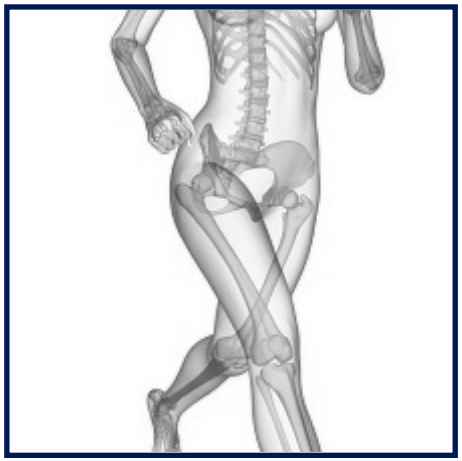
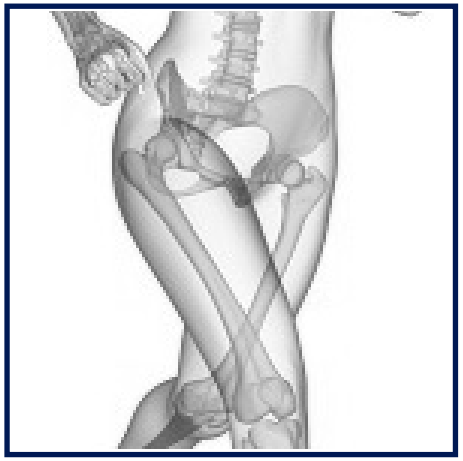
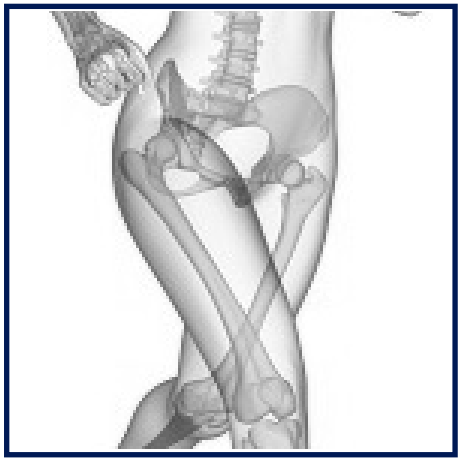
RUN3D CASE-STUDIES



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CASE STUDY 1: COMPETITIVE ATHLETE WITH HEEL-PAIN

BACKGROUND AND HISTORY

Female, competitive level runner, 27 years at time of first assessment (DOB 1990).

Patient had right-sided heel pain in 2007. She had 2 injections and further treatment, the injury took 2 years to settle. In 2011, she had a stress fracture of the 4th metatarsal on the right side.

Patient came to Run3D as she was continuing to have right sided problems with her calf, hamstring (including neural symptoms) and ITB syndrome. She had returned to running but felt she was being held back by recurring problems.

3D GAIT ANALYSIS MAIN OBSERVATIONS

- **Power Generation:** There is a relatively low hip extension but increased knee and ankle dorsiflexion and as a result, a low vertical excursion.
- **Control:** There is a general asymmetry at the pelvis, hip and knee. Interestingly, right pelvic rotation is notably excessive at foot strike and whilst right hip rotation is restricted, adduction is excessive. At the knee, motion is greater on the left.
- **Ankle:** There is a slightly high inversion angle but average eversion and as a result, the eversion excursion is slightly high. The asymmetry in dorsiflexion at foot-strike (reduced on right, high on left) indicates a forefoot strike pattern on the right, with a mid/heel strike on the left.
- **Strength:** There is reduced hip extension strength and given the level at which she wishes to perform, hip adduction, external rotation and ankle inversion/eversion should be improved.
- **Flexibility:** The external hip position is confirmed and there is notable inflexibility of the quadriceps and hamstring muscle groups.

OPINION

The right forefoot strike/absent heel contact was a surprise. On questioning, she feels she may well have trained herself to reduce heel contact on the right due to her plantar fasciitis. Certainly, it is quite possible given that she has an excessive step length (over-stride), she is having to rotate the right pelvis internally in order to get a forefoot strike. This is limiting hip rotation but precipitates excessive adduction.

In addition, she is not getting sufficient hip extension which may well be associated with the excessive step length and the weak hip extension. Instead, she is generating more through the knee/ankle but in turn has reduced hamstring and quadriceps flexibility.

KEY RECOMMENDATIONS

1. **Footwear:** Based on the results of the analysis, a neutral shoe should be sufficient.
2. **Orthoses:** The asymmetry is not due to her underlying foot structure and is most probably due to her modified gait and proximal function. Whilst one could consider heel lifts, at this stage we should focus on rehab and running style.
3. **Flexibility:** The objective clinical evaluation indicates that the key areas to target are: Quadriceps and hamstrings.
4. **Strength and Conditioning:** The objective clinical evaluation indicates that the key areas to target are: Hip extension which should help improve power generation during running. However, given the level at which she wishes to perform optimising hip abduction (it is relatively weak on the right), hip external rotation strength, hamstrings and ankle inversion/eversion will all be of benefit.
5. **Neuromotor Control:** Optimising neuromotor control will be an important feature of the rehab programme.
6. **Mobilisation:** I performed a mobilisation today which did improve function and one would hope that improving strength, flexibility and the loading pattern would help prevent recurrence.
7. **Running Style:** The reduced vertical excursion is due to the degree of ankle and knee flexion during stance. We did discuss the excessive step length and this may be a feature that we need to address, particularly given the right forefoot strike/reduced heel contact and the pelvic rotation. However, trying to control the hip adduction may be more beneficial in the first instance.

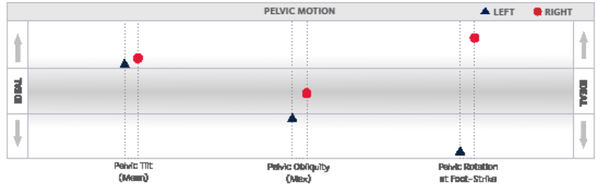
SUMMARY

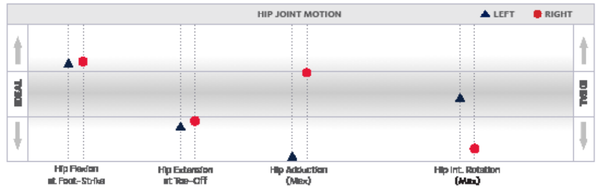
There is obvious asymmetry and all of her symptoms are right-sided. On balance, she may well have adapted her gait such that she has a forefoot strike on the right side hence the degree of asymmetry. We have therefore agreed that we would take a balanced approach of rehab and gait retraining to try and address the problems. She is going to need to do the specific strength-ening and flexibility exercises so that she has the underlying function.

