A Future for the Sport

STRING PINSETTER RESEARCH REPORT

DECEMBER 2020

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OVERVIEW

During the summer of 2020, the United States Bowling Congress Equipment Specifications and Certifications team began a comprehensive research study on string pinsetters, specifically looking at the scoring and pinfall variables between non-approved string pinsetters and USBC-certified free-fall pinsetters.

USBC researchers have designed a series of tests to collect extensive data from various models of string pinsetters. The research project is planned to take more than a year, with the final results scheduled to be published in 2022.

All aspects of the pin area, including pinsetters, pins, pin deck and pit area, play a critical role in scoring.

In the United States, the overwhelming number of USBC-certified leagues and tournaments use average-based divisions or handicap systems. Therefore, equipment that impacts scoring variables must be standardized from center to center in order to compare certified averages for competition.

The goal of USBC's string pinsetter research is to gather enough data about how the machines perform to determine if USBC certification is a reasonable path to consider. Additional issues to be considered could include development of equipment specifications and playing rules specifically related to string pinsetters.

As with all of our research, USBC intends to publish the data and share the analysis for the benefit of bowling. While a final report is more than a year away, USBC may share key preliminary findings, as we understand some industry stakeholders are interested in reviewing data as it becomes available.

This report publishes data and key findings from USBC's initial pin flight and pinfall tests using USBC's Bowlscore ramp.

Key Findings

As of December 2020, more than 45,000 combined shots have been made on free-fall machines and the string pinsetters. USBC's Bowlscore ramp was used for this initial research. A control set of data was completed on a free-fall machine, and six data runs were completed on string pinsetters for comparison.

Key findings for string pinsetters comparison data:

- Average strike percentage down a combined 6.9 percent across all entry angles tested
- Largest decrease in strike percentage occurred on light-pocket hits
- Multi-pin spare combinations were up across nearly all entry angles
- String pinsetter pinfall is statistically different overall compared to traditional free-fall pinsetters

RESEARCH

Testing Environment

The USBC Equipment Specifications and Certifications team, in a cooperative effort with the manufacturers of different string pinsetters, installed machines inside its test facility at the International Training and Research Center. These machines will be used in a variety of both automated and real-world testing.

Overall Test Plans

USBC can report partial data from one phase of the Bowlscore tests. There will be a significant number of additional tests conducted prior to the final report being published. Plans call for several testing environments including:

- **USBC Bowlscore machine**: Testing to measure pin flight and pinfall variable
- **E.A.R.L (robotic bowler)**: Testing to measure pinfall variables and compare spare conversion percentages
- **League and Tournament Study (human bowlers)**: Testing to measure variables using bowlers of various skill levels

USBC intends to measure a wide range of variables within each testing environment and will share comprehensive details about each test design as part of the final report.

USBC Bowlscore

The Equipment Specifications team utilized its custom USBC [1]Bowlscore machine, an automated ramp, in the initial testing of string pinsetters.

The USBC Bowlscore ramp automatically moves to adjust the entry angle and offset and collects the pinfall data for each shot. It is designed to replicate an average bowler's ball speed. For this purpose, we use an average bowler speed of approximately 17 mph and 250 rpm. Then, due to friction, the ball slows to about 14 mph at the pins, and the friction also causes the rotation rate to pick up to about 550 rpm at the pins, which is what the ramp is designed to duplicate.

The USBC Bowlscore ramp was retrofitted by removing the free-fall pinsetter on its stub lane inside the ITRC and replacing it with a string pinsetter. The Bowlscore machine then was calibrated, which included adjusting the Programable Logic Circuit (PLC) that runs the Bowlscore ramp.

A full Bowlscore run is designed to analyze pinfall, including strike percentages, across a variety of pocket-entry variables. As a very simple example, an ideal flush-pocket hit will strike at a higher percentage than a light hit. Bowlscore will measure how much this percentage changes as the entry variables change.

