Wireless inertial sensor based objective lameness evaluation

Outline

- Research studies – justification for objective evaluation
- Instrumentation
- Analysis
- Research studies – accuracy and reliability
- Indications
- Case examples

Justification

2010 study from University of Missouri –

- 131 horses evaluated subjectively by 2-5 veterinarians with a weighted average of 18.7 years of experience
- After straight line evaluation, agreement on whether a limb was lame or not in 77%
  - 93% agreement if lameness grade > 1.5
  - 62% agreement if lameness grade ≤ 1.5
- After full lameness evaluation, agreement on whether the horse was lame and choosing the worst limb in 52%
- Conclusion: "For horses with mild lameness subjective evaluation of lameness is not very reliable"

Keegan et al EVJ 2010

Objective evaluation of lameness

- Camera-based kinematic evaluation of movement on a treadmill
  - Requires carefully controlled lighting and background
  - Requires training of the horse to the treadmill
- Stationary force plate evaluation
  - Requires dedicated space and technical expertise
  - Sufficient data often requires multiple hoof strikes on the plate, which requires time and patience

→ Neither of these techniques are practical in a clinical lameness exam

The Lameness Locator

- Indicates whether the horse is lame, which limb or limbs are affected, the severity of the lameness, and the part of the motion cycle at which peak pain is occurring (impact, mid-stance, or push off)

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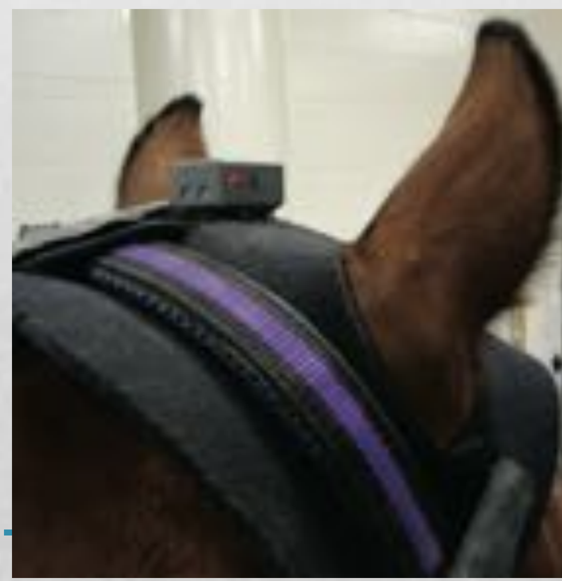
Instrumentation

- 3 wireless sensors: one on the horse's head, another on the center of the pelvis, and a third on the right front pastern
- Data sent wirelessly to a tablet computer for almost instantaneous analysis



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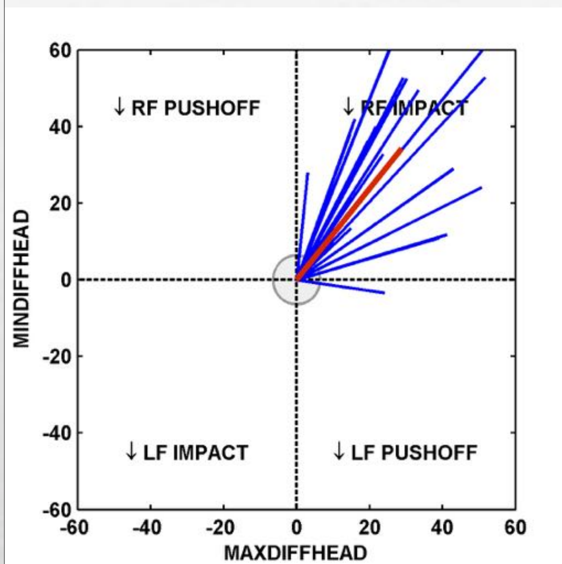
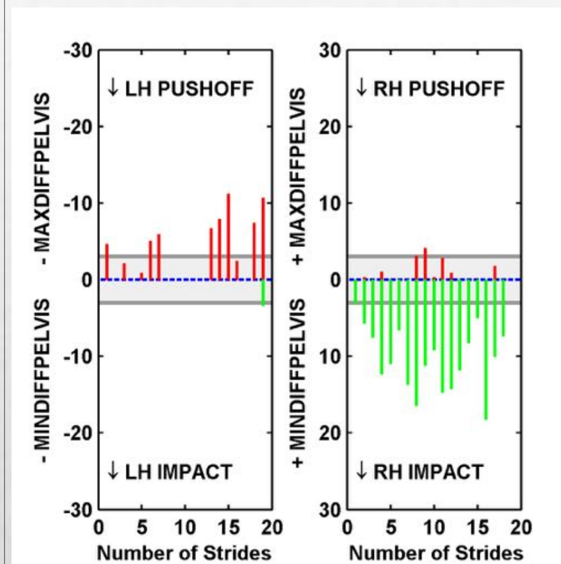
Basic Premise

- Vertical movement of the torso (which is measured by the sensors) will mirror vertical ground reaction forces
- Asymmetry in vertical torso movement between right and left halves of the stride can be quantified and associated with severity of lameness
- Sensors (accelerometers) on the head and pelvis measure and quantify the asymmetry

Basic Premise

Forelimb Evaluation	Hindlimb Evaluation
	

Head Diff (Mean/SD) **Max:** 28.81 / 13.573

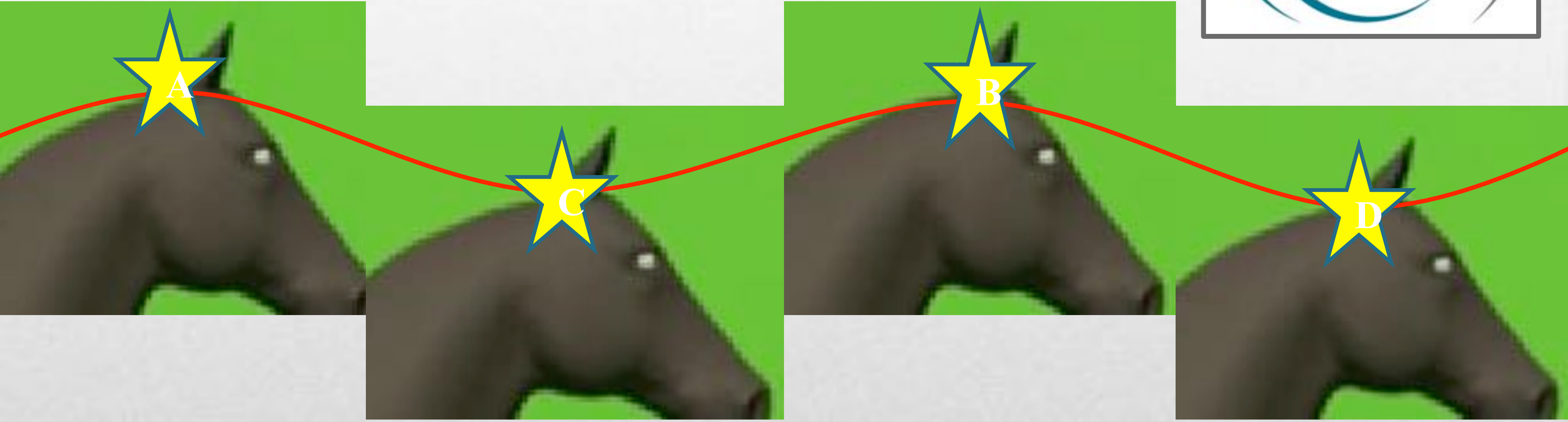
Threshold = ±6mm **Min:** 34.204 / 17.717