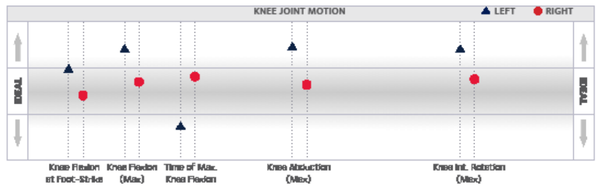
In the first instance, she is going to perform some of her light runs with a view to contacting with a heel strike. I will liaise with Ken Hoye and she will return for an appropriate strengthening programme but also real-time gait analysis. The aim here would be to have her control the hip adduction in the first instance to assess the degree of benefit/affect elsewhere but also vary step length to see if this can reduce the asymmetry. The aim would be to review progress in 3 months.

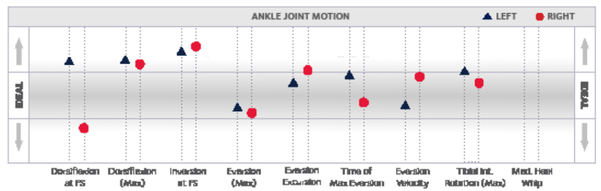
GAIT ANALYSIS KEY PARAMETERS

Trial Conditions: Running at 8:30 min/mile with lightweight footwear on 15/11/2016 (initial)



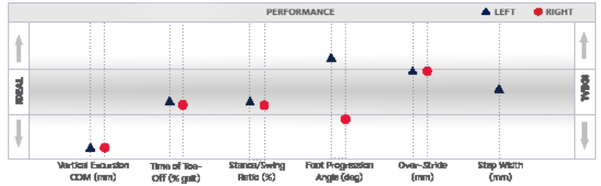






GAIT ANALYSIS KEY PARAMETERS cont'd

Trial Conditions: Running at 8:30 min/mile with lightweight footwear on 15/11/2016 (initial)



PARAMETER Units in Degrees Unless Specified Otherwise	YOUR RESULT (Mean (STD)) L	 R	CONTROLS (Mean) L	 R
Pelvic Tilt (mean stance)	18.9 (0.7)	20.1 (0.6)	10.3	9.9
Pelvic Obliquity (max stance)	0.8 (0.5)	5.6 (0.5)	4.8	5.8
Pelvic Rotation at Foot-Strike	-15.1 (0.8)	10.1 (1.0)	-3.2	-4.5
Hip Flexion at Foot-Strike	57.2 (1.4)	58.0 (1.5)	40.1	39.8
Hip Extension at Toe-Off	6.2 (0.8)	0.3 (1.0)	-12.6	-13.6
Hip Adduction (max stance)	-8.2 (0.6)	8.5 (0.8)	8.2	7.4
Hip Internal Rotation (max stance)	15.9 (0.8)	5.6 (0.7)	17.1	20.2
Knee Flexion at Foot-Strike	18.4 (1.4)	14.1 (2.2)	13.4	15.6
Knee Flexion (max stance)	55.6 (1.4)	50.0 (1.4)	45.2	47.0
Time of Max Knee Flexion (% gait)	14.4 (0.8)	16.8 (1.8)	16.2	15.9
Knee Abduction (max)	13.3 (0.5)	2.4 (0.7)	-0.5	0.7
Knee Internal Rotation (max)	7.2 (1.1)	-8.1 (0.9)	-7.0	-11.3
Dorsiflexion at Foot-Strike	15.6 (1.2)	-3.0 (1.1)	5.2	6.2
DorsiFlexion (max stance)	26.4 (0.8)	25.6 (0.6)	22.2	21.1
Dorsiflexion at Toe-Off				
Inversion at Foot-Strike	12.5 (0.8)	16.8 (1.1)	7.1	8.3
Eversion (max stance)	7.8 (0.6)	6.5 (1.0)	9.4	9.1
Time of max eversion (% gait)	16.7 (2.5)	11.2 (0.8)	14.0	11.8
Eversion Excursion	20.5 (0.9)	23.4 (1.5)	18.5	17.9
Eversion Velocity (degrees/second)	348.7 (23.8)	465.4 (32.5)	398.0	400.6
Tibial Internal Rotation (max)	-0.2 (0.2)	-0.2 (0.2)	-3.8	-1.5
Medial Heel-Whip				
Static Vertical Off-Set Angle				
Vertical excursion centre of mass (mm)	62.6 (4.3)	61.4 (3.8)	83.4	83.3
Time of toe-off (% gait)	35.7 (0.5)	35.2 (0.7)	36.6	36.5
Stance/Swing Ratio (%)	55.6 (1.3)	54.3 (1.6)	58.1	57.8
Foot Progression Angle	33.1 (1.3)	13.9 (1.4)	22.9	21.9
Over-Stride (mm)	218.5 (9.5)	207.3 (10.5)	172.2	167.8
Step-Width (mm)	81.61 (14.38)		79.62	
Cadence (Steps/Minute)	183.53		189.0	

REHABILITATION PROGRAMME PHASE 1

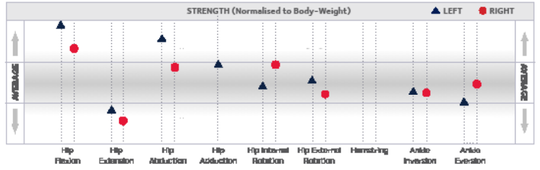
Rehab began with mobility around the hips, quads and hamstrings. The hip flexors and TFL were also targeted with stretches. Trigger point on the ball was used to reduce tension in the glutes and TFL also. Patient was advised to use foam rolling regularly and have sports massage therapy as required.

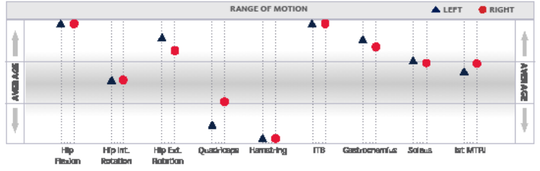
The MSK also showed reduced glute activation strength and so the glutes were targeted with step ups, lunges and work with a theraband. Her usual routine was reviewed and some positions were adjusted for maximum effectiveness under physiotherapy guidance. This included some core work including side plank.

