GOLD STANDARD TESTING OF MOTION BASED TRACKING SYSTEMS

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MARCH 2017

Interim Report

(STINFO COPY)

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14. ABSTRACT
Comparison testing and validation of the Zebra and Catapult tracking systems against a 'Gold Standard' on-field measurement system for human physiological performance monitoring. Data shows that the accuracy of the Zebra (RFID-based) system is very good, due to its high sampling frequency, with most measurements being within ~2% for distance and ~4% for velocity as compared to our standard method. However, the GPS-based Catapult system exceeded 4% error for distance measurements.

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1.0   BLUF

One of the main responsibilities of the STRONG Team in the context of Performance Science is the pervasive test and evaluation of commercial and near-commercial technologies. With industry pushing forward with large investments in this space, the STRONG Team must constantly evaluate the capabilities, and more importantly, the accuracy of these systems.

This report documents the test and evaluation of 2 of the most widely used 'external load' systems in the performance science space, Catapult and Zebra. The STRONG Team had a unique opportunity to at an NFL facility to set up experimental design and test both systems, which have a combined cost of over $400K. Both are location based systems, where Zebra operates based on RFID and Catapult via GPS. Catapult additionally has an accelerometer and gyroscope in the hardware, but these were not evaluated in this set of testing.

All testing (as documented in the next 14 pages) resulted in the Zebra system performing well above the acceptable experimental error. For all tests summed together, the overall error of the Zebra system is less than 1 yard (yd) per 50 yards of athlete movement (shown below). Bland Altman analysis shows that over half the athlete runs are less than 1 yd error, and 81% below 1.5 yd. However, as explained below, this is well below the expected experimental error of the testing protocol, where precise movement of the athlete can only be controlled within 1 yard, at best.

Distance Error	% Error	Yd Error (per 50 yards)
Zebra Summary	1.81%	0.91
Catapult Summary	3.99%	2.00

n=48	% of Athlete runs with distance error below value					
	0.5 yd	1 yd	1.5 yd	2 yd	2.5 yd	2.5+
Zebra	46%	54%	81%	85%	88%	100%
Catapult	13%	21%	40%	54%	69%	100%

2.0   GOLD STANDARD COMPARISON

The "Gold Standard" comparisons for this testing are:
- Measured distance with accuracy to 1", and athlete running distance accuracy defined within each test
- Timing gate system from Zybek (Combine Pro system) with 0.001 second accuracy

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- Instantaneous velocity from radar guns (after assessing the data, the analysis team found that the error of the radar guns was too high to be used in this study)

3.0   ATHLETES AND WEARABLE DEVICES

- 6 athletes ran the tests described below
- Each test was run in duplicate by each athlete, one at a jogging speed, and one at a maximal effort
- Each athlete was wearing a compression shirt with Zebra RFID tags on each shoulder
- Each athlete was also wearing a Catapult

4.0   TESTING PROTOCOL

The testing team mapped out 2 'team' runs, and 4 different field routes between 40-58 yards each, diagrammed below. Each route was run at a jogging speed (at least 4 miles per hour (mph)), and then a maximal effort.

The number of runs (per test) required for statistical power was a minimum of 10.

Before each athlete run, the field testing lead signaled "Start", and both the Zebra and Catapult systems simultaneously started a distinct "Session" in each software system. Upon the "Start" signal, the field testing lead started a stopwatch and the athlete held still for 15 seconds. After exactly 15 seconds, the field testing lead signaled to the athlete "Run" to start their run. For Team Runs 1 and 2, all athletes started simultaneously on signaling, for Runs 3-6, each athlete ran individually. Holding the athletes still for a set amount of time was required for proper alignment of raw data.

4.1   Test 1: Team Run 1

Test 1 had each athlete line up at the sideline, separated by 10 yards each. All athletes stood still for 30 seconds, and then jogged at the same pace (all followed the middle athlete's speed who was running at the 25) to the other sideline, running a straight line on the line marker, and stopped exactly at the other sideline (Figure 1).

A timed rest 30 seconds was led by the field testing lead, and the run was repeated back to the starting point.