Vector Sum: 44.72

Pelvis Diff (Mean/SD): **Max:** -2.665 / 4.725

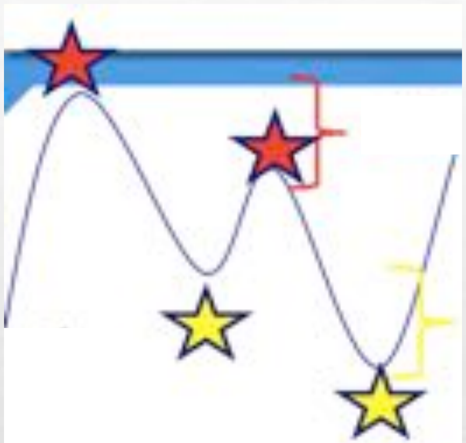
Threshold = ±3mm **Min:** 9.626 / 5.10

Basic Premise

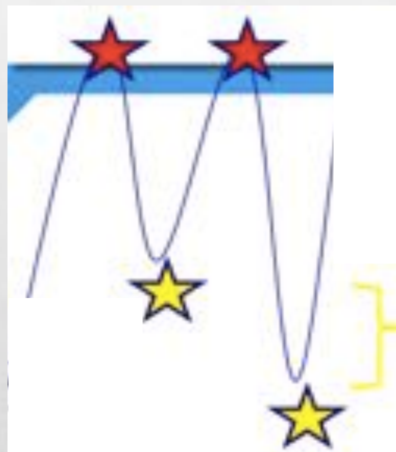


- Maximum and minimum positions of the head

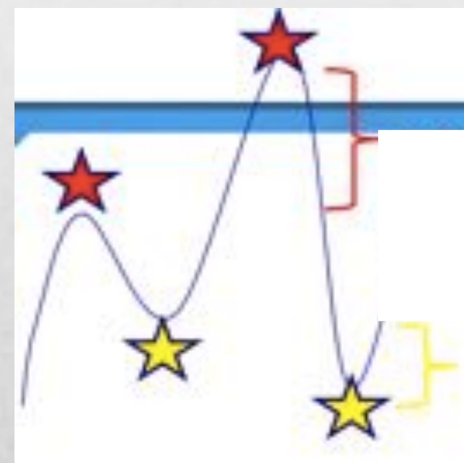
Basic Premise – head movement



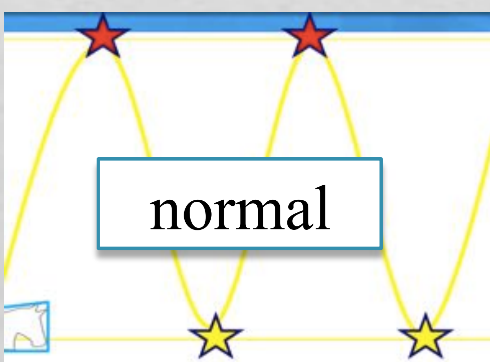
impact



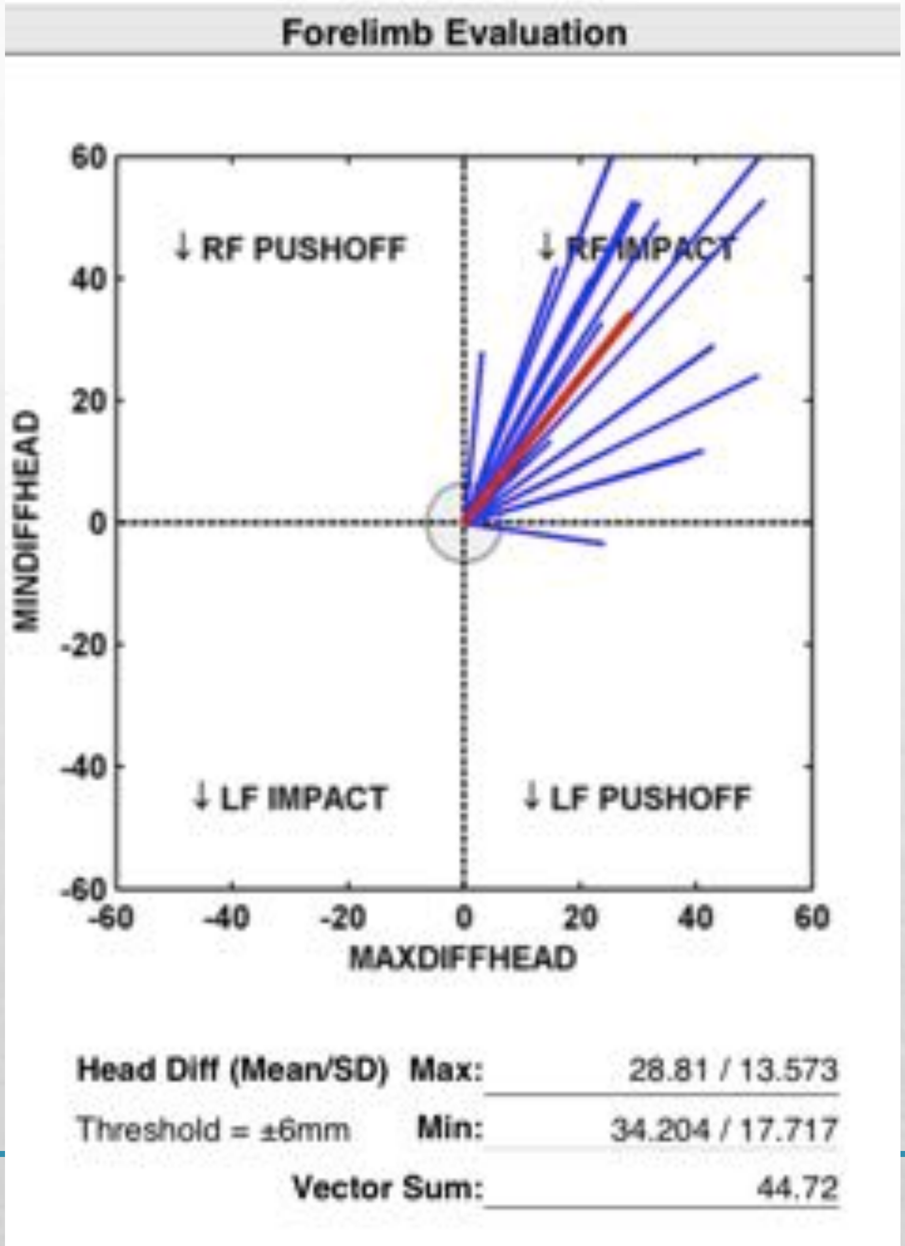
mid stance