A Hoka shoe was introduced for training runs as a Run3D trial showed improved foot function with greater symmetry and reduced dorsiflexion on foot-strike. There was also a reduced inversion at foot-strike. Patient has since returned to more traditional footwear and wears the Hoka more sparingly.

Balance work with a wobble cushion to add some instability was introduced later, the aim was to improve activation around the foot and ankle. Less work was done on this area as the athlete had returned to competition and was injury free.

Various cues for gait retraining were tested using Run3D in an attempt to improve the asymmetry at the ankle, hips and pelvis. A repeat assessment one-year later confirmed improvement at the pelvis and hips, although there is still a notable difference in foot-strike pattern between left and right.





REPEAT GAIT 12-MONTHS LATER

A repeat gait analysis was conducted 12-months later. The athlete was uninjured by this time, training an average of 60 miles/week and competing at a high level in all distances up to the marathon.

MAIN OBSERVATIONS

- **Power Generation:** Improved hip extension at toe-off, pelvic tilt position and hip flexion at foot-strike, resulting in reduced over-stride. Improvement in knee flexion.
- **Control:** There is notable improvement in the asymmetry that was previously observed at the pelvis, hip and knee. Right pelvis rotation at foot-strike and hip adduction have decreased, there is increased motion on the left.
- **Ankle:** There is relatively little change at the ankle, with some improvement in ankle inversion at foot-strike on the right, probably a result of the reduced pelvic rotation at foot-strike that is observed. Given that the athlete is running well and uninjured, the asymmetry at foot-strike will continue to be monitored but not directly altered at this time.

CURRENT PLAN

Training has gone well and the athlete managed to build up to a week of 87 miles at the peak of her marathon training, resulting in a PB by 10 minutes and an England call-up. She also ran PB times over a variety of shorter distances including 10k and half marathon.

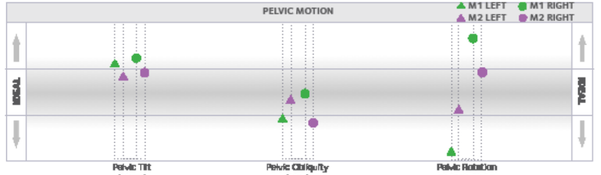
She has regular soft tissue work and maintains some strength work throughout training. Since her marathon she is keen to add more power and strength to help prevent further issues and to help improve speed. She is also looking to add more speed work and race over shorter distances before building up to another marathon.

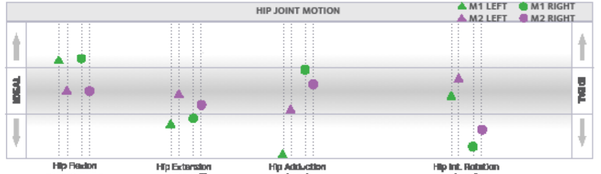
The current phase includes some free weights building on some classic lifts such as squats and dead lifts before moving onto more power based moves. Single leg work is still an area of focus to further improve symmetry. As there is more of a speed focus for the upcoming training block, plyometric running drills will be included in her programme to help convert the strength to power.

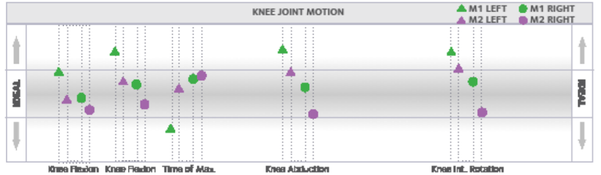
GAIT ANALYSIS COMPARISON

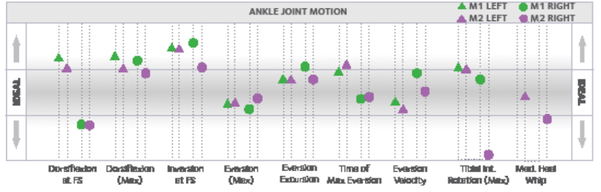
Trial Conditions Measurement 1: Running at 6:30 min/mile with lightweight footwear on 15/11/2016 (initial)

Trial Conditions Measurement 2: Running at 6:30 min/mile with neutral footwear on 31/10/2017 (initial)









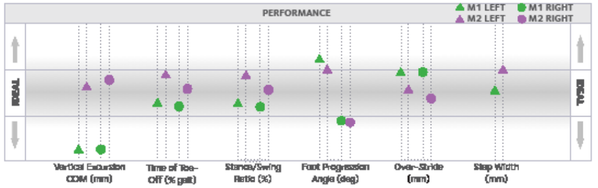
GAIT ANALYSIS COMPARISON cont'd

Trial Conditions Measurement 1: Running at 6:30 min/mile with lightweight footwear on 15/11/2016 (initial)

Cadence 184 (Mean 180) | Step Width 82 (Mean 80mm) | Vertical Excursion 63 (Mean 83mm) | Over-stride 218 (Mean 172mm)

Trial Conditions Measurement 2: Running at 6:30 min/mile with neutral footwear on 31/10/2017 (initial)

Cadence 180 (Mean 180) | Step Width 100 (Mean 80mm) | Vertical Excursion 85 (Mean 83mm) | Over-stride 179 (Mean 172mm)