A full Bowlscore run consists of rolling the ball through the pin deck across 23 offsets, 11 angles and 10 shots each, which totals 2,530 shots per run (23 * 11 * 10 = 2,530). The runs are divided in halves by rolling five shots at each location, then restarting from zero degrees, zero offset. Angles vary from zero to 10 degrees in one-degree increments, and offsets vary from zero to five and half inches in 0.25-inch increments. This means you will see 230 total shots for each angle for expected (free-fall results) and observed (string pinsetter results), as seen in the charts on Page 6.

Small angles normally would represent lower-average bowlers. For example, a league bowler in the 180-200 average range may achieve about a 3- 4 degrees entry angle. Elite professionals would be at 5-7 degrees. Entry angles above that are not typical for most bowlers, but some have been measured to achieve up to 10 degrees when trying to maximize entry angle.

Bowlscore data is evaluated using a statistical analysis called the [2]chi-square proportions test to determine if a product changes pinfall from what is expected in a standard environment on free-fall machines.

By using a free-fall pinsetter control set of 12 runs, made up of six different types of pins (40 pins per pin type, 20 pins used in each run), we can develop baseline proportions of how many strikes, nine-counts, eight-counts and counts of seven or less we can expect to see in any one Bowlscore run.

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[1] Bowlscore on Bowling Explained show
[2] Chi Square Statistic

For example, at zero degrees of entry angle in our control set, we struck 1,001 times in 2,760 shots. This is equivalent to a strike proportion of ~36.3 percent. However, in a single Bowlscore run, there are only 230 shots per angle. Therefore, we expect to see 83.4 strikes at zero degrees (230 shots times 36.3 percent). This method is used to calculate the expected tables.

The chi-square proportions test works by examining the differences between what is expected to happen with free-fall machines and what is observed in the test with string pinsetters. If the differences become too large, the proportions are considered significantly different.

The formula for calculating chi-squared is:

$$\chi^2 = \frac{(Exp. - Obs.)^2}{Exp.}$$

Then, we get a critical statistic by summing the categories. The threshold for a significant difference depends on degrees of freedom and a chosen confidence level. For USBC testing purposes, we use a 99-percent confidence level and have three degrees of freedom, which makes our threshold for significance 11.34.

When a category exceeds 25 percent of the significant threshold (2.84 in this analysis), it becomes a large factor.

We use a 99-percent confidence level and have three degrees of freedom, which makes our threshold for significance 11.34.

Test #1 – Results of Bowlscore

USBC's preliminary tests involved conducting six full Bowlscore runs on string pinsetters. The string pinsetters were monitored throughout the testing and our test team made string adjustments to ensure accurate pinspotting.

For each of our Bowlscore runs, we calculated statistical difference in four categories using chi square analysis. The four categories are strikes, nine-count, eight-count and counts of seven or less at each entry angle.

In the following section, the chi-square data is shown for all six runs on the string pinsetter, compared to the free-fall control set.

The charts below will use the following color-coded key:

Lower Count Than Expected	Higher Count Than Expected	Large Factor Greater Than 2.84	Significantly Different is Greater Than 11.34

Results for Run #1

ANGLE	EXPECTED (FREE-FALL) X	9	8	7 or less
0	83.4	70.0	54.3	22.3
1	90.0	68.8	47.5	23.7
2	95.3	70.4	44.6	19.7
3	111.4	57.3	39.8	21.4
4	122.5	53.7	31.8	22.1
5	131.6	44.8	26.3	27.3
6	135.2	47.7	21.8	25.3
7	138.4	39.9	16.9	34.8
8	135.2	41.0	18.2	35.7
9	117.4	55.6	19.6	37.4
10	90.5	80.0	32.7	26.8

ANGLE	OBSERVED (STRING) X	9	8	7 or less
0	59	65	70	36
1	57	69	57	47
2	72	76	46	36
3	96	62	34	38
4	114	46	31	39
5	128	46	26	30
6	126	55	28	21
7	131	49	24	26
8	124	50	24	32
9	124	49	18	39
10	105	53	28	44