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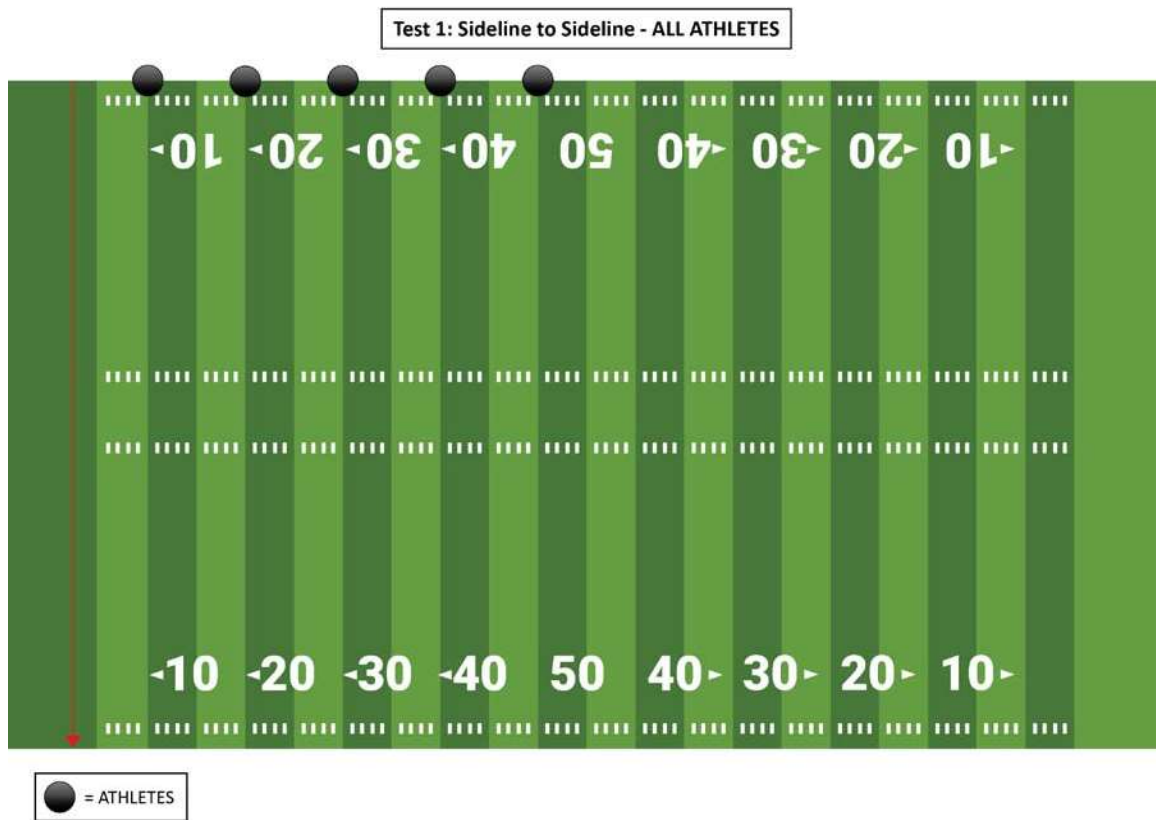
Figure 1. Test 1: Sideline to Sideline – All Athletes

4.1.1. Results:
For this team run, only total distance is compared to the actual Gold Standard measured distance. While the total distance was measured to 1" accuracy, the athlete variation is estimated at +2 yards, due to natural variation in straight line running as well as natural errors in stopping exactly on the sideline markers.

As shown in Table 1, for Team Run 1, total error in the Zebra data was 2.17%, resulting in an average error of 1.15 yards per 53.3 yard run, well within the acceptable limit of an error of +2 yards in the athlete run.

The Bland Altman analysis in Table 2 shows that **82% of Zebra trials** are within the acceptable error of 2 yards (73% half of that, at 1 yard error).

Table 1. Data and error analysis for Team Run 1

TEAM RUN 1						
SUBJECT	Gold Standard (YD)	Catapult (YD)	Zebra (YD)	CatapultDiff	ZebraDiff	Abs % Err Catapult	Abs % Err Zebra
1	53.3	63.41	56	10.11	2.7	18.98%	5.07%
2	53.3	55.12	58	1.82	4.7	3.41%	8.82%
3	53.3	55.23	53	1.93	-0.3	3.62%	0.56%
4	53.3	54.46	53	1.16	-0.3	2.18%	0.56%
5	53.3	55.12	53	1.82	-0.3	3.41%	0.56%
6	53.3	53.59	53	0.29	-0.3	0.54%	0.56%
7	53.3	57.96	54	4.66	0.7	8.75%	1.31%
8	53.3	55.34	55	2.04	1.7	3.82%	3.19%
9	53.3	55.45	54	2.15	0.7	4.03%	1.31%
10	53.3	52.93	54	-0.37	0.7	0.69%	1.31%
11	53.3	55.34	53	2.04	-0.3	3.82%	0.56%
				TOTAL ERROR (%)		4.84%	2.17%
				TOTAL ERROR (YD)		2.58	1.15

Table 2. Bland Altman Analysis of Team Run 1

TEAM RUN 1	BLAND ALTMAN ANALYSIS			
INSIDE	CATAPULT	ZEBRA	%CATAPULT	%ZEBRA
1 yd	2	8	18%	73%
2 yd	6	9	55%	82%
3 yd	9	10	82%	91%
4 yd	9	10	82%	91%
5 yd	10	11	91%	100%
5+	11	11	100%	100%