PARAMETER Units in Degrees Unless Specified Otherwise	M1 (Mean (STD)) L | R	M2 (Mean (STD)) L | R
Pelvic Tilt (mean stance)	18.91 (0.68) | 20.11 (0.55)	14.9 (0.58) | 15.35 (0.41)
Pelvic Obliquity (max stance)	0.84 (0.53) | 5.8 (0.52)	3.47 (0.53) | 2.82 (0.54)
Pelvic Rotation at Foot-Strike	-15.15 (0.8) | 10.05 (0.96)	-6.46 (0.75) | 0.38 (0.91)
Hip Flexion at Foot-Strike	57.15 (1.38) | 57.97 (1.51)	40.78 (1.12) | 39.87 (0.9)
Hip Extension at Toe-Off	6.2 (0.82) | 0.25 (1.0)	-11.38 (1.4) | -6.93 (1.13)
Hip Adduction (max stance)	-8.15 (0.56) | 9.48 (0.81)	5.15 (0.76) | 8.06 (0.88)
Hip Internal Rotation (max stance)	15.92 (0.79) | 5.57 (0.7)	20.92 (0.8) | 10.29 (0.71)
Knee Flexion at Foot-Strike	19.42 (1.42) | 14.08 (2.19)	11.9 (1.49) | 9.89 (1.18)
Knee Flexion (max stance)	55.59 (1.38) | 50.01 (1.44)	48.06 (1.39) | 43.32 (1.12)
Time of Max Knee Flexion (% gait)	14.38 (0.94) | 16.85 (1.8)	16.48 (0.78) | 17.08 (0.76)
Knee Abduction (max)	13.32 (0.46) | 2.36 (0.65)	5.82 (0.54) | -5.01 (0.74)
Knee Internal Rotation (max)	7.21 (1.08) | -8.1 (0.84)	1.18 (1.03) | -16.51
Dorsiflexion at Foot-Strike	15.59 (1.17) | -3.04 (1.11)	12.38 (1.14) | -3.19 (0.8)
Dorsiflexion (max stance)	28.4 (0.82) | 25.58 (0.6)	24.9 (0.84) | 23.73 (0.82)
Dorsiflexion at Toe-Off		-17.16 | -18.26
Inversion at Foot-Strike	12.55 (0.65) | 16.81 (1.12)	12.38 (0.84) | 12.35 (0.79)
Eversion (max stance)	7.81 (0.61) | 6.52 (1.01)	8.01 (0.79) | 8.15 (1.02)
Time of max eversion (% gait)	16.73 (2.5) | 11.22 (0.93)	17.74 (3.56) | 11.38 (0.71)
Eversion Excursion	20.52 (0.85) | 23.38 (1.45)	20.42 (1.12) | 20.62 (1.47)
Eversion Velocity (deg/msec/second)	348.75 | 495.39	311.06 | 404.31
Medial Heel-Whip		2.99 (3.24) | -9.51 (1.75)
Tibial Internal Rotation (max)	-0.18 (0.16) | -0.23 (0.18)	-0.38 (0.24) | -8.17 (0.86)
Static Vertical Off-Set Angle		10.87 (0.0) | 11.65 (0.0)
Vertical excursion centre of mass (mm)	82.81 (4.27) | 81.43 (3.94)	85.37 (4.25) | 87.58 (4.88)
Time of toe-off (% gait)	35.73 (0.52) | 35.2 (0.65)	38.3 (0.66) | 36.88 (0.71)
Stance/Swing Ratio (%)	55.81 (1.26) | 54.32 (1.55)	62.09 (1.73) | 58.46 (1.78)
Foot Progression Angle	33.11 (1.32) | 13.93 (1.45)	29.61 (1.23) | 13.51 (1.44)
Over-Stride (mm)	218.5 (9.5) | 207.3 (10.5)	179.1 (6.8) | 155.9 (8.4)
Step-Width (mm)	81.61 (14.38)	99.96 (14.06)
Cadence (Steps/Minute)	183.53	180

CASE STUDY 2: BILATERAL CALF AND PLANTAR FASCIA PAIN, WALKING

BACKGROUND AND HISTORY

Female, 55 at time of this assessment in early 2018. Referred for gait analysis.

Client attended with pain in both feet legs, and had reduced mobility stating that she felt that her legs were heavy and tired after only a few minutes of walking. The feet feel tender all of the time but once she walks for 20 minutes, her legs feel heavy as though she has worn a new pair of shoes and this will be worse than the feet.

The pain had begun with some plantar fasciitis and had moved to the knees also. She had been experiencing these pains for around 3 years and had seen several specialists and was waiting for an appointment for spinal stimulation therapy. Any significant spinal pathology had been ruled out, she had been assessed for chronic pain and there is no evidence of an inflammatory arthropathy. Blood tests, CT angio an MRI of the lower legs were all normal.

Previous to this the patient had been relatively fit and enjoyed walking and gardening, which she was now unable to do. She was swimming regularly as this was the only exercise that didn't routinely make the pain worse. This was initially plantar fasciitis, She has been referred for gait analysis.

Examination:
- CVS. Both pedal pulses palpable bilaterally.
- CNS. There were some posterior tension signs on straight leg raise but this was otherwise normal.
- LS. Given her symptoms, there was minimal discomfort on palpation of the plantar fascia or plantar heel.

Biomechanical evaluation revealed (bilateral unless stated):

Adequate rearfoot motion.
The left forefoot appears parallel with the right slightly everted to the rearfoot.
On weight-bearing, both heels are relatively perpendicular to the supporting surface and she maintains a medial longitudinal arch.
Foot Posture index L/0, R/-1 (Reference values - Highly supinated: -5 to -12, Supinated: -1 to - 4, Normal: 0 to + 5, Pronated: +6 to +9, Highly pronated: 10+).

Observational gait analysis: On walking, she appeared to have a short step length with early heel lift and increased ankle plantarflexion. If anything, there appeared to be a low gear toe off.

3D GAIT ANALYSIS MAIN OBSERVATIONS (WALK)

- **Power Generation:** There is slightly high hip extension and thus reduced pelvic tilt with left ankle dorsiflexion high.
- **Control:** There is some asymmetry although hip adduction is excessive with knee abduction reduced bilaterally.
- **Ankle:** Consistent with her foot structure, there is reduced eversion but as there is a higher level of inversion at heel strike, the eversion range is high with a high velocity.
- **Gait Parameters:** This confirms a short step length.
- **Strength:** This was revealing in that there is a deficit in all muscle groups and it is interesting that she has reduced hip extension strength yet relatively high hip extension at toe off. She is particularly weak about both ankles.
- **Flexibility:** This was generally good except for calf inflexibility.