ANGLE	CHI-SQUARED RESULTS X	9	8	7 or less	ChiSq
0	7.1	0.4	4.5	8.5	20.5
1	12.1	0.0	1.9	23.0	37.0
2	5.7	0.4	0.0	13.6	19.8
3	2.1	0.4	0.9	12.8	16.2
4	0.6	1.1	0.0	13.0	14.7
5	0.1	0.0	0.0	0.3	0.4
6	0.6	1.1	1.7	0.7	4.2
7	0.4	2.1	3.0	2.2	7.6
8	0.9	2.0	1.9	0.4	5.1
9	0.4	0.8	0.1	0.1	1.3
10	2.3	9.1	0.7	11.0	23.1

Results of the first test showed significant differences at angles zero through four and 10 degrees.

Results for Run #2

ANGLE	EXPECTED (FREE-FALL) X	9	8	7 or less
0	83.4	70.0	54.3	22.3
1	90.0	68.8	47.5	23.7
2	95.3	70.4	44.6	19.7
3	111.4	57.3	39.8	21.4
4	122.5	53.7	31.8	22.1
5	131.6	44.8	26.3	27.3
6	135.2	47.7	21.8	25.3
7	138.4	39.9	16.9	34.8
8	135.2	41.0	18.2	35.7
9	117.4	55.6	19.6	37.4
10	90.5	80.0	32.7	26.8

ANGLE	OBSERVED (STRING) X	9	8	7 or less
0	56	78	59	37
1	64	57	66	43
2	77	55	61	37
3	86	50	66	28
4	90	61	39	40
5	108	64	24	34
6	124	53	34	19
7	127	39	26	38
8	119	48	19	44
9	106	49	25	50
10	91	56	25	58

ANGLE	CHI-SQUARED RESULTS X	9	8	7 or less	ChiSq
0	9.0	0.9	0.4	9.8	20.1
1	7.5	2.0	7.2	15.8	32.5
2	3.5	3.4	6.0	15.3	28.2
3	5.8	0.9	17.2	2.0	25.9
4	8.6	1.0	1.7	14.5	25.8
5	4.2	8.3	0.2	1.6	14.3
6	0.9	0.6	6.8	1.6	9.9
7	0.9	0.0	4.9	0.3	6.1
8	1.9	1.2	0.0	1.9	5.1
9	1.1	0.8	1.5	4.2	7.6
10	0.0	7.2	1.8	36.2	45.2

Results of the second test showed significant differences at angles zero through five and 10 degrees.

Results for Run #3

ANGLE	EXPECTED (FREE-FALL) X	9	8	7 or less
0	83.4	70.0	54.3	22.3
1	90.0	68.8	47.5	23.7
2	95.3	70.4	44.6	19.7
3	111.4	57.3	39.8	21.4
4	122.5	53.7	31.8	22.1
5	131.6	44.8	26.3	27.3
6	135.2	47.7	21.8	25.3
7	138.4	39.9	16.9	34.8
8	135.2	41.0	18.2	35.7
9	117.4	55.6	19.6	37.4
10	90.5	80.0	32.7	26.8

ANGLE	OBSERVED (STRING) X	9	8	7 or less
0	48	82	65	35
1	58	70	68	34
2	65	62	59	44
3	68	66	46	50
4	99	48	32	51
5	107	48	30	45
6	114	64	30	22
7	125	52	23	30
8	118	47	22	43
9	127	36	13	54
10	93	58	31	48

ANGLE	CHI-SQUARED RESULTS X	9	8	7 or less	ChiSq
0	15.0	2.1	2.1	7.3	26.5
1	11.4	0.0	8.8	4.5	24.8
2	9.7	1.0	4.7	30.1	45.4
3	16.9	1.3	1.0	38.1	57.3
4	4.5	0.6	0.0	37.9	43.0
5	4.6	0.2	0.5	11.4	16.8
6	3.3	5.6	3.1	0.4	12.4
7	1.3	3.7	2.2	0.6	7.8
8	2.2	0.9	0.8	1.5	5.4
9	0.8	6.9	2.2	7.3	17.2
10	0.1	6.1	0.1	16.7	22.9

Results of test three showed significant differences at all angles except seven and eight degrees.