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4.2   Test 2: Team Run 2

Test 2 had each athlete line up at the back line of the end zone. On the "Run" signal, all athletes ran 20 yards and stopped on the line marker, this was repeated for a total of 6 intervals at a total distance of 120 yards (Figure 2).
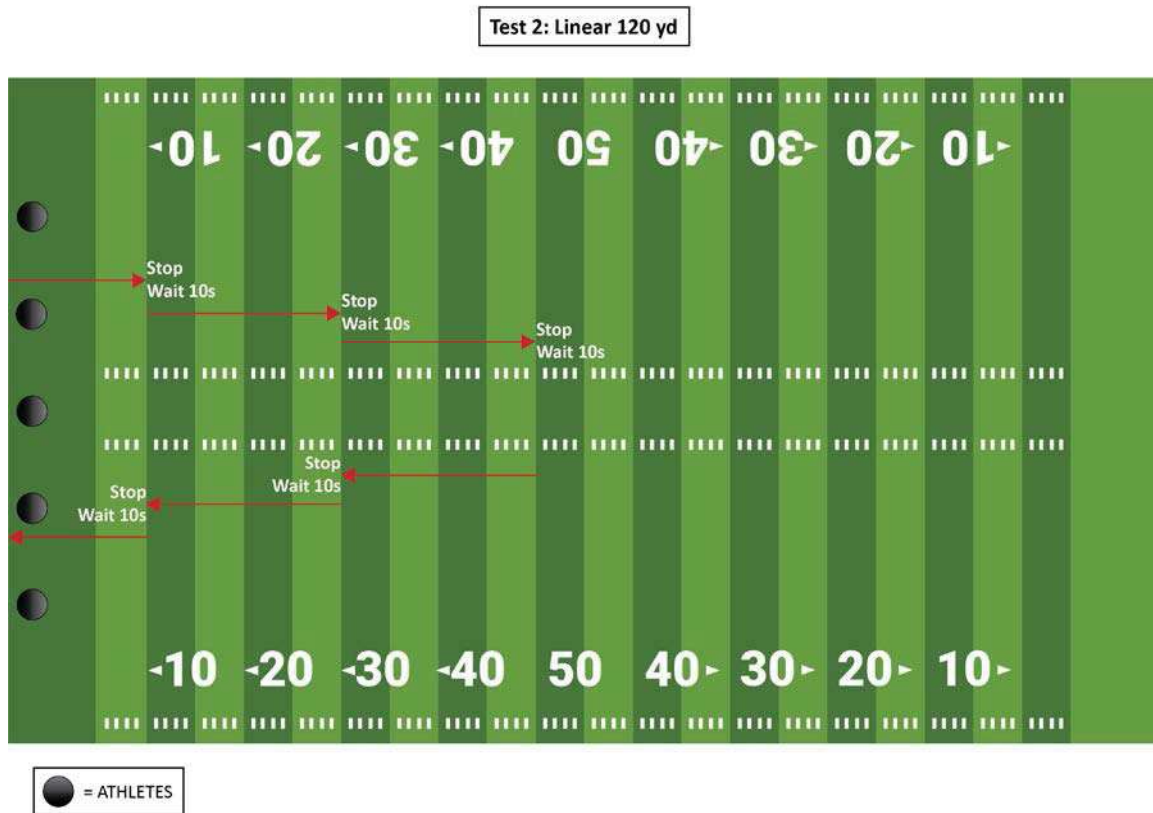
Figure 2. Test 2: Linear 120 yard

4.2.2. Results:
Similarly to Team Run 1, Run 2 looks at overall distance against the measured gold standard distance of 120 yards. For this trial, acceptable error is set at 4 yards for the same reasons as stated in the Team Run 1 section.

As shown in Table 3, total error in Zebra data was 2.22% (in line with Team Run 1 at 2.17%) and a distance error of 2.66 yards per 120 yard run. Again, this is well under the acceptable error of +4 yards for each individual athlete.

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Table 3. Data and error analysis for Team Run 2

TEAM RUN 2		DISTANCE ACCURACY ANALYSIS					
SUBJECT	Gold Standard (YD)	Catapult (YD)	Zebra (YD)	CatapultDiff	ZebraDiff	Abs % Err Catapult	Abs % Err Zebra
1	120	128.94	121	-8.94	-1	7.45%	0.83%
2	120	123.58	121	-3.58	-1	2.98%	0.83%
3	120	128.82	124	-8.82	-4	7.35%	3.33%
4	120	126.53	119	-6.53	1	5.44%	0.83%
5	120	126.09	126	-6.09	-6	5.08%	5.00%
6	120	124.13	123	-4.13	-3	3.44%	2.50%
					TOTAL ERROR (%)	5.29%	2.22%
					TOTAL ERROR (YD)	6.35	2.66

4.3   Tests 3-6: Individual Runs

Tests 3-6 were run individually, and each is described separately below. For these runs, the gold standard comparisons are 1) distance measured to 1" accuracy (and accuracy of the athlete running defined in each run below) and 2) Zybek timing gates with an accuracy of 0.001 seconds measured by breaking a laser beam.

Each Individual Run: Each athlete placed their foot at the start sensor, held still for 15 seconds, and ran (at the signal of the field testing lead) the pattern listed. The timing gates started once the foot beam was broken. After the final beam was broken, the athlete decelerated to a final stopping point between 2 cones for a well-controlled total distance. A testing engineer held the athlete at that point for 15 seconds, and then the run was complete. Again, this is needed for alignment of raw data. The first run for each athlete was at a jogging speed, and then repeated at a maximal effort speed. Speed ranged between 5.4MPH – 17.7MPH between all runs.

4.3.1. Test 3: Linear 40 Yard
In this test, each athlete ran a 40 yard linear route. After crossing the gate at 40 yards, the athlete decelerates and comes to a complete stop between 2 cones placed at the opposite 45 yard line (for a total distance of 55.03 yards when measured). Each athlete ran once at a jogging speed, and again at a maximal speed. The athletes all kept their gait within the hash marks (<2'), and the testing team took great care in starting and stopping the athletes precisely. Therefore, the acceptable error within this testing was within 0.5yd (Figure 3).