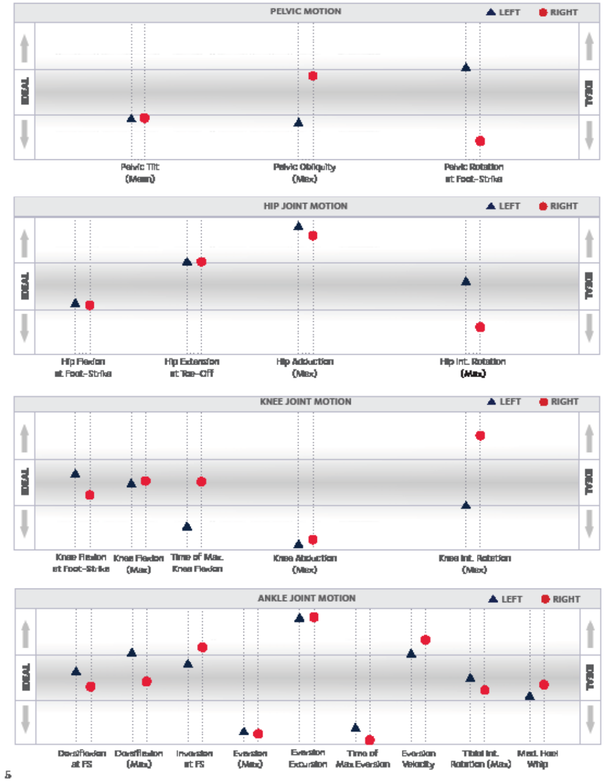
OPINION

Although there is some asymmetry on the gait analysis, she has symmetrical symptoms and thus, in my opinion, the key findings are a tendency towards an ankle dominant gait as there is an early heel lift with increased ankle plantarflexion in latter stance with a short step length. I suspect some of the increased hip extension is reflective of lower back motion and there is poor control in terms of hip adduction.

Furthermore, at the foot, although the degree of eversion is reduced, the overall range of motion from heel strike to maximum eversion is increased with a high velocity requiring greater control. All of these factors will be exacerbated by the general muscle weakness.

GAIT ANALYSIS PARAMETERS

Trial Conditions: Walking with neutral footwear on 20/03/2018 (initial)



GAIT ANALYSIS PARAMETERS cont'd

Trial Conditions: Walking with neutral footwear on 20/03/2018 (initial)

PARAMETER Units in Degrees Unless Specified Otherwise	YOUR RESULT (Mean (STD)) L | R		CONTROLS (Mean) L | R	
Pelvic Tilt (mean stance)	9.2 (0.4)	9.3 (0.4)	16.5	16.6
Pelvic Obliquity (max stance)	**0.7 (0.4)**	**5.3 (0.4)**	**3.3**	**4.1**
Pelvic Rotation at Foot-Strike	5.8 (1.4)	-5.0 (1.6)	3.5	4.1
Hip Flexion at Foot-Strike	**34.2 (0.3)**	**33.7 (0.7)**	**40.1**	**40.4**
Hip Extension at Toe-Off	4.9 (1.2)	4.6 (2.3)	12.6	12.1
Hip Adduction (max stance)	**11.4 (0.4)**	**12.2 (1.0)**	**3.2**	**5.4**
Hip Internal Rotation (max stance)	11.2 (0.9)	5.3 (1.0)	10.4	14.6
Knee Flexion at Foot-Strike	**-0.2 (2.0)**	**-2.9 (1.4)**	**-1.7**	**-0.1**
Knee Flexion (max stance)	17.4 (1.6)	17.9 (1.0)	17.7	17.7
Time of Max Knee Flexion (% gait)	**14.8 (1.3)**	**16.4 (1.7)**	**16.7**	**16.5**
Knee Abduction (max)	-4.6 (0.4)	-4.8 (0.3)	3.3	1.9
Knee Internal Rotation (max)	**-11.9 (0.9)**	**0.3 (0.7)**	**-5.9**	**-12.6**
Dorsiflexion at Foot-Strike	3.3 (0.9)	2.3 (1.5)	2.7	3.5
Dorsiflexion (max stance)	**14.6 (0.3)**	**11.5 (0.3)**	**12.5**	**11.9**
Dorsiflexion at Toe-Off	-14.8 (1.8)	-18.2 (2.0)	0.0	0.0
Inversion at Foot-Strike	**5.0 (1.2)**	**6.4 (1.4)**	**3.7**	**3.8**
Eversion (max stance)	0.8 (1.0)	2.7 (0.9)	5.0	5.2
Time of max eversion (% gait)	**20.3 (0.1)**	**23.0 (3.6)**	**40.7**	**41.1**
Eversion Excursion	15.3 (2.9)	15.4 (3.0)	10.9	10.8
Eversion Velocity (degrees/second)	**245.2 (48.1)**	**303.4 (50.0)**	**186.4**	**205.4**
Tibial Internal Rotation (max)	-0.8 (0.5)	-3.1 (1.2)	-0.8	-0.5
Medial Heel-Whip	**-7.9 (4.3)**	**-3.0 (8.0)**	**0.0**	**0.0**
Static Vertical Off-Set Angle	9.2 (0.0)	10.7 (0.0)	0.0	0.0
Vertical excursion centre of mass (mm)	**45.2 (2.1)**	**45.2 (1.8)**	**41.0**	**40.9**
Time of toe-off (% gait)	65.9 (0.7)	67.1 (0.8)	66.6	66.4
Stance/Swing Ratio (%)	**193.2 (8.1)**	**204.2 (7.1)**	**198.8**	**198.1**
Foot Progression Angle	26.7 (1.5)	27.9 (1.5)	28.7	28.3
Over-Stride (mm)	**173.4 (7.6)**	**174.8 (8.4)**	**214.7**	**216.9**
Step-Width (mm)	148.97 (22.89)		138.51	
Cadence (Steps/Minute)	**128.11**		**118.97**	

KEY RECOMMENDATIONS

1. **Footwear:** Based on the results, a neutral shoe should be sufficient. I have advised her to get a good running shoe for support and to have a laced version. One option going forward would be to consider the Hoka shoe given the rocker sole adaptation but I would prefer her to concentrate on rehab in the first instance.

2. **Orthoses:** At this moment in time, I do not feel orthoses are required but this can be revisited according to symptoms.

3. **Flexibility:** The objective clinical evaluation indicates that the key areas to target are: Gastro-soleus.

4. **Strength and Conditioning:** The objective clinical evaluation indicates that there is a general deficit which needs attention but the key areas to target are: Hip extension, abduction and external rotation, ankle inversion and eversion. Detailed below are the muscle groups relating to the specific areas of altered function with a view to optimising movement patterns.

Excessive: Pelvic obliquity (R): Hip abductor/extensor/external rotator
Pelvic rotation (L): Hip abductor/extensor, Transverse abdominus, multifidus
Hip adduction: Hip abductor/extensor, ankle inversion / eversion
Knee rotation (R): Hip abductor/flexor/internal/external rotator, hamstring

Restricted:- Pelvic tilt: Hip flexor
Pelvis and hip rotation (R): Hip flexor
Knee abduction: Hip internal / external rotator
Rearfoot eversion: Hip abductor, ankle inversion / eversion

5. **Neuromotor Control:** Optimising control will be an important feature of the rehab.

