The Damper Setting: Is Higher Always Better?

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Introduction

All Concept2 rowing machines (or ergs) have a flywheel which moves as the rower takes strokes on the machine. There is also a damper which controls the rate of deceleration of said flywheel (shown in Figure 1). This is a trade off when working out because with a high damper setting it is harder to row one stroke, but you can move a further distance. This means you will get tired faster when the damper setting is higher and may not row as far as you could have with a lower damper setting. At the gym nearly everyone seems to think that the highest damper setting is the best to use, and will result in the best workout. However the experienced rower almost never moves the damper from the middle setting. In fact Concept2 explicitly says that the highest setting will not result in your best score (Damper Setting 101).

Figure 1: This is the damper and flywheel. [1]

If the highest setting is not the best to go by, this brings some questions to mind. First: what is the best setting? And what effect (if any) do different settings have on a workout? In order to answer the later of these 2 questions I have devised an experiment. My own hypothesis comes from my experience as a rower. *I believe that differences in the damper setting will not result in any significant change in the performance of the rower.*

Data Collection

The experiment included four rowers, four trials, and four damper settings. Each rower rowed 100 meters at each of the different damper settings and the time to complete the sprint was recorded. Because the rowers got fatigued (at least slightly) over the course of their trials, this introduced variability into the data. The Latin square design was used to account for this, because it allows for the blocking of two nuisance variables [2]. In this case those variables are the different rowers, and the fatigue they experienced. Therefore the order in which each rower went through the damper setting was different and random for each of them. The damper settings are labeled here from A to D with A being the lowest setting and D being the highest. The data collected is shown in Table 1

	Trial 1	**Trial 2**	**Trail 3**	**Trial 4**
Rower 1	A=17.0s	C=16.0s	B=16.4s	B=16.4s
Rower 2	B=17.6s	A=18.1s	D=17.0s	C=17.5s
Rower 3	C=16.9s	D=17.2s	A=17.9s	B=17.6s
Rower 4	D=22.6s	B=25.0s	C=24.2s	A=26.4s

Table 1: The data collected in the experiment

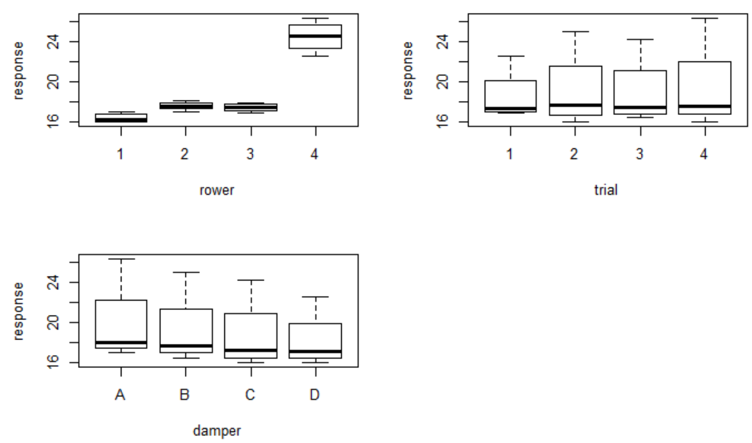

Figure 2: Box plot of each Rowers Performance

In Figure 2 we can see that one rower was significantly slower, this is because they were not an experienced rower. I would have liked to collect data from all experienced rowers. However, due to quarantine restrictions, the pool of people that I could collect data from was limited to my roommates. I do not think this is an issue since the goal of the experiment is to look at the effects of damper settings. So each rower's score does not matter as much because it will be blocked by the Latin Square design.

Method of Analysis

The mathematical model used in this experiment is the standard model for a response for a Latin square design [2]. This model was chosen because the two nuisance variables discussed previously allow for a four by four Latin square:

$$y_{ijk} = \mu + \alpha_i + \tau_j + \beta_k + \epsilon_{ijk} \qquad j = A, B, C, D \qquad i, k = 1, 2, 3, 4$$

For this experiment the y_{ijk} is the response, or the time it takes to row 100 meters. μ is the overall mean. α and β parameters are the effects of the nuisance factors representing the order the trials were completed and the rower respectively. The τ is the main study of this experiment (the effect of the damper setting). Finally ϵ_{ijk} represents random error which is not attributable to any of the other treatment effects. ANOVA will be performed on τ to determine if there is a statistical difference between the τ_j for each damper setting.