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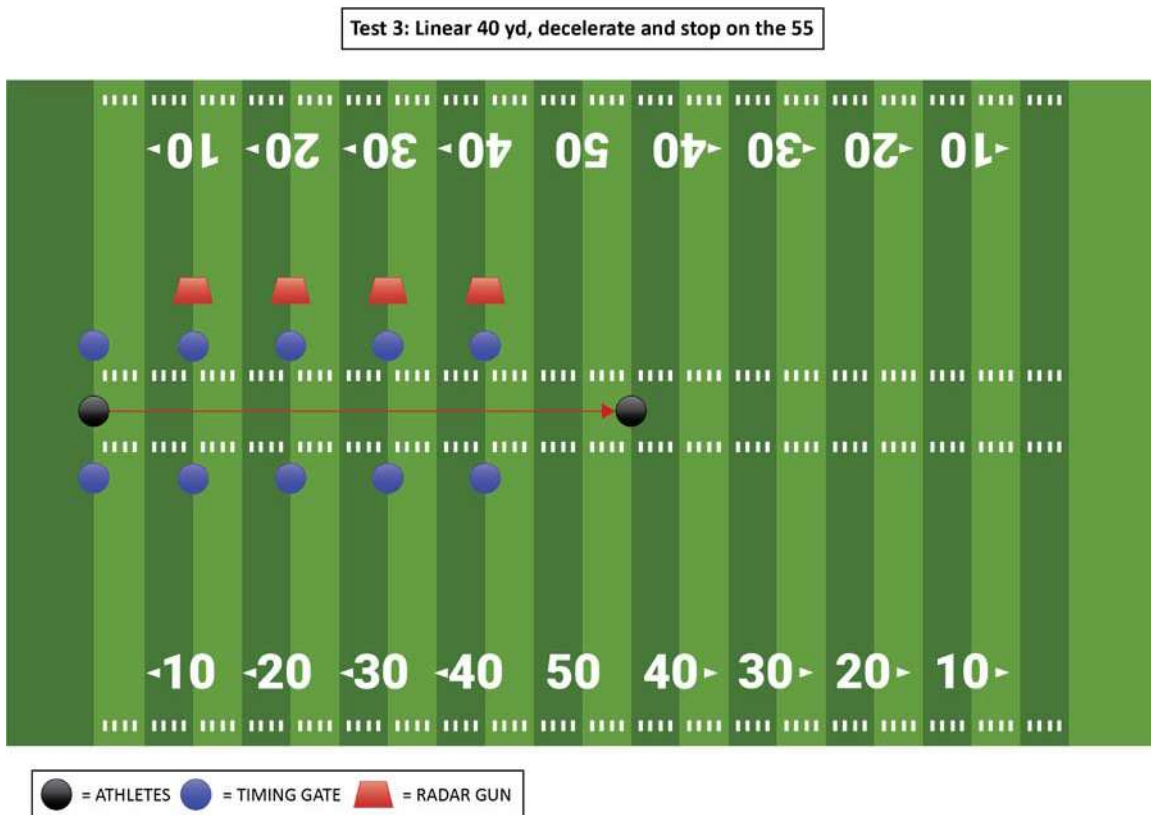
Figure 3. Test 3: Linear 40 yard, decelerate and stop on the 55

4.3.2. Results:

Table 4 shows the accuracy of distance measurements in Run 3. The Zebra system shows an extremely high accuracy with an **average error of 0.66%, or 0.36 yards** for the 55 yard run. This is **well within the 0.5 yard acceptable error of the measurements**.

The Zybek timing gates placed at 10 yard increments, in addition to the raw data access from the Zebra system, allowed the team to assess velocity measurements with high precision. As shown in Table 5, **all measurements show an average error below 0.5MPH**, **well within the acceptable range for this testing**.

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Table 4. Data and error analysis of Distance for Run 3

RUN 3: STRAIGHT 40 yd			DISTANCE ANALYSIS			
Athlete	Gold - Distance (yd)	Catapult (yd)	Zebra (yd)	Catapult Error (yd)	Zebra Error (yd)	Catapult Error (%)	Zebra Error (%)
1 – Jog	55.03	54.57	55.00	-0.46	-0.03	0.83	0.05
2 – Jog	55.03	56.98	55.00	1.95	-0.03	3.54	0.05
3 – Jog	55.03	56.65	55.00	1.62	-0.03	2.95	0.05
4 – Jog	55.03	56.76	55.00	1.73	-0.03	3.15	0.05
5 – Jog	55.03	56.65	54.00	1.62	-1.03	2.95	1.87
6 – Jog	55.03	57.09	55.00	2.06	-0.03	3.74	0.05
1 – Max	55.03	59.49	55.00	4.46	-0.03	8.11	0.05
2 – Max	55.03	56.98	55.00	1.95	-0.03	3.54	0.05
3 – Max	55.03	58.18	54.00	3.15	-1.03	5.73	1.87
4 – Max	55.03	55.99	54.00	0.97	-1.03	1.75	1.87
5 – Max	55.03	56.54	54.00	1.51	-1.03	2.75	1.87
6 – Max	55.03	57.10	55.00	2.07	-0.03	3.76	0.05
				TOTAL ERROR (%)		3.57%	0.66%
				TOTAL ERROR (yd)		2.03	0.36

Table 5. Data and error analysis of Average Velocity between gates (Zebra only)

RUN 3: STRAIGHT 40 yd			VELOCITY ANALYSIS			
Athlete	Gold - Distance (yd)	Gold G1-G2 Avg Vel (yd/s)	Gold G2-G3 Avg Vel (yd/s)	Gold G3-G4 Avg Vel (yd/s)	%err Vel G1-G2	%err Vel G2-G3	%err Vel G3-G4
1 – Jog	55.03	5.52	5.36	5.37	3.50	8.02	0.79
2 – Jog	55.03	5.83	5.61	5.27	1.47	4.39	8.54
3 – Jog	55.03	5.64	5.70	5.68	8.67	3.80	9.76
4 – Jog	55.03	5.80	5.71	5.56	5.94	3.00	6.51
5 – Jog	55.03	6.04	5.92	5.97	3.01	2.81	4.34
6 – Jog	55.03	5.43	5.78	5.54	14.35	9.06	4.72
1 – Max	55.03	6.66	6.68	6.79	4.84	14.64	19.33
2 – Max	55.03	7.54	8.01	8.16	4.97	1.31	1.92
3 – Max	55.03	8.08	7.84	7.77	35.50	20.66	1.97
4 – Max	55.03	7.70	8.47	8.35	5.54	24.32	2.09
5 – Max	55.03	8.16	8.65	8.55	24.34	0.51	22.47
6 – Max	55.03	7.72	8.09	8.28	4.40	26.00	16.03
				TOTAL ERROR (%)	9.71%	9.88%	8.21%
				TOTAL ERROR (yd/s)	0.65	0.67	0.56
				TOTAL ERROR (MPH)	0.44	0.46	0.38

4.4   Test 4: Linear 30 Yard with 45 Degree Cut

In this test, each athlete runs a 30 yard linear route. After crossing the gate at 30 yards, the athlete cuts at a 45 degree angle to the last gate, and then decelerates and comes to a complete stop between 2 cones for a total distance of 58.2 yards. The addition of a 45 degree cut adds an experimental error of approximately 2 yards to the overall athlete run, bringing the overall acceptable error to +2.5 yards (Figure 4).