push off

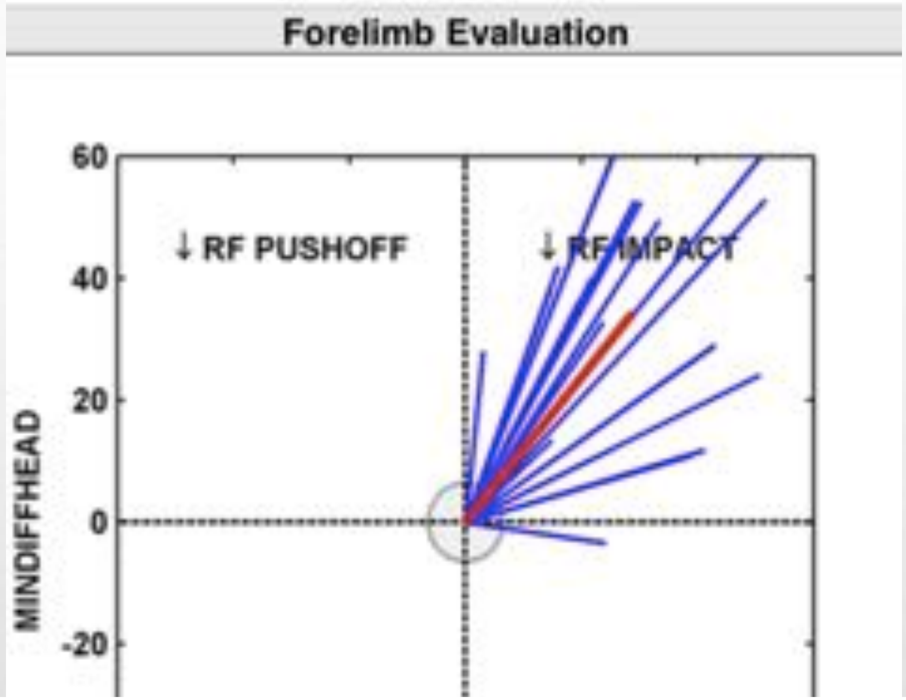


Analysis



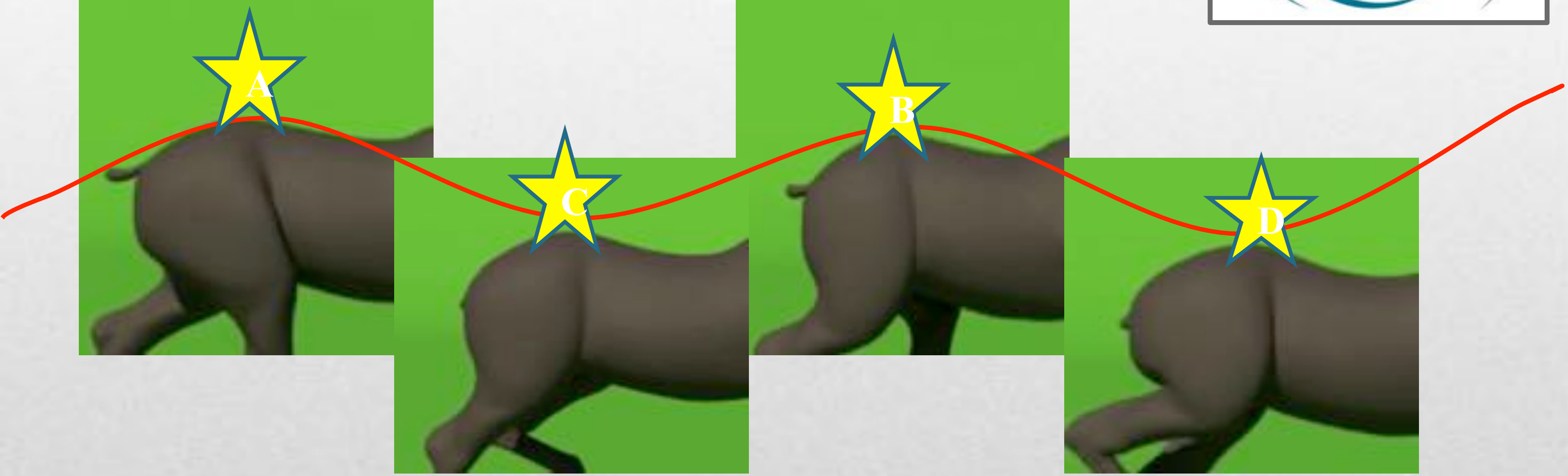
Forelimb Evaluation
↓ RF PUSHOFF
↓ RF IMPACT
↓ LF IMPACT
↓ LF PUSHOFF
MINDIFFHEAD
MAXDIFFHEAD
60
40
20
0
-20
-40
-60
Head Diff (Mean/SD) Max: 28.81 / 13.573
Threshold = ±6mm Min: 34.204 / 17.717
Vector Sum: 44.72

Analysis



Head Diff (Mean/SD)	**Max:**	28.81 / 13.573
Threshold = ±6mm	**Min:**	34.204 / 17.717
	Vector Sum:	44.72

