Factors Affecting Tennis Ball Bounce Height

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Experiment Formulation

Brainstorming Session

After it was decided to perform an experiment to analyze the effect of water on the bounce height of a tennis ball, several designs came to mind. The initial proposal was to use a blocked split-plot design. Blocks were to be the stores where the tennis balls could be bought, and the whole plot and subplot factors were the brand of tennis ball and level of wetness, respectively. This design accounted for store to store variation, but it did not address the effect of surface type on the bounce height of a tennis ball. Furthermore, the cost of the experiment would be quite high, since the experiment required new tennis balls to be purchased. For these reasons, the design was changed to examine the effects of wetness and surface type on the bounce height of tennis balls. One of the experimenters had a large bag of used tennis balls which could be used, which made the experiment very affordable. However, because ball to ball variation could be large, it was decided to block on tennis balls and perform the experiment with many tennis balls. Further brainstorming was needed in order to determine how to measure the height of the bounce of the ball and which surfaces to use. Also, the experimenters decided on the levels of wetness for the tennis balls, which were supposed to replicate realistic playing conditions.

Objectives of the Experiment

The main objective of the experiment was to determine the influence of water on tennis ball bounce height. Since there could be an interaction between the degree of wetness and the type of tennis court surface, a factor for the surface type was included. This effect is of particular interest because tennis matches are rarely played in the rain. During professional matches on the ATP tour (Association of Tennis Professionals), the matches are often delayed due to rain. If tennis ball wetness does not greatly impact bounce height, then it could be suggested that junior tournament players can possibly play in the rain, assuming that the other effects of rain are not as important. Also, a wet tennis ball on a carpet court might behave differently compared to a wet tennis ball on a hard court. If no interaction between surface type and degree of wetness is found to exist, then the analysis can proceed in the direction of analyzing the main effects of the two factors. Again, the effect of tennis ball wetness is of particular interest in this experiment.

Pilot Study

The pilot study was conducted by randomly choosing three tennis balls from a bag that one of the experimenters had at home. These three tennis balls were then dropped from a height of two metres, and their bounce height was measured. A tape measure was placed against a wall to aid in the measurement of the tennis ball bounce heights, which were visually determined by another experimenter. Each tennis ball received a total of six treatments, using two factors (surface material and level of wetness), with two and three levels, respectively. Since it was a rainy day, all measurements were taken indoors in a hallway, with the hard surface being a floor in a hallway, which was believed to resemble the surface of a hard tennis court. The soft surface was a carpet in the hallway. Carpet courts were in use in higher level professional tennis competitions until 2009. The three levels of wetness in the pilot study consisted of a completely dry tennis ball, a tennis ball submerged in a bucket of water for ten seconds, and a tennis ball submerged in a bucket of water for ten seconds and then bounced on a carpet several times.

The major change decided to be made after the initial pilot experiment was to use a camera and tracking software in order to determine the ball bounce height. The other aspects of the pilot study were mostly kept the same. The decision to release the ball from a two metre height provided realistic ball bounce heights, and the levels of wetness produced results which were expected (a wet tennis ball should bounce less than a dry tennis ball).

A slight difficulty encountered was randomizing the surface type. In the pilot study, since it was time consuming to randomize the order of the surface type for each ball, all balls were first bounced on the carpet, and then on the hard surface. However, this required wet balls to be dried, which impacted the results. The decision was made that tennis balls should not be allowed to dry (the run order for treatments should first involve the dry balls), and that surface type should be randomized, even though it may take more time.

Estimate of Experimental Error and Power Calculation

The estimate of the experimental error was obtained by fitting the appropriate ANOVA model in R, using the data obtained in the pilot study. Balls were treated as random blocks, since ball to ball variation was believed to be high, and the three balls were taken from a bag. Two factors were used with two and three levels.

The estimate for the MSE was 10.4 cm^2. Since the blocks were treated as random, an estimate for the variance between the blocks was obtained as MSBlock, with a large value of 293.0 cm^2. A power study was conducted to determine how many blocks (tennis balls) were to be used in the main experiment in order to be able to detect a given minimum significant difference between treatment effects. One interesting note is that the main effects and the interaction between the two factors were significant even from the pilot study data. This would mean that the three blocks were sufficient to determine that there is a difference between the treatments. Therefore, attention was focused more on producing narrower confidence intervals between treatment contrasts.