Some notable restrictions on this model are that Latin Square is an incomplete design; it does not include observations for all possible combinations of *i,j,k*. This means that the sums of squares and the means are calculated using the assumption that all the treatments do not interact with each other.

The Grand Mean is the average response for all the observations in the experiment. For this data it can be calculated as 18.96 seconds to complete the 100 meter sprint. The sample means for each damper setting are $\bar{y}_A = 19.85$, $\bar{y}_B = 19.15$, $\bar{y}_C = 18.65$, $\bar{y}_D = 18.175$. These are the times (in seconds) it took for the sprint on each damper setting, averaged across all rowers. From these, the treatment effects for each damper setting can be found by subtracting each sample mean from the grand mean:

τ_A= .89375
τ_B= .19375
τ_C= -.30625
τ_D= -.78125

All these treatment effects are in seconds, and the last two (representing the 2 highest damper settings) are negative. This means that on an average, rowers were .3 and .8 seconds faster for damper settings of C and D respectively. So it is clear to see that that rowers are faster when using a higher damper setting. However it must be determined if this effect is *statistically significant*.

Results

With the mathematical model established, the hypothesis in the introduction states that differences in the damper setting will not result in any significant change in the performance of the rower. This can be re-written in the context of the model: $\tau_A = \tau_B = \tau_C = \tau_D$. Since this hypothesis proposes no difference it is the null-hypothesis, or H_0. Therefore, the alternative hypothesis or H_a states that at least one τ_j is different. Performing ANOVA in R on all of the parameters will answer whether the previously computed differences between τ_j are *statistically significant* [3].

```
## Analysis of Variance Table
##
## Response: response
```

```
##           Df  Sum Sq Mean Sq  F value    Pr(>F)    
## rower      3 170.452  56.817 181.4524 2.823e-06 ***
## trial      3   1.447   0.482   1.5403   0.29813    
## damper     3   6.162   2.054   6.5595   0.02533 *  
## Residuals  6   1.879   0.313                       
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