Basic Premise



- Maximum and minimum positions of the pelvis

Basic Premise – pelvic movement

Maximum
height

Minimum
height

Basic Premise – RH impact lameness

Diff
Min

Minimum position during
RH stance

Minimum position during
LH stance

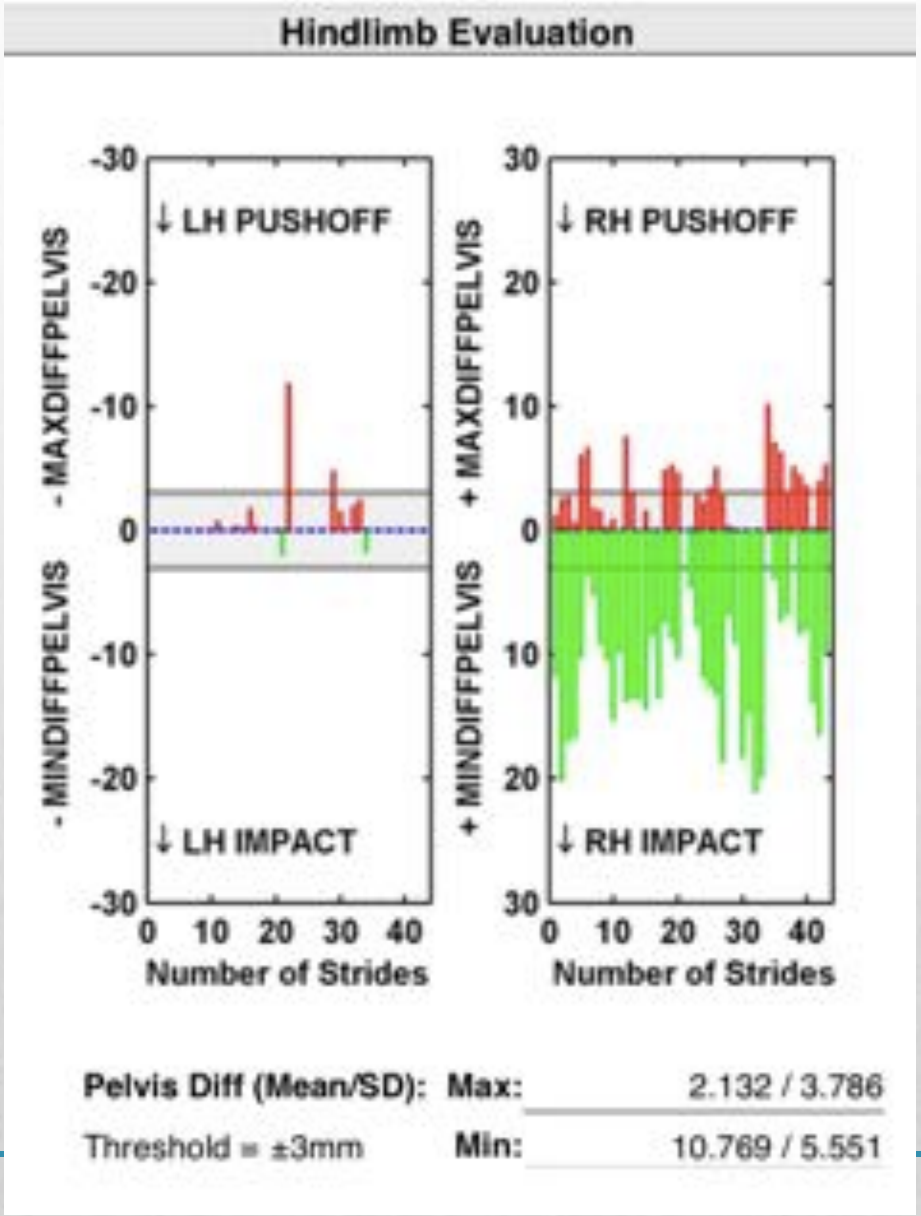
Basic Premise – RH push off lameness

Maximum position after LH push off

Diff Max

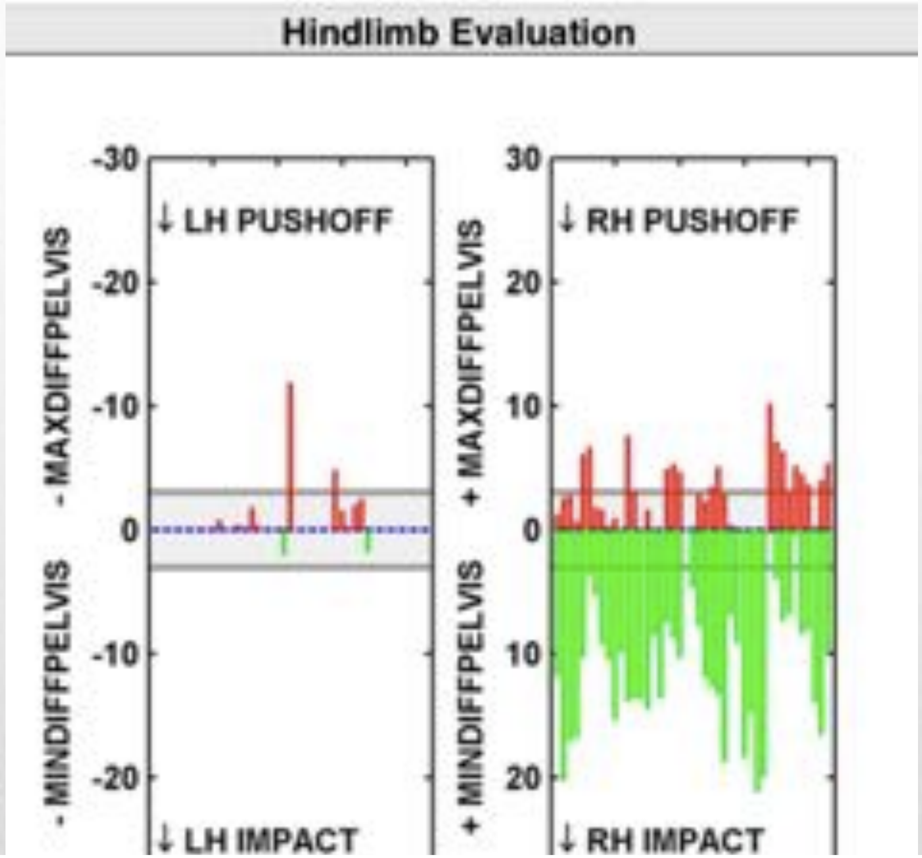
Maximum position after RH push off

Analysis



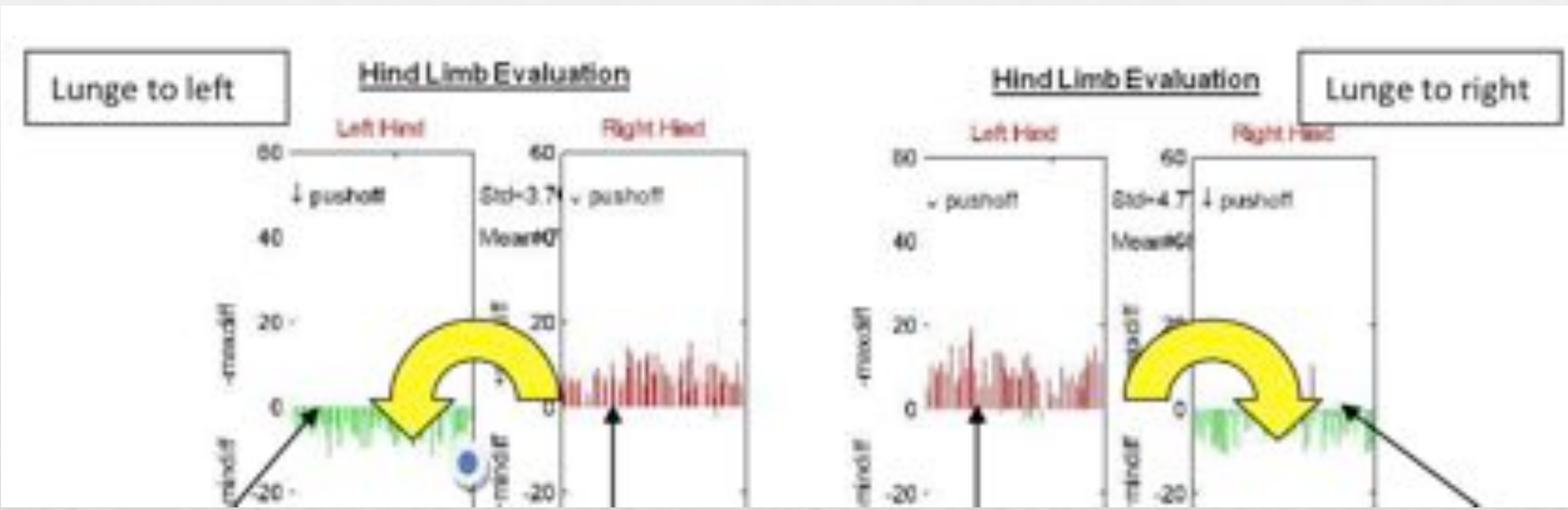
Hindlimb Evaluation
↓ LH PUSHOFF
↓ LH IMPACT
- MAXDIFFPELVIS
- MINDIFFPELVIS
↓ RH PUSHOFF
↓ RH IMPACT
+ MAXDIFFPELVIS
+ MINDIFFPELVIS
-30
-20
-10
0
-10
-20
-30
30
20
10
0
10
20
30
0 10 20 30 40
Number of Strides
0 10 20 30 40
Number of Strides
Pelvis Diff (Mean/SD): Max: 2.132 / 3.786
Threshold = ±3mm Min: 10.769 / 5.551

Analysis



Pelvis Diff (Mean/SD):	**Max:**	2.132 / 3.786
Threshold = ±3mm	**Min:**	10.769 / 5.551