Figure 4. Test 4: Linear 30 yard, 14.1 yard

4.4.1. Results:
Table 6 shows the accuracy of distance measurements in Run 4. The Zebra system shows a high accuracy with an **average error of 3.78%, or 2.2 yards** for the 58.2 yard run. This is **within the 2.5 yard acceptable error of the measurements**.

Velocity measurements are shown in Table 7. **All measurements (with the exception of gate 3-4 at 0.54 yards) show an average error below 0.5MPH, well within the acceptable range for this testing**. The higher error for gates 3-4 can be attributed to the higher experimental error of the 45 degree cut.

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Table 6. Data and error analysis of Distance for Run 4

| RUN 4: 45 DEGREE CUT AT 30 | | | DISTANCE ANALYSIS | | | |
Athlete	Gold – Distance (yd)	Catapult (yd)	Zebra (yd)	Catapult Error (yd)	Zebra Error (yd)	Catapult Error (%)	Zebra Error (%)
1 – Jog	58.24	65.64	58.00	7.40	–0.24	12.71	0.41
2 – Jog	58.24	66.60	62.00	8.36	3.76	14.36	6.46
3 – Jog	58.24	62.01	58.00	3.77	–0.24	6.48	0.41
4 – Jog	58.24	62.45	56.00	4.21	–2.24	7.23	3.84
5 – Jog	58.24	63.32	54.00	5.08	–4.24	8.73	7.27
6 – Jog	58.24	60.80	65.00	2.57	6.76	4.41	11.61
1 – Max	58.24	60.37	58.00	2.13	0.24	3.66	0.41
2 – Max	58.24	59.27	58.00	1.04	–0.24	1.78	0.41
3 – Max	58.24	58.95	61.00	0.71	2.76	1.22	4.75
4 – Max	58.24	58.62	57.00	0.38	–1.24	0.66	2.12
5 – Max	58.24	59.60	55.00	1.37	–3.24	2.35	5.56
6 – Max	58.24	60.36	57.00	2.12	–1.24	3.64	2.12
				TOTAL ERROR		5.60%	3.78%
				TOTAL ERROR (yd)		3.45	2.20

Table 7. Data and error analysis of Average Velocity between gates (Zebra only)

| RUN 4: 45 DEGREE CUT AT 30 | | | VELOCITY ANALYSIS | | | |
Athlete	Gold – Distance (yd)	Gold G1-G2 Avg Vel (yd/s)	Gold G2-G3 Avg Vel (yd/s)	Gold G3-G4 Avg Vel (yd/s)	%err Vel G1-G2	%err Vel G2-G3	%err Vel G3-G4
1 – Jog	58.24	4.42	4.39	4.44	2.87	2.37	16.74
2 – Jog	58.24	5.15	5.15	4.65	10.83	8.53	1.96
3 – Jog	58.24	5.79	5.41	5.04	3.90	6.07	2.25
4 – Jog	58.24	4.49	4.25	3.95	3.17	2.82	0.56
5 – Jog	58.24	6.08	5.63	6.02	0.32	8.24	23.55
6 – Jog	58.24	4.98	4.96	4.64	1.54	10.31	5.13
1 – Max	58.24	6.45	6.25	6.08	0.98	9.16	31.37
2 – Max	58.24	7.61	7.13	7.16	12.79	16.64	14.37
3 – Max	58.24	7.39	6.71	6.61	2.13	6.83	21.38
4 – Max	58.24	6.78	6.40	5.55	8.25	2.21	4.74
5 – Max	58.24	7.45	7.13	6.90	2.84	0.46	23.42
6 – Max	58.24	7.17	6.44	6.23	0.37	18.53	24.19
				TOTAL ERROR	4.17%	7.68%	14.14%
				TOTAL ERROR (yd/s)	0.26	0.45	0.79
				TOTAL ERROR (MPH)	0.17	0.30	0.54