6. **Mobilisation:** There is no indication for mobilisation.

7. **Gait Parameters:** She has a short step length and does appear to have increased ankle plantar flexion towards toe off. Thus trying to improve the step length with power generation via the hip should help to reduce load through the foot.

SUMMARY

She has an ankle dominant gait with likely compensation in the lower spine providing a false degree of hip extension. In addition, of note, is the excessive hip adduction. All of this is exacerbated by general weakness. At the ankle, there is a high overall range of motion and velocity and thus improving strength and control around the ankle would be of benefit. I recommended she see Ken Hoye for appropriate rehab guidance and I will review in 3 months to assess progress and further options.

REHABILITATION PROGRAMME

The MSK revealed strength deficit across most areas with good mobility with the exception of calf complex. Although she was able to complete 30 calf raises and the bridge exercises, her balance scores were low, including control in squat, and she failed most of the bridge tests. Her 3D Gait showed asymmetrical pelvic motion and high hip adduction, so we began the exercises to address this and look at improving her balance. This improved her confidence and allow us to build up the difficulty of the exercises quicker.

The patient was keen to improve and felt that we were the first people she had seen that could offer a solution, and as she could see what needed to be worked on was fully committed to the program. Initial exercises were limited by her lack of balance so we began with some inversion and eversion exercises with a theraband. We added split squad which she initially did next to the wall to use as support if needed. Some of these exercises were performed in the swimming pool as the patient continued to swim and added these exercises here as she felt more confident doing them in the water.

Step 2 a couple of weeks later and there was already an improvement so we progressed the exercises adding dead bug, and step ups with balance at the top position. This worked strength, balance and coordination and provided a challenge to her which she was keen to embrace. We also did Glute kicks with 4 point kneeling to engage the glutes and work on the hip position whilst activating the core.

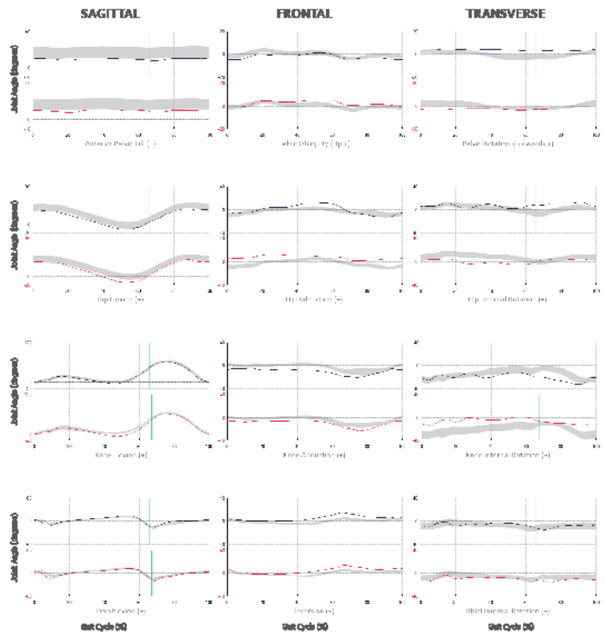
At 5 weeks after initial test we were able to progress to forward lunge as balance had improved considerably. We still kept the movement relatively short but advised on increasing the step length of this exercise as a goal. We also added hip abduction with theraband to improve glute and hip strength with control and balance also challenged. Crab walks were introduced for similar reasons and to make the program more interesting. Client was also able to add some weights to her step up increasing the level of difficulty whilst maintaining the challenge to both strength and control. She mentioned she had some pain recently after spending too much time gardening, but that she would not have been able to do any gardening previous to her assessment. We discussed moderating the exercises on days when she had any discomfort.

After one further session reviewing her exercises and discussing progression we decided to allow her to continue her exercises on her own and only attend if needed. She had said she had met some friends for dinner which she had been avoiding as she had found it difficult to get up from a chair and felt embarrassed. She was now able to do this and move much more easily to and from the table. She now only had any discomfort on days she had been overdoing her activity and was more confident doing many tasks she had not been able to do for some time. She had even added a couple of minutes of running to her gym routine.

GAIT ANALYSIS GRAPHS

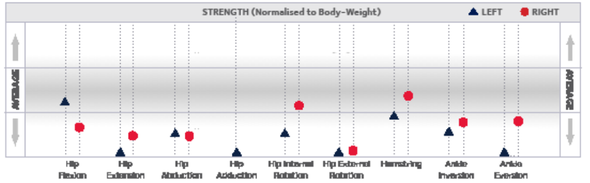
Trial Conditions: Walking with neutral footwear on 20/03/2018 (initial)

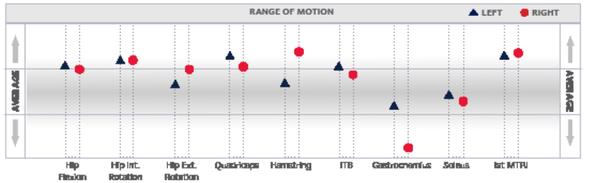
Left Leg | Right Leg | Uninjured Controls

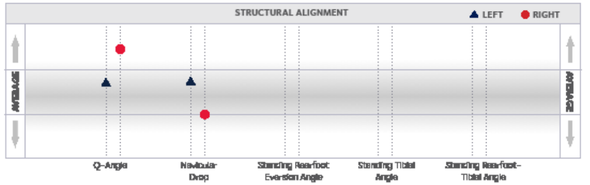


CLINICAL EXAM PARAMETERS

Trial Conditions: MSK Advanced on 20/03/2018







CASE STUDY 3: GAIT RETRAINING FOR BILATERAL CALF AND ACHILLES INJURIES

BACKGROUND AND HISTORY

Male, 47 years at time of first assessment, long-distance runner and triathlete.

Patient had history of chronic and recurring bilateral and Achilles injuries. At time of the assessment he reported progressive calf tightness that worsened with increased running speed. Previous rehabilitation involved soft tissue massage and calf stretching.