Analysis - Lunging



Multiple Limb Lameness

- Secondary lameness
  - Actual pain that occurs as a result of overload on the other limbs
- Compensatory lameness
  - Shifting of weight that only appears to be lameness (more common)
  - Subtle primary hindlimb lameness can cause compensatory forelimb lameness on the same side (left hind; left front)
  - Severe primary forelimb lameness can cause compensatory hindlimb lameness in both hindlimbs

Research - reliability

- On two consecutive trials, coefficient of variation was 14-17% (force plate analysis is <10%); this was considered sufficiently repeatable for clinical use
- Compared with force plate, correct classification for head movement asymmetry was 83%; this was considered to be adequate sensitivity for clinical use

Keegan et al AJVR 2011; 2012

Research – comparing with subjective evaluation

2012 study from University of Missouri

- 15 horses fitted with special shoes that allowed for lameness induction via sole pressure


McCracken et al 2012


McCracken et al 2012

McCracken et al EVJ 2012

Research – comparing with subjective evaluation

- 4 episodes of lameness induced in each horse, for a total of 60 lameness inductions over the 15 horses
- Evaluators (3 experienced equine practitioners) were blinded to the limb, the location of the screw, and the other evaluators' results
- Each trial:
  - Baseline evaluation in a straight line twice
  - Successive additional evaluations in which the screw was sequentially tightened an additional half turn
  - Successive evaluations repeated until lameness of the selected limb detected by all three evaluators and the sensors

McCracken et al EVJ 2012

Research – comparing with subjective evaluation

- Results:
  - The inertial sensors selected the correct limb sooner (after fewer turns of the screw) than the consensus of 3 subjective evaluators
  - The inertial sensors selected the correct limb an average of one half-turn before the consensus of 3 subjective evaluators
  - Proportion of lameness chosen correctly first by:
    - Subjective consensus was in 8% of trials
    - Inertial sensors was in 58% of trials
    - Subjective consensus and inertial sensors at the same time was in 33% of trials

McCracken et al EVJ 2012

Research – comparing with subjective evaluation

- Likely reason for higher sensitivity of the inertial sensors at detecting mild lameness is the higher sampling frequency (200Hz) compared with temporal resolution of the unaided human eye (15-20Hz)
- Conclusions:

  "inertial sensor system was more sensitive than the consensus of 3 equine veterinarians"

McCracken et al EVJ 2012

Research – comparing with subjective evaluation in naturally occurring lameness

2013 study from University of Missouri

- 106 horses evaluated by inertial sensors during trotting in a straight line, and then via subjective evaluation by 3 experienced practitioners who performed complete lameness examinations including lunging and flexions
- Evaluators agreed on classification into three categories (primarily right limb lameness, primarily left limb lameness, or equal right and left limb lameness) in 59% of forelimb lamenesses and 55% of hindlimb lamenesses

Keegan et al AJVR 2013

Research – comparing with subjective evaluation in naturally occurring lameness

- All inertial sensor measures were positively and significantly correlated with subjective results
- Agreement between inertial sensors and subjective results was fair to moderate for forelimbs and slight to fair for hindlimbs
  - However, strong association would suggest that inertial sensor evaluation could not yield additional information
- Conclusion:

  "inertial sensor-based evaluation may augment but not replace subjective lameness examination"

Keegan et al AJVR 2013

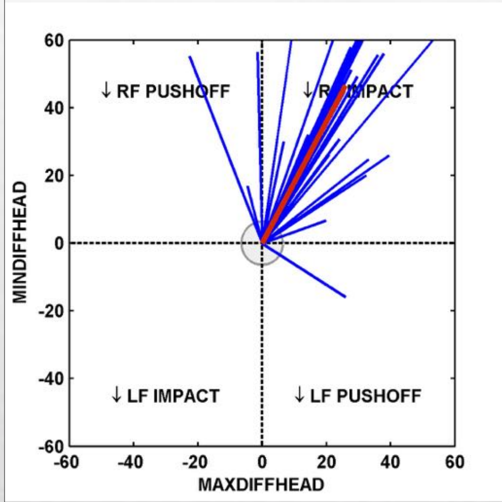
Specific indications

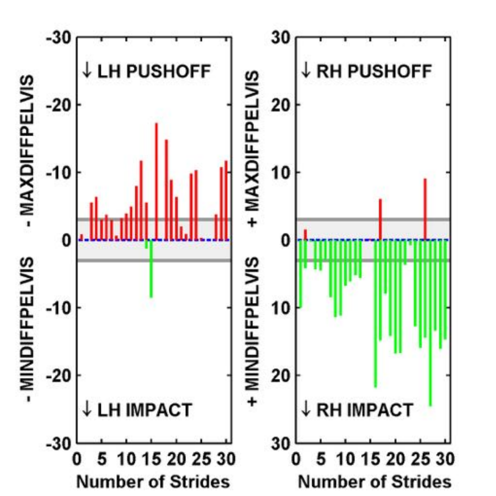
- Subtle lameness
- Multiple limb lameness
- Compensatory lameness
- Nerve and joint blocks, especially in subtle lameness
- Rechecks or monitoring improvements during a rehabilitation program

- Useful as an adjunct to all lameness evaluations

Case example 1 – straight line evaluation

Forelimb Evaluation	Hindlimb Evaluation





Head Diff (Mean/SD)	**Max:**	25.929 / 21.696
Threshold = ±6mm	**Min:**	46.488 / 27.717
	Vector Sum:	53.23

Pelvis Diff (Mean/SD):	**Max:**	-4.684 / 5.764
Threshold = ±3mm	**Min:**	9.266 / 7.203

Evaluator Notes

Expert System Assessment

There is "no" evidence of LF lameness.
There is "strong" evidence of "severe" RF lameness.
There is "weak" evidence of "mild/moderate" LH lameness.
There is "strong" evidence of "moderate/severe" RH lameness.
These results may be indicative of a primary RF lameness.

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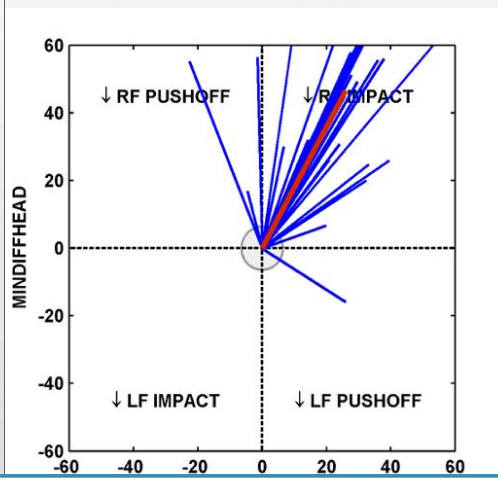
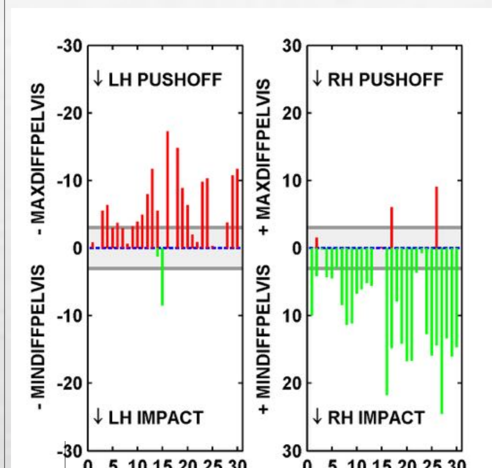
Thursday, March 5, 2015 at 2:08 PM