4.5   Test 5: Linear 30 Yare with -45 Degree Cut

In this test, each athlete runs a 30 yard linear route. After crossing the gate at 30 yards, the athlete cuts at a negative 45 degree angle to the last gate, and then decelerates and comes to a complete stop between 2 cones for a total distance of 58.2 yards. The addition of a -45 degree cut adds an experimental error of approximately 2 yards to the overall athlete run, bringing the overall acceptable error to +2.5 yards (Figure 5).
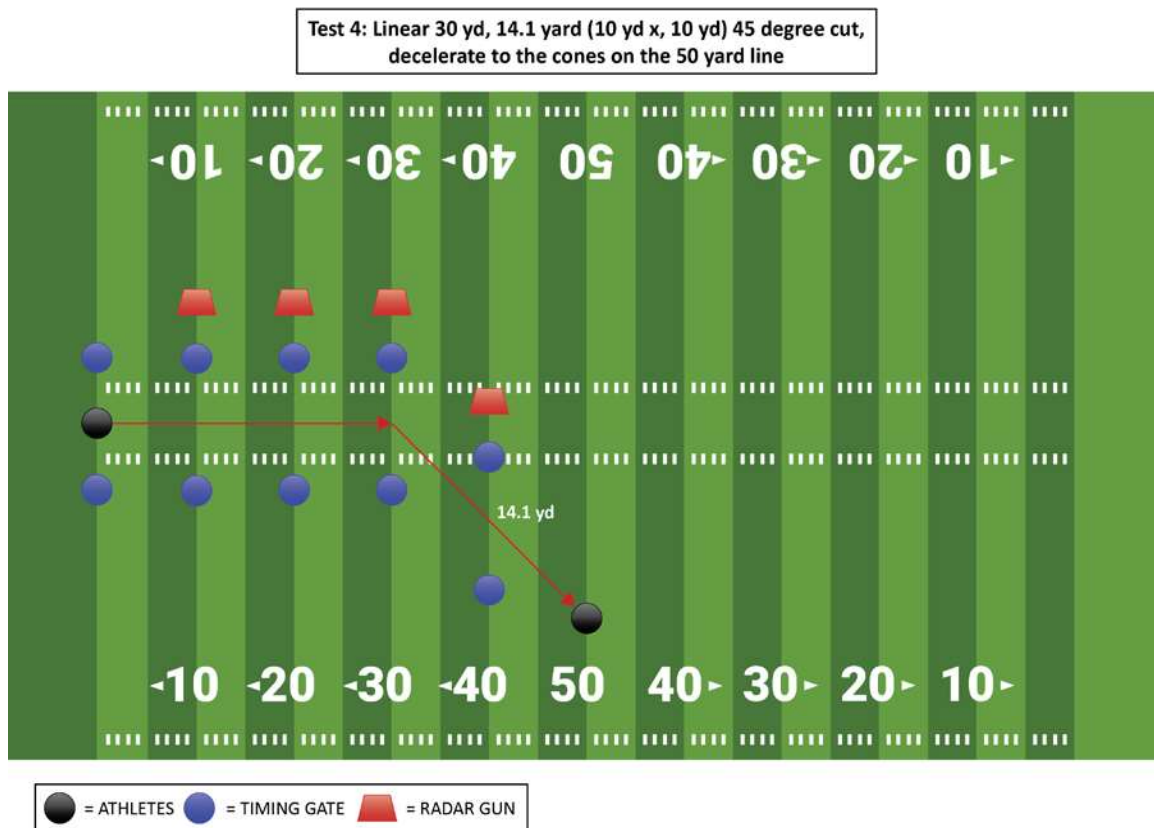
Figure 5. Test 5: Linear 30 yard, 14.1 yard reverse angle

4.5.1. Results:

Table 8 shows the accuracy of distance measurements in Run 5. The Zebra system shows an extremely high accuracy with an **average error of 1.56%, or 0.91 yards** for the 55 yard run. This is **well below the 2.5 yard acceptable error of the measurements**.

As shown in Table 9, **all measurements (with the exception of gates 2-3 at 0.79) show an average error below 0.5MPH**, **well within the acceptable range for this testing**. When all measurements are added together, the velocity measurements have an average overall error of 0.5MPH.

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Table 8. Data and error analysis of Distance for Run 5

| RUN 5: -45 DEGREE CUT AT 30 | | | DISTANCE ANALYSIS | | | |
Athlete	Gold – Distance (yd)	Catapult (yd)	Zebra (yd)	Catapult Error (yd)	Zebra Error (yd)	Catapult Error (%)	Zebra Error (%)
1 – Jog	58.23	53.04	59.00	-5.19	0.77	8.91	1.32
2 – Jog	58.23	59.49	60.00	1.26	1.77	2.17	3.04
3 – Jog	58.23	58.51	58.00	0.28	-0.23	0.48	0.39
4 – Jog	58.23	57.74	58.00	-0.49	-0.23	0.84	0.39
5 – Jog	58.23	59.71	58.00	1.48	-0.23	2.55	0.39
6 – Jog	58.23	61.78	59.00	3.55	0.77	6.09	1.32
1 Max	58.23	58.73	60.00	0.50	1.77	0.85	3.04
2 – Max	58.23	56.87	57.00	-1.36	-1.23	2.34	2.11
3 – Max	58.23	58.18	57.00	-0.05	-1.23	0.08	2.11
4 – Max	58.23	61.13	57.00	2.90	-1.23	4.99	2.11
5 – Max	58.23	59.71	57.00	1.48	-1.23	2.55	2.11
6 – Max	58.23	57.52	58.00	-0.71	-0.23	1.21	0.39
				TOTAL ERROR		2.75%	1.56%
				TOTAL ERROR (yd)		1.61	0.91