Main Experiment Plans

Objectives

See the “Experiment Formulation” section.

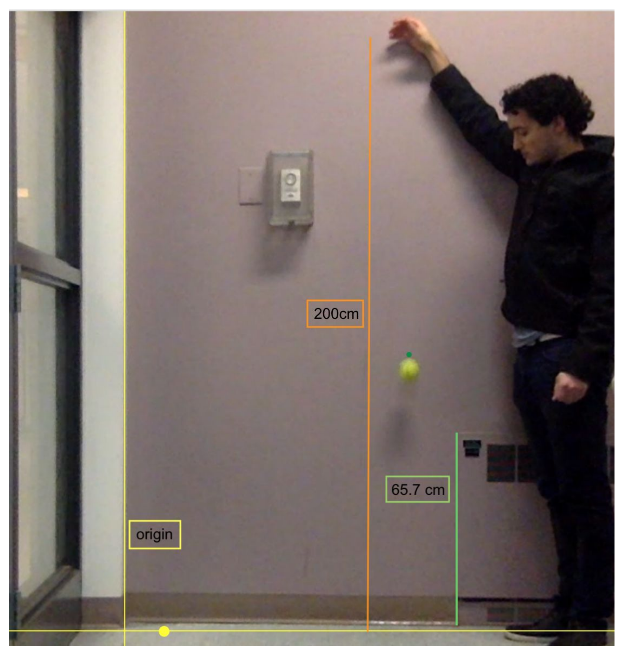
Factors Used and Their Levels

Two factors were used, as well as one blocking variable. The first factor was tennis ball wetness (factor A), and the second factor was surface type (factor B). Tennis ball wetness had three levels: completely dry (labelled dry in SAS output), fully submerged in water for 10 seconds (labelled wet in SAS output), and fully submerged in water for 10 seconds (labelled wetB in SAS output) and then bounced on the ground eight times from waist height. Surface type had two levels: hard and soft. The hard material was the floor in a hallway at SFU, which was believed to behave similarly to a real tennis court surface. The soft surface was a carpet mat in the hallway, which would somewhat resemble a carpet tennis court. The blocking unit was each tennis ball, since ball to ball variation was believed to be high.

Response Variable and Method of Measurement

The response variable was the maximum height that the tennis ball bounces back when dropped from a certain height (2 meters). To measure the height, the procedure was recorded by a laptop video camera facing parallel to the ground so that it could record the entire bounce on video. A laptop camera was used because of the convenience of sorting and categorizing videos. As a reference length, a particular part of the wall perpendicular to the floor with specific length (65.7 cm) was used and the corner of the wall was decided to be the origin. The ball was recorded as it was released from a height of 200 cm. Using Logger Pro video analysis[1], the position of the ball at the peak point after the bounce was determined in centimeters. Figure 1 shows one of the trials on a soft surface with a wet tennis ball dropping from 200 cm height.

Figure 1. The procedure of releasing a tennis ball from the height of 2m by one of the experimenters, as recorded by Logger Pro



[1] Logger Pro is a data-collection and analysis software that can analyze a video frame by frame or take measurements from a still photo.
https://www.vernier.com/products/software/lp/

Experimental Design and Randomization Procedure

Our choice of design is a randomized complete block design with one observation of each treatment combination per block (tennis ball). This yields six observations per block for a total of 48 observations, since eight tennis balls are used in the main experiment. Because the tennis balls would take too long to dry once they were already wet, and because a dried tennis ball can behave slightly differently and look different from a tennis ball that has never been wet before, the order in which the levels of wetness were carried out was not randomized. Therefore, both dry bounces of a single ball had to be recorded before both wet bounces, followed by the observations at the "wetB" level (submerged in water, and then bounced on the ground several times). This requires the assumption that run order within blocks does not impact the response, and this was deemed to be a reasonable assumption because experimental conditions were held fairly constant for each observation. There were no expected time effects such as changes due to weather, and a ball can be bounced many times before it deflates and differences between bounces become noticeable. However, future experimenters without time constraints might try to randomize within-block observations as well, by drying the balls completely between observations. Again, even this approach might not work, since dried tennis balls have a different physical appearance from completely dry ones, suggesting that they might behave differently.