Case example 1 – straight line evaluation

Forelimb Evaluation	Hindlimb Evaluation





Head Diff (Mean/SD)	**Max:**	25.929 / 21.696	**Pelvis Diff (Mean/SD):**	**Max:**	-4.684 / 5.764
Threshold = ±6mm	**Min:**	46.488 / 27.717	Threshold = ±3mm	**Min:**	9.266 / 7.203
	Vector Sum:	53.23			

Expert System Assessment

There is "no" evidence of LF lameness.
There is "strong" evidence of "severe" RF lameness.
There is "weak" evidence of "mild/moderate" LH lameness.
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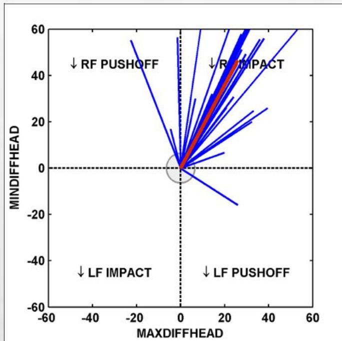
Case example 1 –
before and after nerve blocks

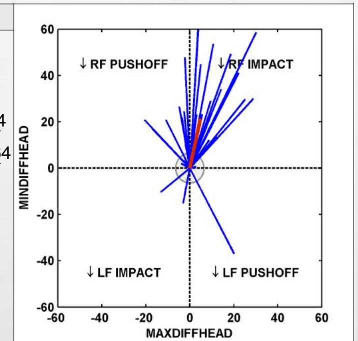


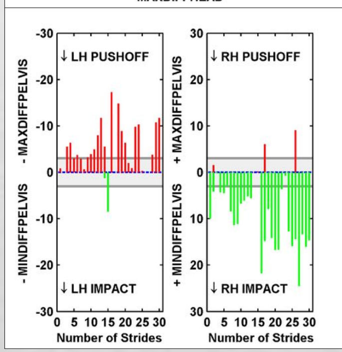
Forelimb Evaluation

Head Diff (Mean/SD)

Threshold = ±6mm

25.929 / 21.696	**Max**	4.849 / 12.254
46.488 / 27.717	**Min**	21.328 / 20.864



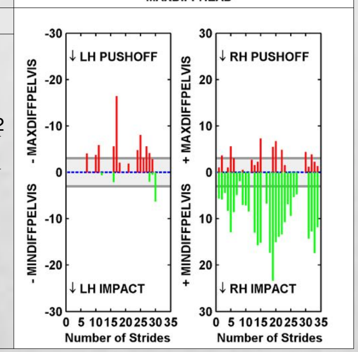


Hindlimb Evaluation

Pelvis Diff (Mean/SD)

Threshold = ±3mm

-4.684 / 5.764	**Max**	-0.239 / 4.902
9.266 / 7.203	**Min**	8.513 / 6.511



Trial 1 Evaluator Notes	Trial 2 Evaluator Notes

Expert System Assessment (Trial 1)

There is "no" evidence of LF lameness.
There is "strong" evidence of "severe" RF lameness.
There is "weak" evidence of "mild/moderate" LH lameness.
There is "strong" evidence of "moderate/severe" RH lameness.
These results may be indicative of a primary RF lameness.

Expert System Assessment (Trial 2)

There is "no" evidence of LF lameness.
There is "strong" evidence of "mild/moderate" RF lameness.
There is "no" evidence of LH lameness.
There is "strong" evidence of "moderate/severe" RH lameness.
These results may be indicative of a primary RH lameness.
The RF blocking caused a 69% improvement in the RF lameness.

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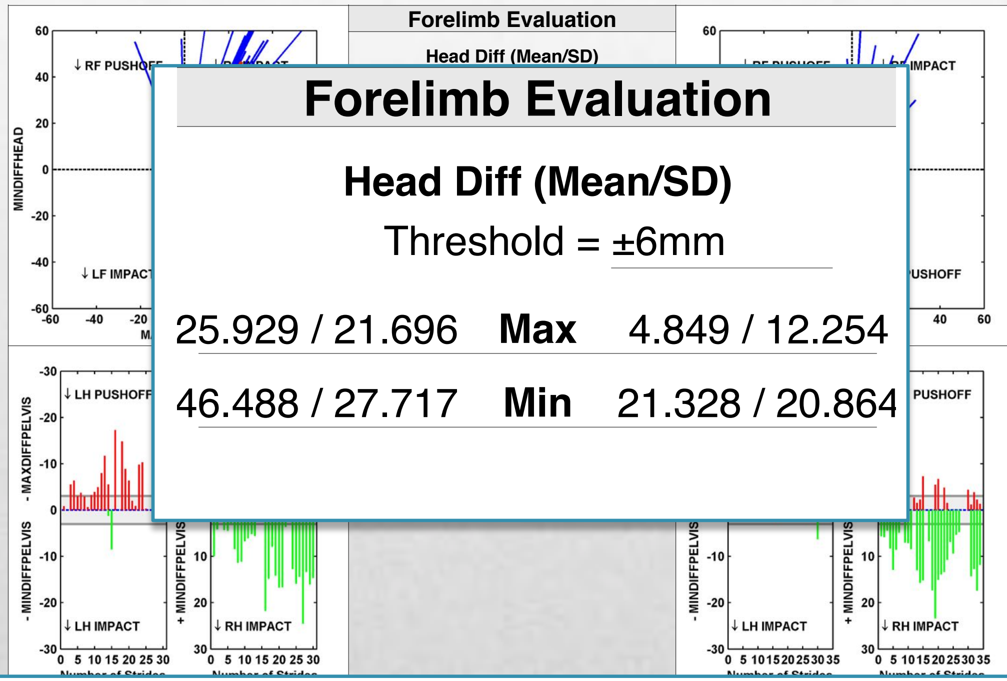
Case example 1 – before and after nerve blocks



Forelimb Evaluation

Head Diff (Mean/SD)

Threshold = ±6mm

25.929 / 21.696	**Max**	4.849 / 12.254
46.488 / 27.717	**Min**	21.328 / 20.864

The RF blocking caused a 69% improvement in the RF lameness.

There is "no" evidence of LF lameness.
There is "strong" evidence of "severe" RF lameness.
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The RF blocking caused a 69% improvement in the RF lameness.