Table 9. Data and error analysis of Average Velocity between gates (Zebra only)

| RUN 5: -45 DEGREE CUT AT 30 | | | VELOCITY ANALYSIS | | | |
Athlete	Gold – Distance (yd)	Gold G1-G2 Avg Vel (yd/s)	Gold G2-G3 Avg Vel (yd/s)	Gold G3-G4 Avg Vel (yd/s)	%err Vel G1-G2	%err Vel G2-G3	%err Vel G3-G4
1 – Jog	58.23	3.72	3.37	2.79	3.95	10.11	6.98
2 – Jog	58.23	3.78	3.57	2.63	2.23	15.64	29.15
3 – Jog	58.23	4.59	4.00	3.51	0.03	20.59	3.87
4 – Jog	58.23	4.89	4.09	3.53	5.05	19.08	2.82
5 – Jog	58.23	6.26	5.28	4.49	4.69	19.87	23.03
6 – Jog	58.23	5.09	4.47	3.39	2.90	21.07	20.69
1 – Max	58.23	4.48	3.87	3.54	2.68	11.84	18.70
2 – Max	58.23	6.39	5.13	4.81	16.71	47.85	27.05
3 – Max	58.23	6.84	4.98	4.77	9.64	22.67	28.29
4 – Max	58.23	6.84	5.07	4.56	5.20	22.72	30.54
5 – Max	58.23	7.37	6.01	4.64	9.77	64.88	10.68
6 – Max	58.23	6.93	5.47	4.48	5.19	26.99	16.82
				TOTAL ERROR	5.67%	25.28%	18.22%
				TOTAL ERROR (yd/s)	0.32	1.17	0.72
				TOTAL ERROR (MPH)	0.22	0.79	0.49

4.6   Test 6: Linear 30 Yard with 90 Degree Cut

In this test, each athlete runs a 30 yard linear route. After crossing the gate at 30 yards, the athlete cuts at a 90 degree angle to the last gate, and then decelerates and comes to a complete stop between 2 cones for a total distance of 53.97 yards. The addition of a 90 degree cut adds an experimental error of approximately 1 yard to the overall athlete run, bringing the overall acceptable error to +1.5 yards (Figure 6).
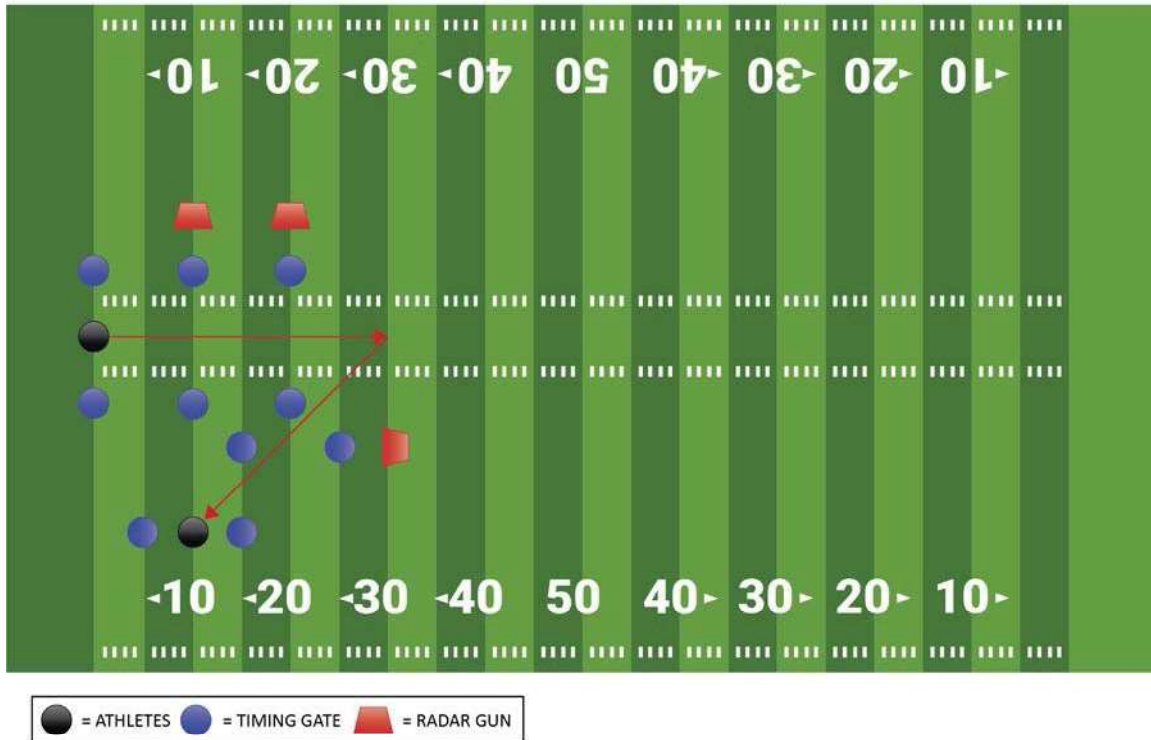
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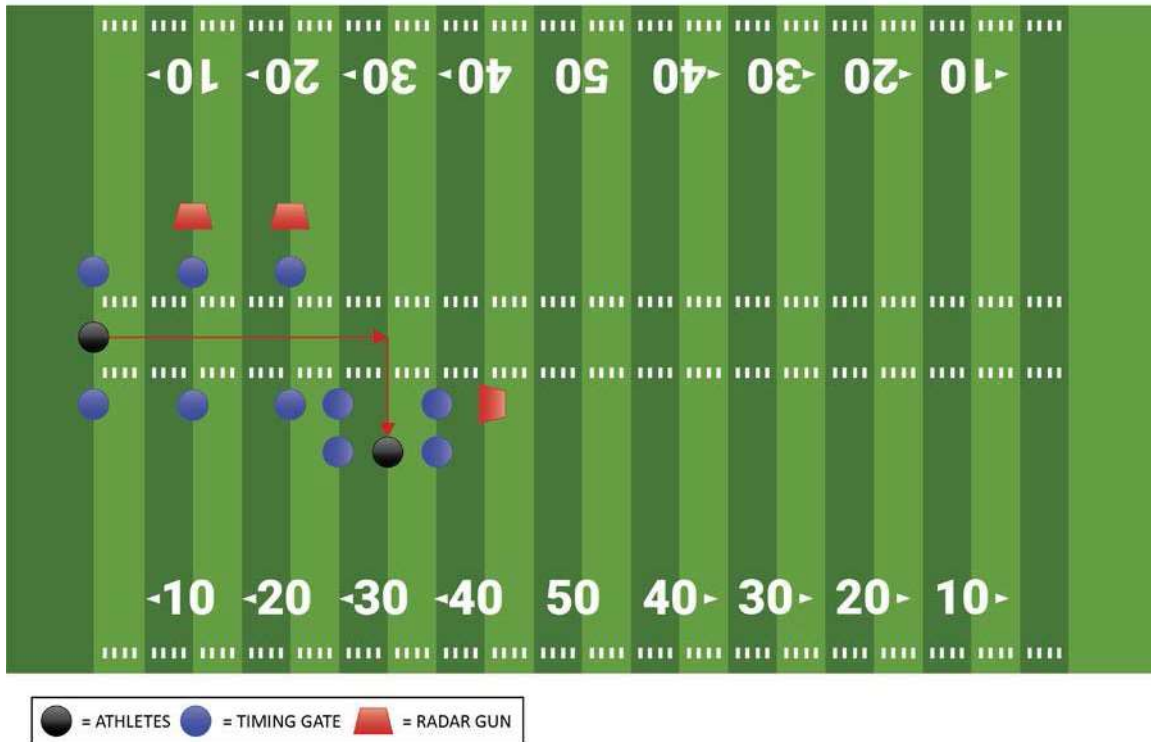
Figure 6. Test 6: Linear 30 yard, 90 degree cut, 23.97 yards