The ideal randomization method under our current set of conditions is as follows. Consider the matrix:

Block	1	2	.	.	.	8	1	2	.	.	8
Surface	1	1	1	1	1	1	2	2	2	2	2
Run Order	1	2	.	.	.	8	9	10	.	.	16

A matrix like this would be used for each of three "phases" of the experiment, one for each level of the wetness treatment factor. The experimenter would permute the bottom row of each matrix and use the corresponding run order to determine which ball to drop and on which surface. They would implement each matrix in order of dry, wet and wet while bounced.

In general, if the experimenter had complete control over the dryness of each ball, a single matrix with a fourth row (to include the levels of the wetness factor), with run order ranging from 1 to 48. The permutation would then take place in the last row and the corresponding runs would be taken in the order from smallest to largest as in the three phase version. Due to the time constraint and drying problems throughout our version of the experiment, we were required to assume that the run order would not impact the response and observations close in run order would be independent. This assumption is not unreasonable, since the experimental conditions did not involve a component that would change over time.

Detailed Experimental Procedure

For this experiment the location was one of the main limitations due to the weather conditions at the time. The procedure was run indoors on two types of surfaces, hard (floor) and soft (carpet) with three levels of wetness: (1) completely dry, (2) wet, with the ball having been bounced several times, and (3) completely wet as explained before. After the location was chosen, the wall was measured and marked at a 2 meter height (from where the ball was supposed to be released). From a bag of approximately 50 tennis balls, eight balls were randomly selected and marked from 1 to 8 in order to be able to run the experiment with the dry balls first and then do the same for the wet balls afterwards. The eight dry balls were released from the height of 2 meters in a random order onto the surfaces that were randomly assigned; the procedures were recorded by a laptop camera which sat in front of the wall as mentioned in the "Response Variable and Method of Measurement" section. After each drop, the recorded video was saved with a specific name to be able to keep track of all of the recordings. For example, ball number two in dry condition on the hard surface was saved with the name "b2-d-h". An example of a randomization procedure could involve randomly labelling the balls from "b1" to "b8" (using R, for example). Then, going from the first ball to the eighth ball, randomly deciding between the hard or soft surface. Finally, since treatment combinations are not fully randomized, apply the "dry", "wetB", and "wet" treatments. Each time randomization is required on x elements, this could be done by generating x numbers from a uniform distribution in R, labelling them from 1 to x, and then sorting the labels in order, depending on which number they were matched up with from the draw from the uniform distribution.

In order to make sure the balls have the right level of wetness during the different procedures of the experiments, after randomly selecting each ball, they were soaked into a bucket of water for 10 seconds. They were then released from the marked height as soon as possible (completely wet treatment). The other level of wetness was done by soaking the ball into the bucket for 10 seconds and then hitting it to the floor a few times to release some of the water contained in the ball. The ball was then released from the marked height (for the "wetB" treatment).

Use of the Pilot Study as an Aid to the Main Experiment

The pilot study provided was a useful aid to the main experiment; it was noticed that balls which are left to dry after being submerged in water do not perform as well as dry balls not yet submerged in water. For this reason, it was decided to first run all trials which required the balls to be dry. Another change made after the pilot study was to use a camera and tracking software in order to determine the heights of the ball bounces. More on the pilot study can be found in the "Experiment Formulation" section. The pilot study helped to determine the number of tennis balls to use in the main experiment. Since using even three tennis balls produced in the pilot study produced significant results, it was decided that using more than three balls would be sufficient; it was decided to use eight tennis balls, so that confidence intervals during the analysis would be narrower.