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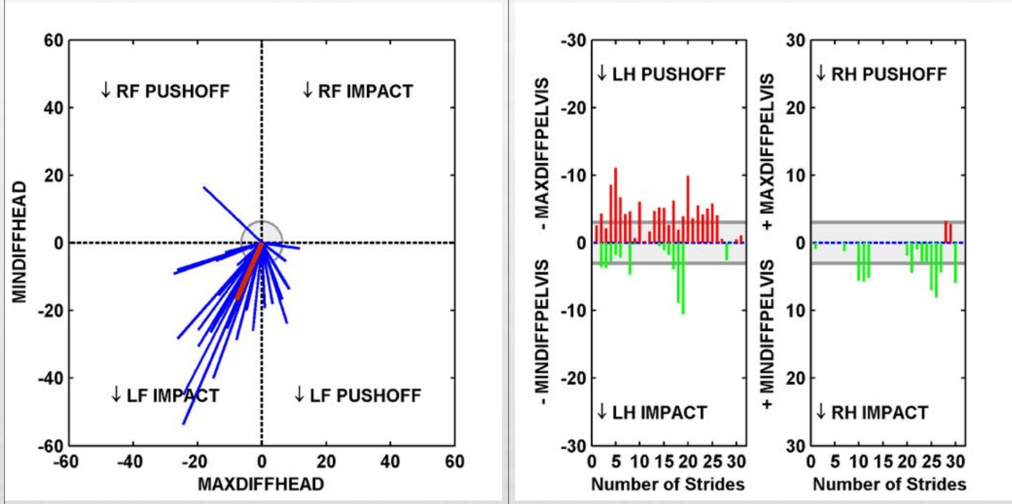
Case example 2 – first straight line evaluation

Forelimb Evaluation	Hindlimb Evaluation



Head Diff (Mean/SD) **Max:** -7.898 / 11.946
Threshold = ±6mm **Min:** -16.718 / 14.493
Vector Sum: 18.49

Pelvis Diff (Mean/SD): **Max:** -3.782 / 3.185
Threshold = ±3mm **Min:** 0.276 / 4.355

Evaluator Notes

Expert System Assessment

There is "strong" evidence of "mild/moderate" LF lameness.
There is "no" evidence of RF lameness.
There is "strong" evidence of "mild" LH lameness.
There is "no" evidence of RH lameness.
There is insufficient evidence to suggest which limb is primary and which limb is compensatory.

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Case example 2 – first straight line evaluation

Forelimb Evaluation	Hindlimb Evaluation

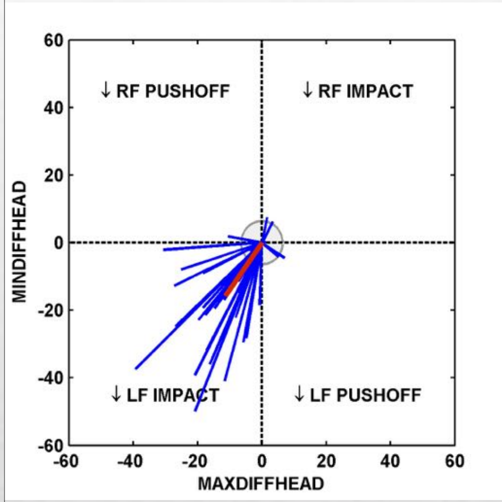
Head Diff (Mean/SD)	**Max:**	-7.898 / 11.946	**Pelvis Diff (Mean/SD):**	**Max:**	-3.782 / 3.185
Threshold = ±6mm	**Min:**	-16.718 / 14.493	Threshold = ±3mm	**Min:**	0.276 / 4.355
	Vector Sum:	18.49			

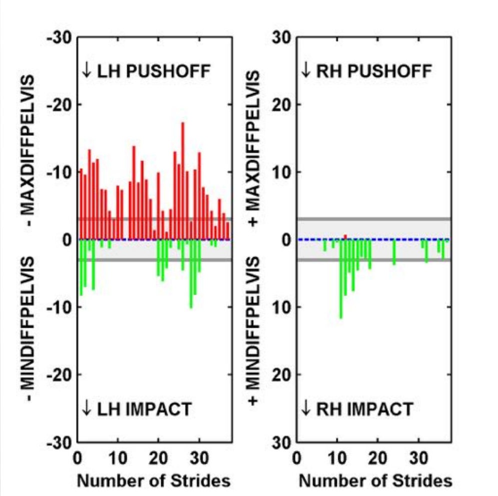
Expert System Assessment

There is "strong" evidence of "mild/moderate" LF lameness.
There is "no" evidence of RF lameness.
There is "strong" evidence of "mild" LH lameness.
There is "no" evidence of RH lameness.
There is insufficient evidence to suggest which limb is primary and which limb is compensatory.

Case example 2 – second straight line evaluation

Forelimb Evaluation	Hindlimb Evaluation





Head Diff (Mean/SD)	**Max:**	-11.356 / 10.595	**Pelvis Diff (Mean/SD):**	**Max:**	-7.646 / 4.199
Threshold = ±6mm	**Min:**	-15.677 / 13.898	Threshold = ±3mm	**Min:**	-0.311 / 4.875
	Vector Sum:	19.358			

Evaluator Notes

Expert System Assessment

There is "strong" evidence of "mild/moderate" LF lameness.
There is "no" evidence of RF lameness.
There is "strong" evidence of "moderate/severe" LH lameness.
There is "no" evidence of RH lameness.
These results may be indicative of a primary LH lameness.

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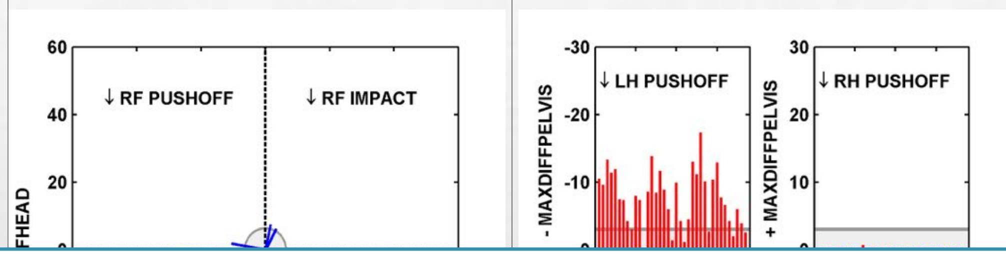
Tuesday, March 17, 2015 at 1:54 PM

Case example 2 –
second straight line evaluation

Forelimb Evaluation	Hindlimb Evaluation



MAXDIFFHEAD			Number of Strides	Number of Strides	
Head Diff (Mean/SD)	**Max:**	-11.356 / 10.595	**Pelvis Diff (Mean/SD):**	**Max:**	-7.646 / 4.199
Threshold = ±6mm	**Min:**	-15.677 / 13.898	Threshold = ±3mm	**Min:**	-0.311 / 4.875
	Vector Sum:	19.358			

Threshold = ±6mm **Min:** -15.677 / 13.898
Vector Sum: 19.358
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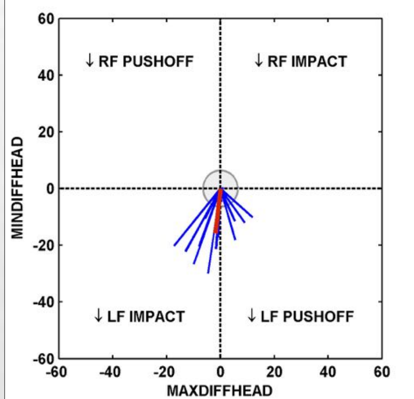
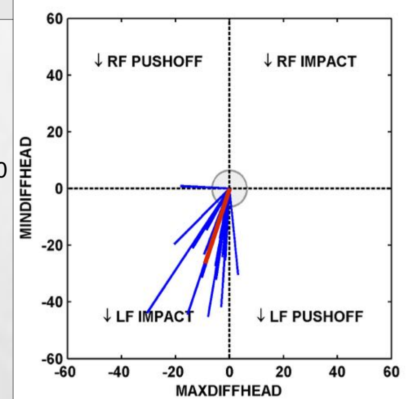
Case example 2 –
before and after hindlimb flexion