The output shows the difference between groups considering the damper setting is significant since the p-value $= .02533 < .05$. Which means that at the 95% significance level H_0 should be rejected. However, at the 99% level of significance, the cutoff value becomes $1 - .99 = .01$ and the p-value (.02533) is greater than .01. Hence, at a 99% level of significance there is not enough evidence to reject H_0.

Although this test does show that there could be some *significant* differences between damper settings, it does not give enough information to actually provide a meaningful conclusion. To get a better idea of exactly which damper setting is different, Tukey's Honest Significant Difference test can be used to determine which sample means ($\bar{y}_j$) differ significantly. The TukeyHSD test statistic is

$$q_s = \frac{\bar{y}_\alpha - \bar{y}_\beta}{SE},$$

where $\bar{y}_\alpha$ is the larger of the two means and $\bar{y}_\beta$ is the smaller. The q_s statistic is compared to the Studentized range distribution to determine if the difference is statistically significant [4]. With this test, a confidence interval can be calculated for all possible differences between $\bar{y}_{A,B,C,D}$. Any interval which contains zero cannot be considered a significant difference between the two means.

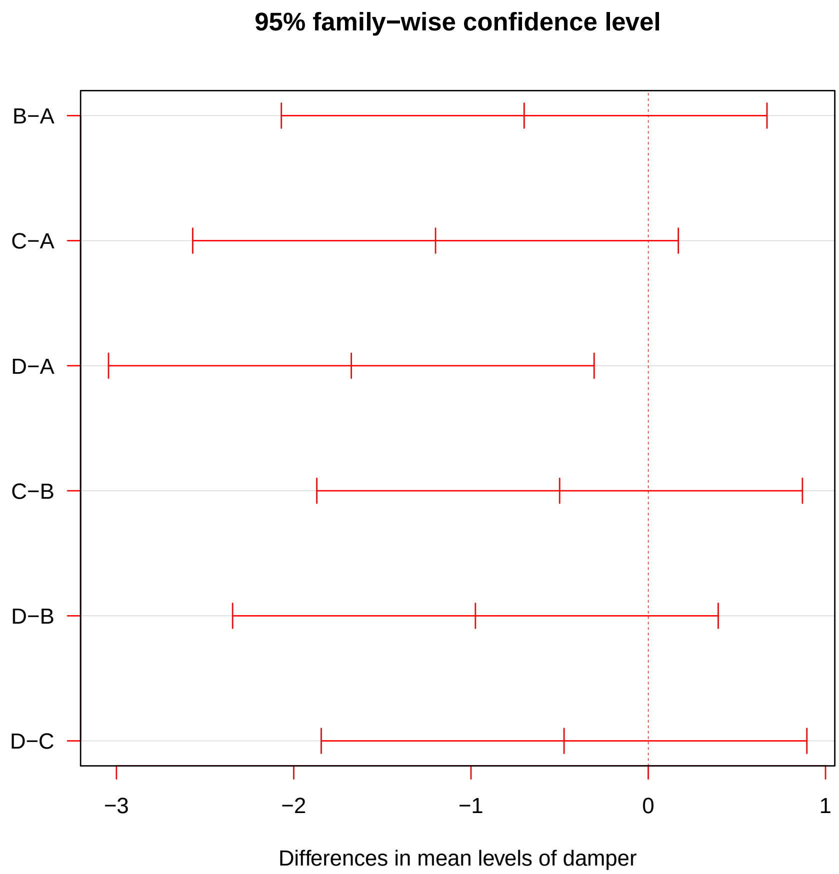

Figure 3: Tukey HSD at $\alpha = .05$

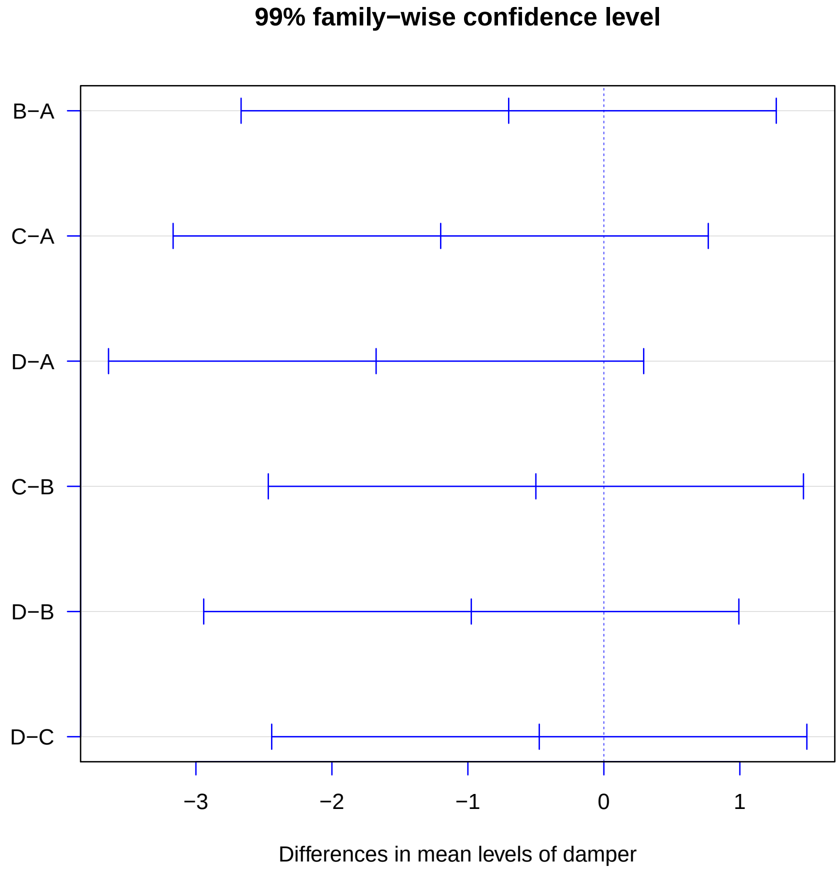

Figure 4: Tukey HSD at $\alpha = .01$

According to the pairwise comparison with the Tukey method, we can see that the distinct damper settings which are different from each other are only A and D in figure 3. This is probably because the differences between the other damper settings are only slight, so the only *significant difference* is between the two extremes. The difference is no longer present when the level of confidence is increased to 99% as is shown in Figure 4.

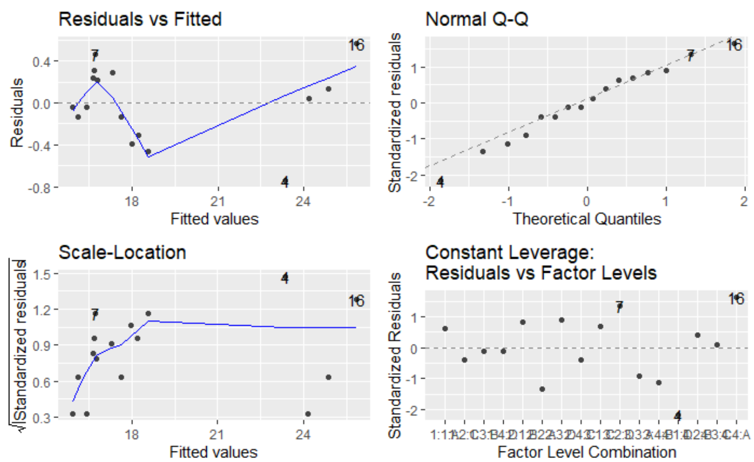

Figure 5: The residuals for the linear model

The residuals in this experiment are shown in Figure 5. They appear to have a relatively close to normal distribution. In the residuals vs fitted graph there are some signs of heteroscedasticity. Based on the fact that there are only 16 data points, I don't think it is enough to cause worry, especially since the Q-Q plot shows us that the residuals closely resemble a normal distribution. With this information I believe all the assumptions have been met, and that this experiment is valid.

Conclusions

