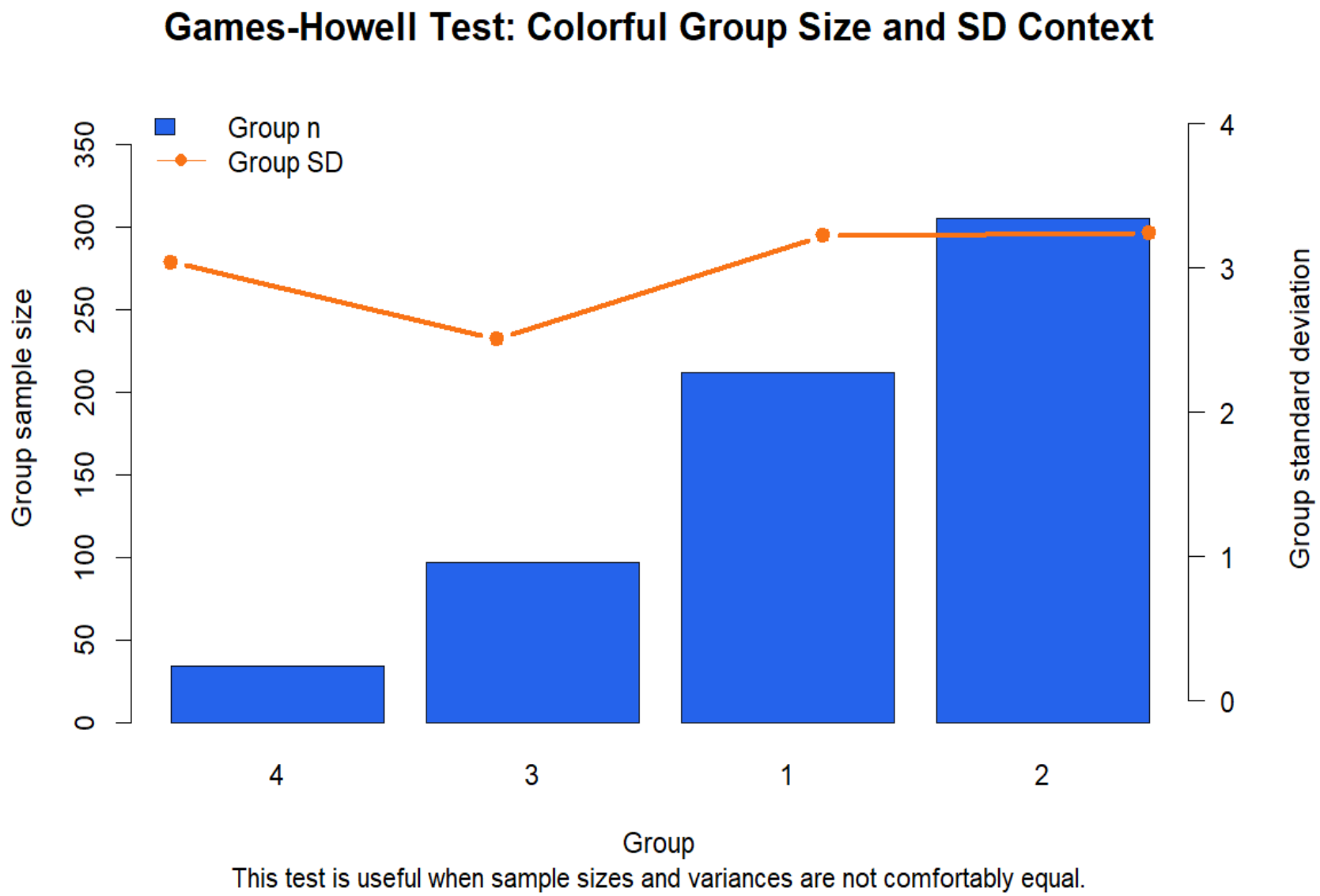

Games-Howell Test: Colorful Group Mean Comparison
Mean with 95% CI
15
10
5
0
10.84
12.09
13.06
13.23
1
2
4
3
Group
The post-hoc question is which group means differ after unequal-variance adjustment.


Games-Howell Test: Unequal Variance Context
Group
2
1
4
3
9.23
6.26
0
2
4
6
8
10
Sample variance
Games-Howell is commonly selected when equal-variance assumptions are doubtful.


Games-Howell Test: Colorful Adjusted p-value Ranking
3 vs 4
2 vs 4
2 vs 3
1 vs 4
1 vs 2
1 vs 3
0.3025
0.0022
0.0014
0.0001
0.0000
0.0
0.2
0.4
0.6
0.8
Games-Howell adjusted p-value
Red bars indicate pairwise differences below the 0.05 decision threshold.


Games-Howell Test: Colorful Mean Difference Intervals
Comparison
3 - 4
2 - 4
2 - 3
1 - 2
1 - 4
1 - 3
-3
-2
-1
0
1
Mean difference with Games-Howell 95% CI
Intervals crossing zero suggest no adjusted pairwise difference at alpha 0.05.


Games-Howell Test: Colorful Pairwise p-value Heatmap
0.001
0.303
0.991
—
<.001
0.002
—
0.991
<.001
—
0.002
0.303
—
<.001
<.001
0.001
4
3
2
1
Group
1
2
3
4
Group
Lower p-values mark stronger evidence of a post-hoc group difference.


Games-Howell Test: Colorful Group Size and SD Context
Group n
Group SD
Group sample size
0
50
100
150
200
250
300
350
Group standard deviation
0
1
2
3
4
4
3
1
2
Group
This test is useful when sample sizes and variances are not comfortably equal.