Estimate of Time and Cost for the Ideal Experiment

The ideal experiment would involve new tennis balls and, as such, would not necessarily require blocking on the balls. However, this may require blocking on the can of tennis ball due to potential differences in the air pressure in each can. This experiment would most likely require less time to perform, since power could be attained more easily. However, the cost of the experiment would increase dramatically, since a can of three tennis balls costs approximately six dollars. If we implement the proposed design with used tennis balls, which requires blocking, the ideal experiment would cost zero dollars and use up to approximately 50 tennis balls. This experiment would then use all of the 50 tennis balls at no cost, since one of the experimenters offered their used tennis balls. The time to complete the experiment would be approximately five hours. Using more than 50 tennis balls is most likely unnecessary, based on the calculations from the pilot study.

Details of the Main Experiment

Data Collected

The observations made from the main experiment can be found in Table 1 (the response variable is measured in centimeters).

Table 1. Dataset for the main experiment

Obs	ballNum	wetness	height	courtType
1	1	wetB	107.50	soft
2	1	wetB	100.60	hard
3	1	dry	113.70	soft
4	1	dry	111.20	hard
5	1	wet	107.40	soft
6	1	wet	93.50	hard
7	2	dry	111.50	soft
8	2	wetB	97.96	soft
9	2	wetB	98.87	hard
10	2	wet	96.35	hard
11	2	dry	109.40	hard
12	2	wet	93.80	soft
13	3	dry	102.40	hard
14	3	wetB	101.00	soft
15	3	wetB	93.35	hard
16	3	wet	89.30	hard
17	3	dry	88.52	soft
18	3	wet	96.01	soft
19	4	wet	78.80	hard
20	4	wetB	88.45	hard
21	4	dry	99.00	hard
22	4	wetB	84.63	soft
23	4	wet	76.78	soft
24	4	dry	91.38	soft
25	5	wetB	92.09	hard
26	5	wet	88.52	hard
27	5	dry	102.10	hard
28	5	wetB	95.90	soft
29	5	wet	91.50	soft
30	5	dry	100.30	soft
31	6	wetB	96.55	soft
32	6	wet	95.13	soft
33	6	dry	108.10	soft
34	6	wetB	98.46	hard
35	6	wet	95.92	hard
36	6	dry	107.40	hard
37	7	wetB	103.90	soft
38	7	wet	99.56	soft
39	7	wetB	107.20	hard
40	7	dry	111.90	soft
41	7	wet	102.00	hard
42	7	dry	112.90	hard
43	8	wetB	95.17	hard
44	8	wetB	90.84	soft
45	8	wet	92.42	soft
46	8	wet	94.84	hard
47	8	dry	99.50	soft
48	8	dry	99.56	hard

Model Used

The model used for the experiment is given below:

$$Y_{hij} = \mu + \theta_h + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \epsilon_{hij}$$

$$\epsilon_{hij} \sim N(0, \sigma^2); \quad \theta_h \sim N(0, \sigma_\theta^2) \quad \text{all mutually independent}$$

$$i = 1, 2, 3;\ j = 1, 2;\ h = 1, 2, ..., 8$$

The theta terms represent the eight blocks used (eight tennis balls). Since we are interested in the effects on general playing performance in these conditions, the blocking effects are considered random. The alpha terms represent the level of wetness, with completely dry balls, wet balls that have not been bounced, and wet balls that have been bounced labelled as 1, 2, and 3, respectively. The beta terms represent the surface type, with soft courts and hard courts labelled as 1 and 2, respectively. An interaction term is included in the model because it was believed that the impact of wetness might depend on the surface type.

This model assumes that neither of our treatment effects interacts with our blocking factor.

Checks of Model Assumptions / Model Diagnostics

The model assumptions are:

1. There is no block-treatment interaction

2. The error variables have equal variances, are independent, and have a normal distribution

3. The block effect variables have equal variances, are independent (and are independent of the error terms), and have a normal distribution

To visually check the Block Treatment interaction assumption, plots of response values against treatment factor levels grouped by block factor levels are provided below. Figure 2 plots the average of height over courtType ($\overline{Y_{hi.}}$) versus the levels of wetness, grouped by block. Visually, there appears to be a strong block effect (with some balls consistently higher than others), which is confirmed by the size of MSθ. The figure shows a similar pattern for each block for different levels of wetness. Figure 3 presents the average of the heights over the different wetness levels ($\overline{Y_{h.j}}$) versus courtType, grouped by block. Similarly, the same pattern appears for the different block levels, and the pattern fluctuates because of block variations. Therefore, a block-treatment interaction is likely to be absent and our first assumption is satisfied.