4.6.1. Results:

Table 10 shows the accuracy of distance measurements in Run 6. The Zebra system shows an extremely high accuracy with an **average error of 1.26%, or 0.68 yards** for the 53.97 yard run. This is **well within the 1.5 yard acceptable error of the measurements**.

As shown in Table 11, when averaged, **all measurements show an average error of 0.52MPH, slightly above (0.02MPH) the acceptable range for this testing**.

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Table 10. Data and error analysis of Distance for Run 6

RUN 6: 90 DEGREE CUT AT 30			DISTANCE ANALYSIS			
Athlete	Gold – Distance (yd)	Catapult (yd)	Zebra (yd)	Catapult Error (yd)	Zebra Error (yd)	Catapult Error (%)	Zebra Error (%)
1 – Jog	53.97	56.76	54.00	2.79	0.03	5.16	0.05
2 – Jog	53.97	52.82	55.00	-1.15	1.03	2.13	1.90
3 – Jog	53.97	56.43	53.00	2.46	-0.97	4.55	1.80
4 – Jog	53.97	58.61	54.00	4.63	0.03	8.59	0.05
5 – Jog	53.97	54.02	53.00	0.05	-0.97	0.10	1.80
6 – Jog	53.97	58.62	55.00	4.65	1.03	8.61	1.90
1 – Max	53.97	56.43	54.00	2.46	0.03	4.55	0.05
2 – Max	53.97	54.24	54.00	0.27	0.03	0.50	0.05
3 – Max	53.97	55.99	54.00	2.02	0.03	3.74	0.05
4 – Max	53.97	55.01	54.00	1.04	0.03	1.92	0.05
5 – Max	53.97	56.87	51.00	2.90	-2.97	5.37	5.51
6 – Max	53.97	55.72	55.00	1.75	1.03	3.24	1.90
				TOTAL ERROR		4.04%	1.26%
				TOTAL ERROR (yd)		2.26	0.68

Table 11. Data and error analysis of Average Velocity between gates (Zebra only)

RUN 6: 90 DEGREE CUT AT 30			VELOCITY ANALYSIS			
Athlete	Gold – Distance (yd)	Gold G1-G2 Avg Vel (yd/s)	Gold G2-G3 Avg Vel (yd/s)	Gold G3-G4 Avg Vel (yd/s)	%err Vel G1-G2	%err Vel G2-G3	%err Vel G3-G4
1 – Jog	53.97	3.89	3.72	2.71	6.15	11.10	19.96
2 – Jog	53.97	4.10	3.99	3.03	1.93	14.01	22.79
3 – Jog	53.97	5.20	4.29	3.26	6.58	13.27	5.29
4 – Jog	53.97	4.87	4.35	3.02	6.98	27.79	37.25
5 – Jog	53.97	6.12	5.23	4.90	10.98	20.61	30.79
6 – Jog	53.97	4.37	4.11	3.23	3.76	18.87	12.82
1 – Max	53.97	4.10	3.86	2.92	6.27	16.10	16.00
2 – Max	53.97	6.31	5.69	3.78	11.43	55.89	32.44
3 – Max	53.97	7.18	5.63	4.77	11.69	15.03	16.16
4 – Max	53.97	6.76	5.66	4.14	3.72	23.21	10.39
5 – Max	53.97	7.70	5.92	5.53	2.05	32.70	72.39
6 – Max	53.97	6.83	5.53	4.10	2.15	11.62	13.45
				TOTAL ERROR	6.14%	21.68%	24.15%
				TOTAL ERROR (yd/s)	0.34	1.05	0.91
				TOTAL ERROR (MPH)	0.24	0.71	0.62

5.0   CONCLUSION

The experimental testing and data documented above shows that the Zebra RFID 'external load' based system performed above experimental error of the testing protocol, with an overall error of 1.81%. Catapult had a much higher error of 3.99%. This is attributed to the increased accuracy via location of RFID vs. GPS. However, it should be noted that RFID systems require a fixed antenna system to be installed, so there is an inherent limitation with the locations available for use.

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