Results for Run #4

ANGLE	EXPECTED (FREE-FALL) X	9	8	7 or less
0	83.4	70.0	54.3	22.3
1	90.0	68.8	47.5	23.7
2	95.3	70.4	44.6	19.7
3	111.4	57.3	39.8	21.4
4	122.5	53.7	31.8	22.1
5	131.6	44.8	26.3	27.3
6	135.2	47.7	21.8	25.3
7	138.4	39.9	16.9	34.8
8	135.2	41.0	18.2	35.7
9	117.4	55.6	19.6	37.4
10	90.5	80.0	32.7	26.8

ANGLE	OBSERVED (STRING) X	9	8	7 or less
0	51	85	60	34
1	53	78	59	40
2	72	60	53	45
3	78	55	46	51
4	90	41	44	55
5	101	63	30	36
6	123	60	25	22
7	128	46	23	33
8	122	41	17	50
9	112	54	20	44
10	105	44	36	45

ANGLE	CHI-SQUARED RESULTS X	9	8	7 or less	ChiSq
0	12.6	3.2	0.6	6.2	22.6
1	15.2	1.2	2.8	11.3	30.5
2	5.7	1.5	1.6	32.6	41.5
3	10.0	0.1	1.0	40.9	51.9
4	8.6	3.0	4.7	49.1	65.4
5	7.1	7.4	0.5	2.7	17.8
6	1.1	3.2	0.5	0.4	5.2
7	0.8	0.9	2.2	0.1	4.0
8	1.3	0.0	0.1	5.8	7.1
9	0.2	0.0	0.0	1.2	1.5
10	2.3	16.2	0.3	12.3	31.2

Results for Run #5

EXPECTED (FREE-FALL)				
Angle	X	9	8	7 or less
0	83.4	70.0	54.3	22.3
1	90.0	68.8	47.5	23.7
2	95.3	70.4	44.6	19.7
3	111.4	57.3	39.8	21.4
4	122.5	53.7	31.8	22.1
5	131.6	44.8	26.3	27.3
6	135.2	47.7	21.8	25.3
7	138.4	39.9	16.9	34.8
8	135.2	41.0	18.2	35.7
9	117.4	55.6	19.6	37.4
10	90.5	80.0	32.7	26.8

OBSERVED (STRING)				
Angle	X	9	8	7 or less
0	71	70	63	26
1	67	64	70	29
2	89	52	55	34
3	93	50	56	31
4	98	53	50	29
5	127	40	25	38
6	138	34	27	31
7	137	31	9	53
8	113	45	23	49
9	101	61	28	40
10	79	70	29	52

CHI-SQUARED RESULTS					
Angle	X	9	8	7 or less	ChiSq
0	1.8	0.0	1.4	0.6	3.9
1	5.9	0.3	10.7	1.2	18.1
2	0.4	4.8	2.4	10.4	18.1
3	3.0	0.9	6.6	4.3	14.8
4	4.9	0.0	10.5	2.2	17.6
5	0.2	0.5	0.1	4.2	4.9
6	0.1	3.9	1.2	1.3	6.5
7	0.0	2.0	3.7	9.6	15.3
8	3.6	0.4	1.3	5.0	10.3
9	2.3	0.5	3.6	0.2	6.6
10	1.5	1.3	0.4	23.6	26.7

The data showed significant differences at angles one, two, three, four, seven, and 10 degrees.