Next, the assumption on the error variables needs to be checked. To check the equality of the variance and outliers, the residuals were plotted against predicted values and the normality assumption was checked by using a normal probability plot with the residuals. The assumptions are checked and summarized in Figure4. The residuals vs. predicted plot shows no significant outliers and the equality of the error variance is satisfied since the residuals are randomly scattered around zero at an approximately equal amount for each predicted value. Also, the QQ plot for the residuals gives a fairly straight line. This indicates that the errors follow an approximately normal distribution. Overall, the assumptions on the error variances seem to be satisfied.

Block assumptions are assumed to be true, since the size of the data is too small to check for normality and independence; there were only eight tennis balls with one observation per treatment.

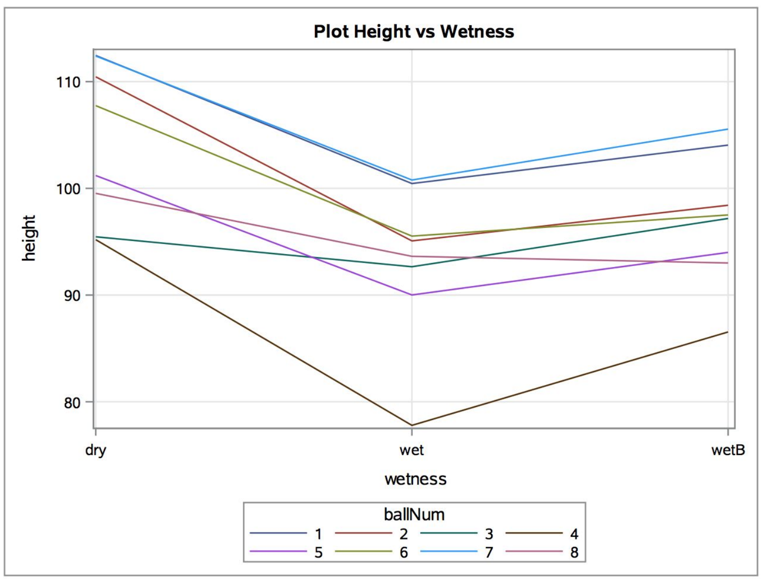


Figure 2. Checking block x treatment interaction by plotting height vs wetness grouped by block.

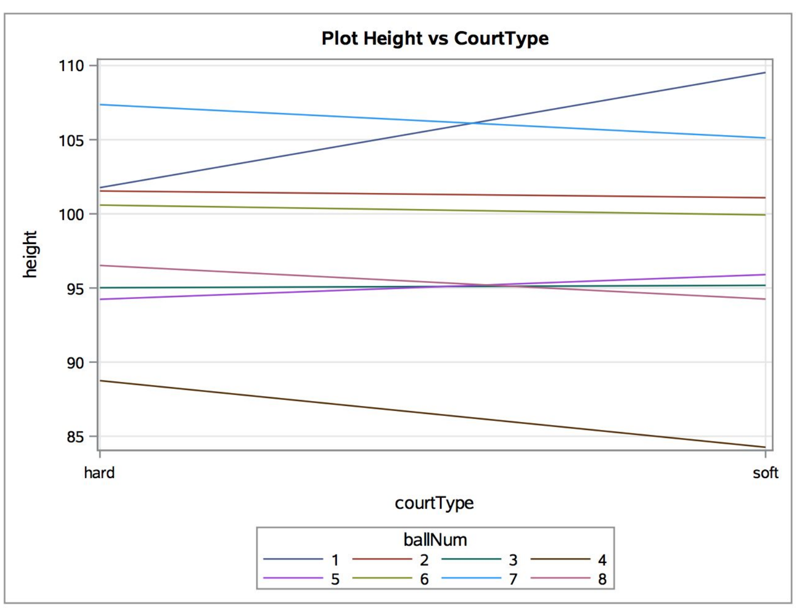


Figure 3. Checking block x treatment interaction by plotting height vs courtType grouped by block.