From this experiment I found that there is a statistical difference at a 95% level of significance between performances at the highest and lowest damper settings. This goes away at the 99% level, and helps to support my hypothesis. The result at the 95% level is still interesting though. It contradicts the statement on Concept2's website. However, it hints at a deeper purpose of the damper, and helps to explain what the damper setting actually does. For the experiment the rowers were asked to row 100 meters. This was chosen because a short distance will allow for multiple quick trials without significant fatigue. It was necessary for rowers to apply the same amount of effort in each trial, so that the largest treatment effect was the damper setting. I believe that this distance choice played a role in the results of the experiment. A good analogy for the damper setting on a rowing machine is the gears on a bicycle. Different gear settings do not affect the work a cyclist does, but definitely have an impact on their performance, depending on if they are going up a steep hill or coasting down one. If we bring this analogy back to the rowing machine it makes sense that a higher damper (or "gear") setting will result in better performance for short distances. The shorter distance is like going up a hill on a bicycle. In conclusion, the measured difference between damper settings is likely because of the short distance rowed. With a greater distance to row fatigue may become more of a problem, but the effects of damper setting would most likely be less significant.

If I were to do this experiment again I would increase the distance for each trial. With this change I would expect rower performance to differ less for the damper settings. While longer distances might increase the fatigue for rowers greatly, the variability could be accounted for in the Latin square design. Further experiments that could be done are ones where both distance and damper setting are controlled variables and the rower's pace is the response, rather than the time for completion. However, this design has flaws of its own: mainly the fact that a rower's pace for distances that vary greatly would not be the same.

References

[1] Concept2. *Damper Setting 101.* English. 2019. URL: `www.concept2.com/indoor-rowers/training/tips-and-general-info/damper-setting-101`.

[2] Linlin Dr. Chen. *Design of Experiments: Latin Squares.* Class Lecture. 2020.

[3] Todos Logos. *Latin Squares Design in R.* 2010. URL: `www.r-bloggers.com/2010/01/latin-squares-design-in-r/`.

[4] Wikipedia. *Tukey's Range Test.* Sept. 2020.