Results for Run #6

EXPECTED (FREE-FALL)				
Angle	X	9	8	7 or less
0	83.4	70.0	54.3	22.3
1	90.0	68.8	47.5	23.7
2	95.3	70.4	44.6	19.7
3	111.4	57.3	39.8	21.4
4	122.5	53.7	31.8	22.1
5	131.6	44.8	26.3	27.3
6	135.2	47.7	21.8	25.3
7	138.4	39.9	16.9	34.8
8	135.2	41.0	18.2	35.7
9	117.4	55.6	19.6	37.4
10	90.5	80.0	32.7	26.8

OBSERVED (STRING)				
Angle	X	9	8	7 or less
0	61	79	60	30
1	76	63	55	36
2	69	60	70	31
3	99	42	60	29
4	104	55	42	29
5	119	40	43	28
6	126	35	29	40
7	120	42	16	52
8	119	35	10	66
9	106	47	22	55
10	88	56	28	58

CHI-SQUARED RESULTS					
Angle	X	9	8	7 or less	ChiSq
0	6.0	1.2	0.6	2.7	10.5
1	2.2	0.5	1.2	6.4	10.3
2	7.3	1.5	14.5	6.5	29.8
3	1.4	4.1	10.2	2.7	18.4
4	2.8	0.0	3.3	2.2	8.3
5	1.2	0.5	10.5	0.0	12.3
6	0.6	3.4	2.4	8.5	14.8
7	2.5	0.1	0.0	8.6	11.2
8	1.9	0.9	3.7	25.8	32.3
9	1.1	1.3	0.3	8.3	11.0
10	0.1	7.2	0.7	36.2	44.1

The data showed significant differences at angles two, three, five, six, eight and 10 degrees.

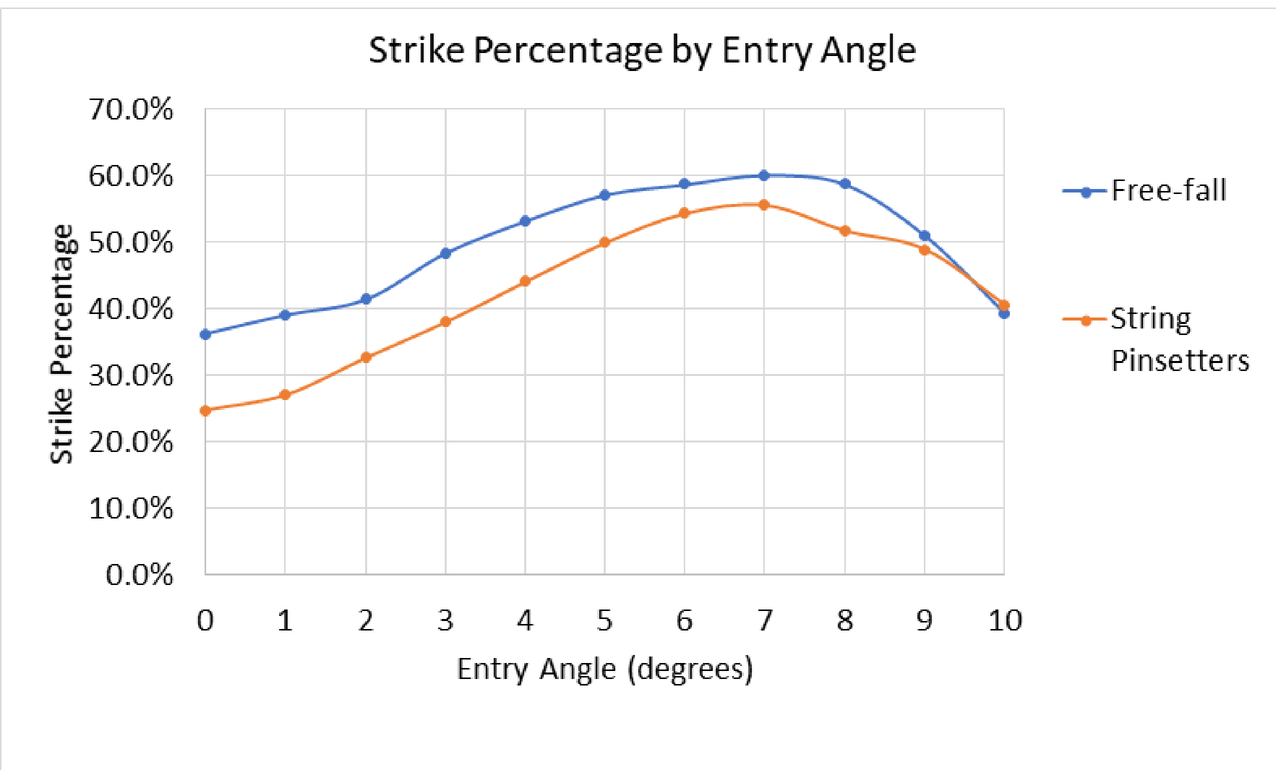
The results of the chi-square proportion testing show:

- Strikes are lower in almost all accounts.
- Counts of eight or seven or less are up throughout the angles.
- The smaller entry angles are more strongly affected than the larger entry angles

The result says that the string pinsetter's pinfall is significantly different from the pinfall on traditional free-fall machines, particularly at lower entry angles. Not only that, but in the following table, we can see striking is down 6.9 percent across all the angles on average:

Angle	Free-Fall X	String X	Free-Fall Shots	String Shots	Free-Fall X%	String X%	Difference
0	1001	342	2760	1380	36.3%	24.8%	-11.5%
1	1080	374	2760	1380	39.1%	27.1%	-12.0%
2	1144	451	2760	1380	41.4%	32.7%	-8.8%
3	1337	525	2760	1380	48.4%	38.0%	-10.4%
4	1470	609	2760	1380	53.3%	44.1%	-9.1%
5	1579	690	2760	1380	57.2%	50.0%	-7.2%
6	1622	751	2760	1380	58.8%	54.4%	-4.3%
7	1661	768	2760	1380	60.2%	55.7%	-4.5%
8	1622	715	2760	1380	58.8%	51.8%	-7.0%
9	1409	676	2760	1380	51.1%	49.0%	-2.1%
10	1086	561	2760	1380	39.3%	40.7%	1.3%
Total	**15011**	**6462**	**30360**	**15180**	**49.4%**	**42.6%**	**-6.9%**

Below is a chart showing the strike percentage at different entry angles comparing free-fall and string pinsetters.



These results show some interesting data:

- In general, the string pinsetters carry fewer light-pocket hits.
- It shows a larger separation in strike percentages between the free-fall and string pinsetter at smaller entry angles, and then it narrows as the entry angle increases.
- At 10 degrees, there are relatively less strikes on the high pocket on the free-fall machine due to many solid 9 pins, but the strings appear to be helping carry in that zone.

Observationally, we have recorded that we see string entanglements improving the strike rate on the high-pocket hits, whereas on the light-pocket hits, the pin action is deadened by the strings. Pins will still fall over, but they do not spin around or roll around the pin deck nearly as much as on traditional machines.

The pin flight and pinfall is meaningfully different with string pinsetters.

SUMMARY AND NEXT STEPS

Preliminary findings indicate pin flight and pinfall on string pinsetters is significantly different than free-fall machines. More research is needed to understand how this impacts scoring and to what extent. The USBC Equipment Specifications and Certifications team will continue the study and plans to publish full results in 2022.

In the meantime, string pinsetters are non-approved equipment and may not be used in USBC-certified competition, including USBC-certified leagues and tournaments. The results of USBC's research may or may not provide conclusive data to support a position on the certification of string pinsetters.

If USBC does explore a certification standard for string pinsetters in the future, there could be a wide range of equipment or installation specifications and potential rule changes to consider.