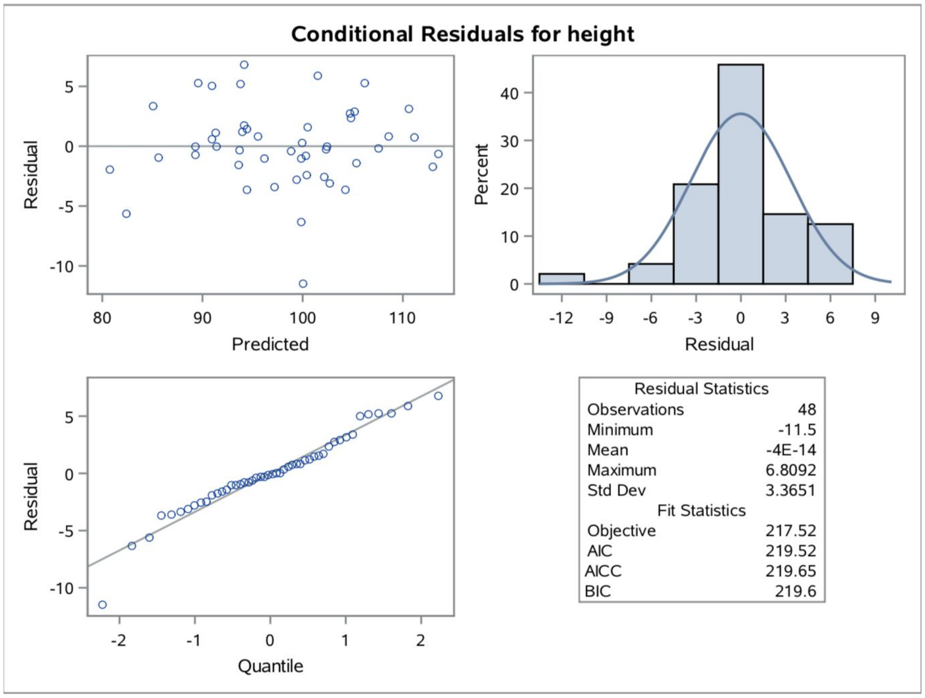


Figure 4. Checking error variance assumption

Variability / Uncontrolled Variables

There are some other potential sources of variability not taken into consideration in the design of the experiment. Spin on the ball during release from a height of two metres could affect the bounce height. Also, it is possible for the ball to hit a dead spot on the ground if the ball is not always released at the same location or it bounces back with an angle. Since balls were the blocks in the experiment, it would not be necessary to add the brand of the tennis ball as another factor. However, this could provide some fairly useful information. In particular, this would allow us to make conclusions on which brands perform better.

Statistical Inference

Hypothesis Tests

With the desire to test whether ball wetness or court type affects the bounce height of our balls, our first test is to determine whether or not there exists a significant interaction effect between wetness and court type. Formally, a test of:

$$H_0^{AB} : \alpha\beta_{ij} - \alpha\beta_{ip} - \alpha\beta_{uj} + \alpha\beta_{up} = 0 \text{ for all i, j, u, p versus}$$

$$H_1^{AB} : \text{ at least one of the above sums is nonzero}$$

If the interaction effects appear to be significant, we would compare treatment combinations including interactions (for a total of six treatments, and fifteen comparisons) to determine whether there is a significant or problematic difference (with regards to playing conditions) between the heights of the balls. The following ANOVA tables and corresponding expected mean squares table describes our procedure for conducting these tests:

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	12	2835.927908	236.327326	15.54	<.0001
Error	35	532.209858	15.205996		
Corrected Total	47	3368.137767			

Source	DF	Type III SS	Mean Square	F Value	Pr > F
ballNum	7	1789.266067	255.609438	16.81	<.0001
wetness	2	1011.738804	505.869402	33.27	<.0001
courtType	1	0.053333	0.053333	0.00	0.9531
wetness*courtType	2	34.869704	17.434852	1.15	0.3294

Source	Type III Expected Mean Square
ballNum	Var(Error) + 6 Var(ballNum)
wetness	Var(Error) + Q(wetness,wetness*courtType)
courtType	Var(Error) + Q(courtType,wetness*courtType)
wetness*courtType	Var(Error) + Q(wetness*courtType)

Under the null hypothesis, MS(AB) / MSE ~ $F_{2,35}$ and the probability of observing an F value at least as large as 17.43/15.21 is 0.3294, greater than any reasonable significance level. Therefore, we fail to reject the H_0^{AB} hypothesis and conclude that there is weak evidence of an interaction between factor A (ball wetness) and factor B (court type).