INITIAL 3D GAIT ANALYSIS MAIN OBSERVATIONS

- **Power Generation:** There is high (++) anterior pelvic tilt, and as a result high hip flexion and low hip extension. Low knee flexion at FS bilaterally, although dorsiflexion normal.
- **Control:** There is general asymmetry with low pelvic obliquity, hip adduction and rotation on the left compared to right.
- **Ankle:** Ankle dorsiflexion is within normal range. There is low inversion at FS and slightly high peak eversion. Time to peak eversion is high (++) bilaterally and low tibial rotation on left.
- **Gait Parameters:** High foot progression angle on left and higher overstride on left compared to right. Very low cadence.

OPINION

The results suggest power is being produced elsewhere than the hips. Further investigation into the kinematic curves confirmed high plantarflexion throughout the second half of stance and therefore an ankle dominant gait. The combination of an excessive anterior pelvic tilt and low hip extension, plus reduced dorsiflexion from mid-stance through to toe-off indicates that the calves are being over-worked. The function of the glutes reduces significantly in an anterior pelvic tilt. Furthermore, as the pelvis moves more into increased anterior tilt with increased speed, the problem will be exacerbated at faster running speeds.

It is likely that there is a limitation of the anterior muscle groups (quads / hip flexors), creating a structural limitation to the position of the pelvis and this should be worked on in addition to gait retraining .

Cadence is very low, reflected in low knee flexion at foot-strike and encouraging an over-stride.

On the control side of things, there is significant asymmetry with stiffening happening in the left hip/pelvis that could be explored further, as well as reduced tibial internal rotation on the left. High knee abduction and right knee internal rotation are possibly a result of poor hip and pelvic control (seen in the high hip adduction and high pelvic obliquity on the right).

RECOMMENDATIONS AND PLAN

1. **Gait Retraining:** Based on the results of the gait analysis, a faded feedback protocol to address: excesssive anterior pelvic tilt (also high hip flexion and low hip extension) and low cadence was implemented. Strength, neuromotor and flexibility work to complement the proposed gait retraining cues were included in the plan.
2. **Strength and Neuromotor:** Key areas to target: Hip abductors, hamstrings, glute activation, single-leg squat.
3. **Flexibility:** Key areas to target: Hip flexors, quadriceps and calves.

GAIT RETRAINING PROTOCOL

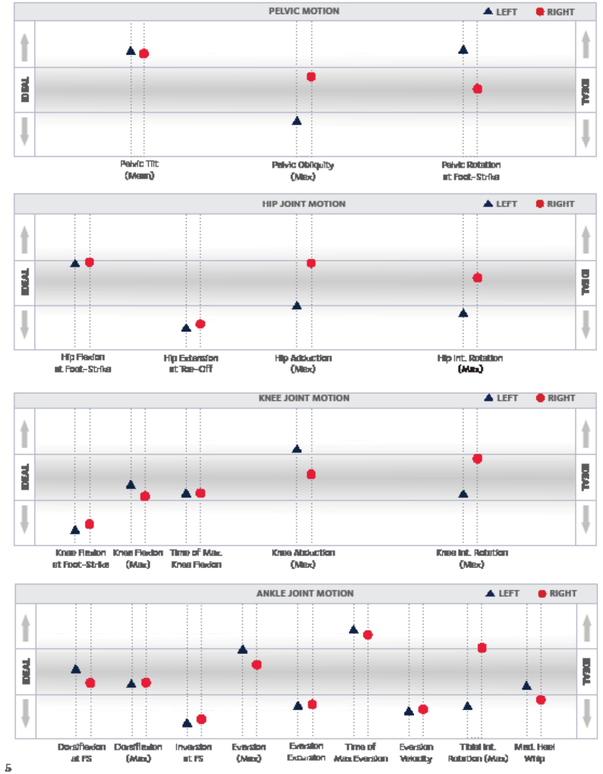
A gait retraining protocol was implemented, comments and results are shown on the next pages.

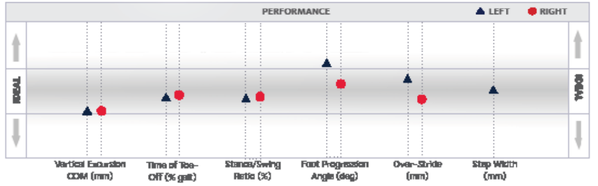
Retraining session were carried-out weekly. Patient also ran a minimum of 2x per week between sessions focussing on the cues. 3x Physiotherapy session were included to improve hip flexor mobility, hip mobility and guide through the exercise programme described above.

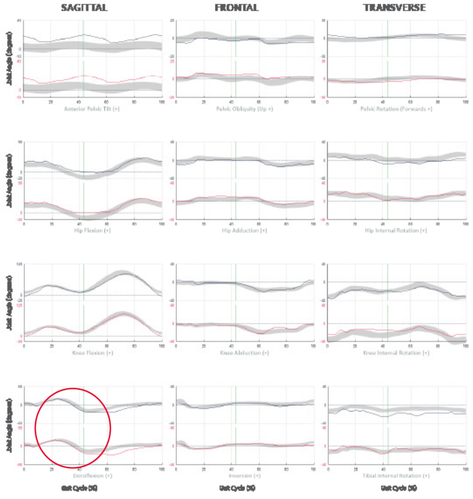
Retraining Session	Total Assessment Time	Running Time	Visual Feedback Allocation	Gait Retraining Cues	Other comments
Initial Silver Assessment	1 hour	5 mins	Silver Assessment	NA	ON shoes
Retrain 1	30 mins	15 mins	15 minutes, Pelvic tilt graph.	Tuck bottom under Quicker turnover	ON shoes
Retrain 2	30 mins	15 mins	3 mins beginning 3 mins middle 3 mins end Pelvic tilt graph	Tuck bottom under Extend hip Faster feet	ON shoes
Retrain 3	30 mins	15 mins	2 mins beginning 2 mins middle 2 mins end Pelvic tilt graph	Tuck bottom under extend with hip quicker turnover, faster feet	Mizuno Wave Riders
Retrain 4	30 mins	15 mins	1 min beginning 1 min middle 1 min end Pelvic tilt graph	Tuck bottom under, faster turnover	Mizuno Wave Riders
Retrain 5	30 mins	15 mins	1 min beginning Pelvic tilt graph	Tuck bottom under Bend left knee	Mizuno Wave Riders

GAIT ANALYSIS KEY PARAMETERS

Trial Conditions: Running at 10 min/mile with neutral footwear on 21/08/2018 (initial) - cm's