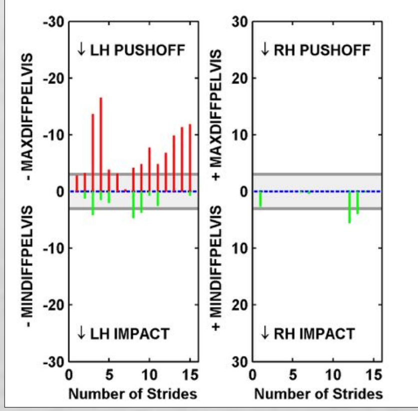


Forelimb Evaluation

Head Diff (Mean/SD)

-1.887 / 8.064	**Max**	-9.07 / 8.391
-15.778 / 8.106	**Min**	-26.298 / 13.10

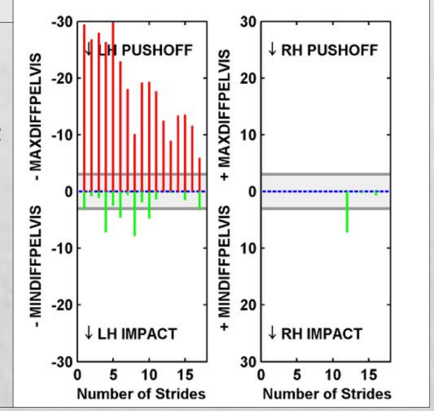




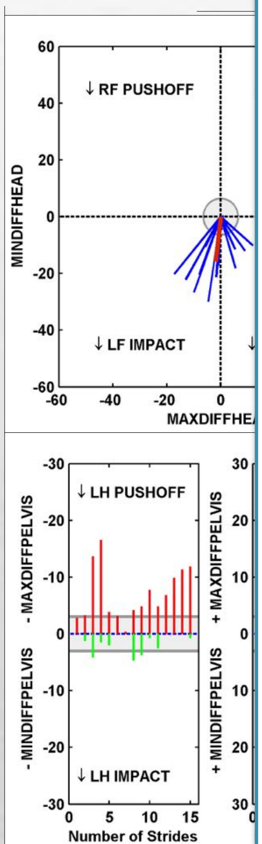
Hindlimb Evaluation

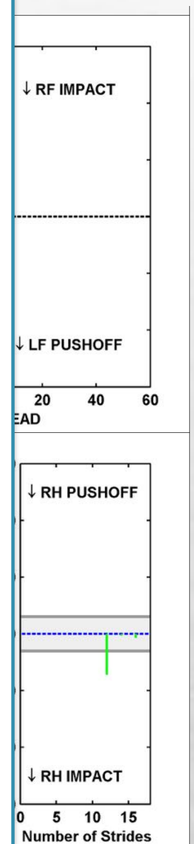
Pelvis Diff (Mean/SD)

-7.016 / 4.651	**Max**	-18.472 / 7.72
-0.551 / 2.884	**Min**	-1.90 / 3.367



Case example 2 – before and after hindlimb flexion





Forelimb Evaluation

Head Diff (Mean/SD)

-1.887 / 8.064	**Max**	-9.07 / 8.391
-15.778 / 8.106	**Min**	-26.298 / 13.10

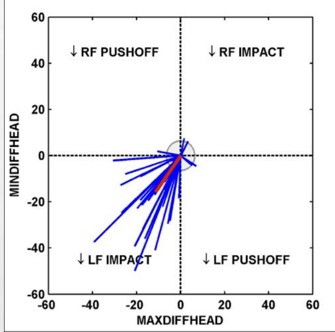
Hindlimb Evaluation

Pelvis Diff (Mean/SD)

-7.016 / 4.651	**Max**	-18.472 / 7.72
-0.551 / 2.884	**Min**	-1.90 / 3.367

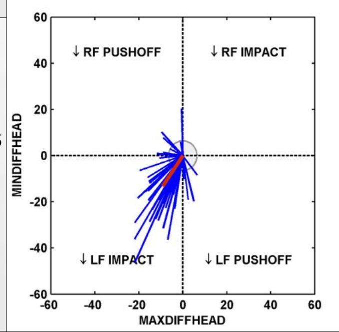
Case example 2 – before and after joint blocks

Forelimb Evaluation

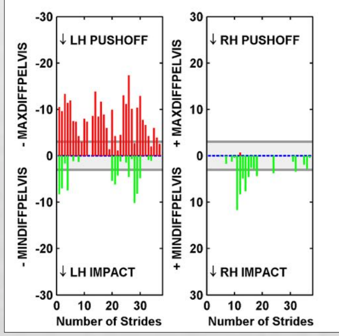


Head Diff (Mean/SD)
Threshold = ±6mm

-11.356 / 10.59	**Max**	-9.107 / 7.042
-15.677 / 13.89	**Min**	-13.16 / 13.575

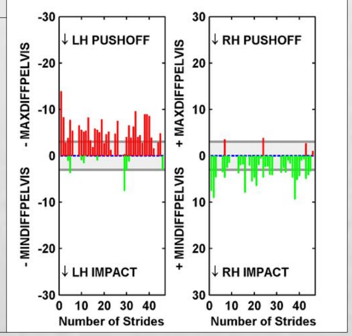


Hindlimb Evaluation



Pelvis Diff (Mean/SD)
Threshold = ±3mm

-7.646 / 4.199	**Max**	-4.347 / 3.597
-0.311 / 4.875	**Min**	2.479 / 3.355



Trial 1 Evaluator Notes

Expert System Assessment

There is "strong" evidence of "mild/moderate" LF lameness.
There is "no" evidence of RF lameness.
There is "strong" evidence of "moderate/severe" LH lameness.
There is "no" evidence of RH lameness.
These results may be indicative of a primary LH lameness.

Trial 2 Evaluator Notes

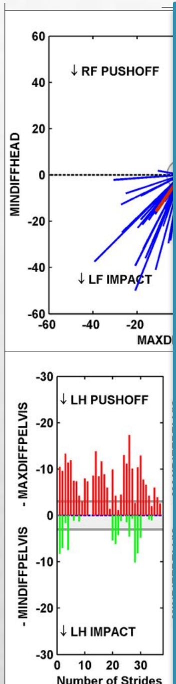
Expert System Assessment

There is "strong" evidence of "mild" LF lameness.
There is "no" evidence of RF lameness.
There is "moderate" evidence of "mild" LH lameness.
There is "no" evidence of RH lameness.
These results may be indicative of a primary LH lameness.
The LH blocking improved the LH pushoff lameness by 71%.

Generated with Lameness Locator® 2014 by Equinosis®

Tuesday, March 17, 2015 at 4:31 PM

Case example 2 – before and after joint blocks



Forelimb Evaluation

Head Diff (Mean/SD)

Threshold = ±6mm

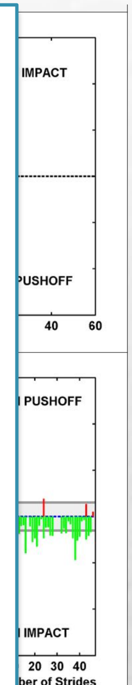
-11.356 / 10.59	**Max**	-9.107 / 7.042
-15.677 / 13.89	**Min**	-13.16 / 13.575

Hindlimb Evaluation

Pelvis Diff (Mean/SD)

Threshold = ±3mm

-7.646 / 4.199	**Max**	-4.347 / 3.597
-0.311 / 4.875	**Min**	2.479 / 3.355



The LH blocking improved the LH pushoff lameness by 71%.

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