Since we failed to reject H_0^{AB}, we proceed to test for differences in the main effects (level of wetness and court type). Formally, this is the set of hypotheses:

$$H_0^A : \alpha_i^* = \alpha \text{ for all i} \in \{1,2,3\}\text{versus} \quad H_1^A : \alpha_i^* \neq \alpha \text{ for some i}$$

and

$$H_0^B : \beta_j^* = \beta \text{ for all j} \in \{1,2\}\text{versus} \quad H_1^B : \beta_j^* \neq \beta \text{ for some j}$$

where

$$\alpha_i^* = \alpha_i + \overline{\alpha\beta}_{i.} \text{ and } \beta_j^* = \beta_j + \overline{\alpha\beta}_{.j}$$

Under these null hypotheses, MSA/MSE ~ $F_{2,35}$ and MSB/MSE ~ $F_{1,35}$, which yield p-values of 8.03601e-09 (computed using R) and 0.9531 respectively. We reject H_0^A and fail to reject H_0^B at any reasonable significance level (say, 0.05). Therefore, there is strong evidence that there exists a main effect for ball wetness (A) but very weak evidence indicating a main effect exists for court type (B). This assumes that we average over the levels of the other factor in each case, noting that we average the interaction terms.

Confidence Intervals and Multiple Comparisons

The intention of the experiment is to determine the size of the combined effects of wetness and court type if there exists an interaction term. In this case, we would desire to compute 99% confidence intervals for Tukey's pairwise differences of treatment combination effects. If we fail to conclude that there exists significant evidence of an interaction term in the model, we would be interested in computing pairwise differences between responses at different court types and at different levels of wetness separately, each at the 99% level using Tukey's method.

Based on our conclusions above, we see that the computation of only one set of the confidence intervals is of particular interest (testing the difference in response at different levels of wetness), since we failed to reject the other two sets of null hypotheses. However, we have computed both sets of intervals and included them below.

The intervals in question are of the form:

$$\alpha_i^* - \alpha_k^* \in (Y_{.i.} - Y_{.k.} \pm \frac{q_{3,35}}{\sqrt{2}}\sqrt{\frac{2 * MSE}{16}})$$

and

$$\beta_j^* - \beta_l^* \in (Y_{..j} - Y_{..l} \pm \frac{q_{2,35}}{\sqrt{2}}\sqrt{\frac{2 * MSE}{24}})$$

where $q_{3,35}$ and $q_{2,35}$ correspond to the upper tailed 1% quantile of the studentized range distribution. The intervals in question are printed below:

Differences of Least Squares Means												
Effect	wetness	courtType	_wetness	_courtType	Estimate	Standard Error	DF	Adjustment	Adj P	Alpha	Adj Lower	Adj Upper
wetness	dry		wet		11.0644	1.3787	35	Tukey	<.0001	0.01	6.7710	15.3578
wetness	dry		wetB		7.2744	1.3787	35	Tukey	<.0001	0.01	2.9810	11.5678
wetness	wet		wetB		-3.7900	1.3787	35	Tukey	0.0248	0.01	-8.0834	0.5034
courtType		hard		soft	0.06667	1.1257	35	Tukey	0.9531	0.01	-2.9992	3.1326

The figure above indicates that the difference in effect for dry and wet balls ranges between 6.77 cm and 15.36 cm with at least 99% confidence (considering the experiment-wise confidence level). This range is quite large but clearly does not contain zero, an indication of a significant difference at our chosen 0.01 level. We observe a similar situation for dry balls and wet balls that were bounced first. We will analyze the size of these differences and the potential effect on the play of tennis under these conditions in our summary of these results below.

The two non-significant intervals are shown below, and both contain zero. However, the difference between wet balls and wet balls that had been bounced is nearly significant and would have been at the 0.05 level, indicating that the difference between the two treatments may need further investigation in a separate experiment. The interval comparing treatment effects for hard and soft court types indicates that there is little difference between the two, with extremes at less than half the diameter of a tennis ball.

Summary of Conclusions

Since the interaction term was not found to be significant, this may be taken into account in replicated versions of the experiment, and one could consider omitting this term from the model. One may also consider omitting the court factor (B) in future experiments due to its very high p-value of 0.95, in the hypothesis test averaging that effect over the levels of wetness (factor A).

Our two significant confidence intervals (not containing zero) indicate a very large deviation in bounce height, particularly for the dry versus wet comparisons. The lower limit of 6.77 cm is approximately the same as the diameter of a tennis ball and could impact play on a court severely in terms of a player’s ability. The table of confidence intervals indicates that the difference between a dry ball and a wet one that has been bounced is also significant with a lower bound of almost 3 cm. Both of the lower bounds of these differences can greatly affect the play of tennis and are addressed further in our conclusion.

The intervals that contain zero confirm intuitive assumptions, particularly the interval comparing wet balls versus wet balls that have been bounced. However, this interval nearly excludes zero and would demonstrate a significant difference at the 0.0248 level. Future experiments should perhaps take this into account as well. As expected due to the very high p-value, the interval comparing hard and soft court bounce heights is nearly symmetric about zero and serves to further emphasize the conclusion of little to no difference between these surfaces. It should be noted that under ideal conditions this may not have been the case, taking our replacement of hard court into consideration.

Summary

Summary of Findings

Based on the results from the main experiment, we have found that the interaction effect between the factors A and B (wetness and court type) is not significant. Also, the court type main effect was not significant, while the wetness factor was highly significant. As a result, this could have the following interpretation: only the level of wetness of a tennis ball determines the height of its bounce. In other words, the height of the tennis ball bounce does not change by much with a change in the court type. This is slightly surprising, especially because professional players often talk about a change in surface type as they play different tournaments. However, looking at the confidence intervals for the differences between the main effects, we can see that changing the court type affects the ball bounce height by less than a centimetre. On the other hand, changing the wetness of a tennis ball can change the height of the bounce of the ball somewhere between seven and eleven centimetres. One thing to note is that we found all of our terms to be significant in our pilot study (including the interaction term). One explanation for this is due to the different randomization procedure used in the pilot experiment. During the pilot study, three tennis balls were allowed to dry before reusing them again for another surface type. This seemed to cause problems, since the dried tennis balls still bounced fairly low, unlike a truly dry tennis ball. Because of this, the analysis suggested that there were significant interactions between the level of wetness and surface type. In the main experiment, balls which were submerged in water were not allowed to be dried and reused as a “dry” ball, for the reason just given.

As a suggestion for tournament organizers, the final verdict is to not allow tennis matches to be played on a rainy day. This has been the rule traditionally, and this experiment confirms that this decision is a good one. Playing on a wet tennis court could also potentially lead to more injuries, so dry conditions are heavily preferred.

Future Recommendations

It would be interesting to determine the interactions between tennis ball brand and level of wetness, as well as ball brand and surface type. Our current experimental design does not allow for this, since balls were taken from a large bag and treated as blocks. It is possible for certain tennis balls, such as Slazenger tennis balls which are used primarily on grass courts, to behave differently compared to other brands, such as Wilson, Dunlop, or Penn. A larger variety of surfaces would be more interesting, as well. Performing the experiment on hard, grass, clay, and carpet tennis courts would be ideal. It is almost beyond a doubt that tennis balls behave very differently on clay and grass, compared to a hard court. The two surfaces that were used in this experiment were perhaps too similar. At the same time, introducing clay as a surface could potentially uncover an interaction effect, since wet clay can behave differently from dry clay. Also, using only new tennis balls could help reduce variability in the measurements, thereby increasing the power of tests.