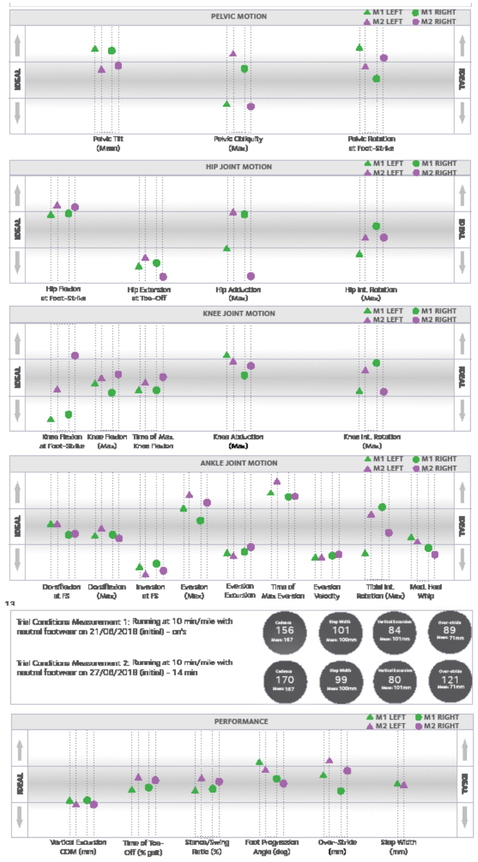




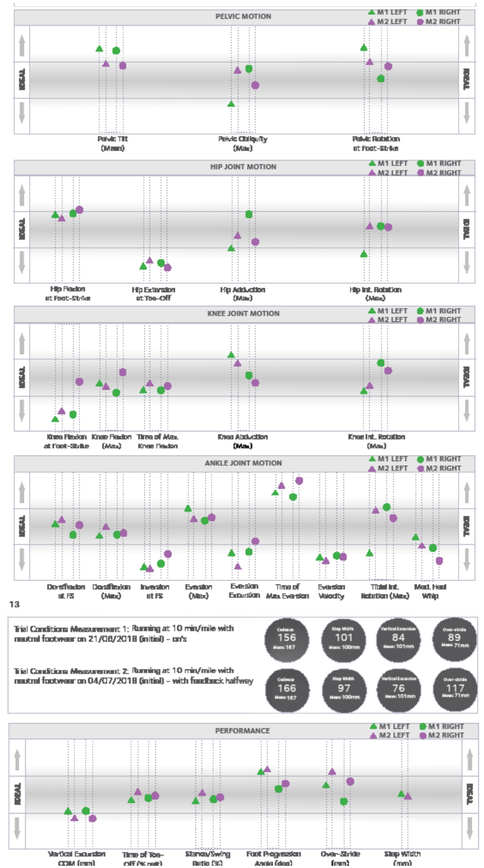


Retraining Session	TOTAL RUNNING TIME	FEEDBACK TIME	VERBAL CUES AND VISUAL FEEDBACK	KEY FINDINGS: POWER	KEY FINDINGS: CONTROL	KEY FINDINGS: ANKLE	KEY FINDINGS: GAIT PARAMETERS	COMMENTS
Initial (ON Trainers)	5 mins	NA	NA	See previous page	See previous page	See previous page	See previous page	
Retraining 1 (see opposite for comparison report) (ON Trainers)	15 mins	15 mins	Tuck bottom under Faster turn-over Feedback: Pelvic tilt, cadence to 165	Significant improvement in pelvic tilt compared to initial assessment (IA) BUT still very poor hip extension. Explained to patient that this caused by him trying to 'SIT' down rather than tilt and use his glutes. Hip extension also limited by hip flexors and glute activation. Increased knee flexion at FS has enabled the increased cadence, note asymmetry between right and left. No change in DF at FS.	Frontal plane movement has inverted pattern compared to initial and transverse plane movement has become more symmetrical. Could be a response to increased cadence.	Relatively little change. Slight increase in peak eversion and time to peak eversion remains high bilaterally. Consider ankle strengthening to try and address this.	Significant increase in cadence from 156 to 170.	Added ankle strengthening and hip extension drills to rehab.
Retraining 2 (ON Trainers)	15 mins	3 mins beginning 3 mins middle 3 mins end	Tuck bottom under Extend hip Faster feet Feedback: Pelvic tilt, cadence to 165	As above: pelvic tilt improving but still high. Hip extension still very reduced. Increases in knee flexion at foot-strike lower than observed in Session 1 as cadence increase is much lower. Note asymmetry stiffness still in the left despite improvement in right.	Same patterns of change as observed in Gait Retraining Session 1 but to a lesser extent as cadence increase is less.	Changes similar to those observed in Retraining Session 1.	Cadence improved from 156 to 166, not as big a difference compared to Gait retraining session 1 and other kinematic changes reflect this, with similar changes compared to retraining session 1 but to a lesser extent.	

INITIAL VERSUS RETRAINING SESSION 1

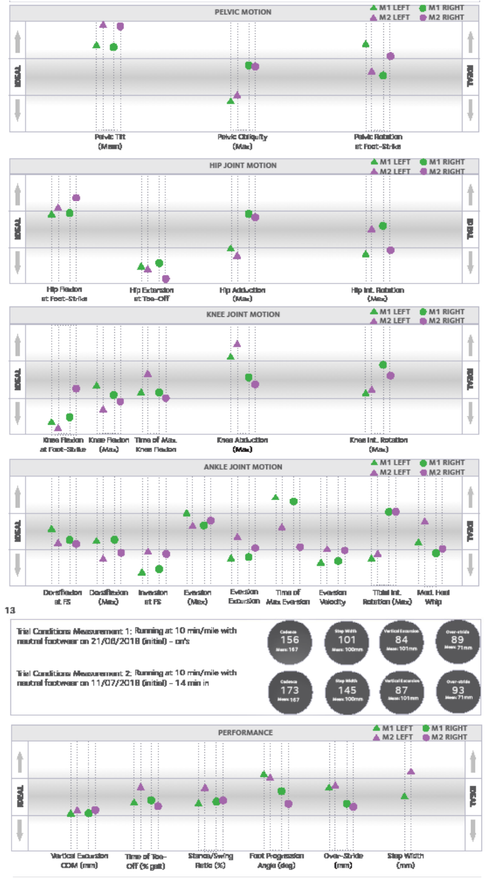


INITIAL VERSUS RETRAINING SESSION 2

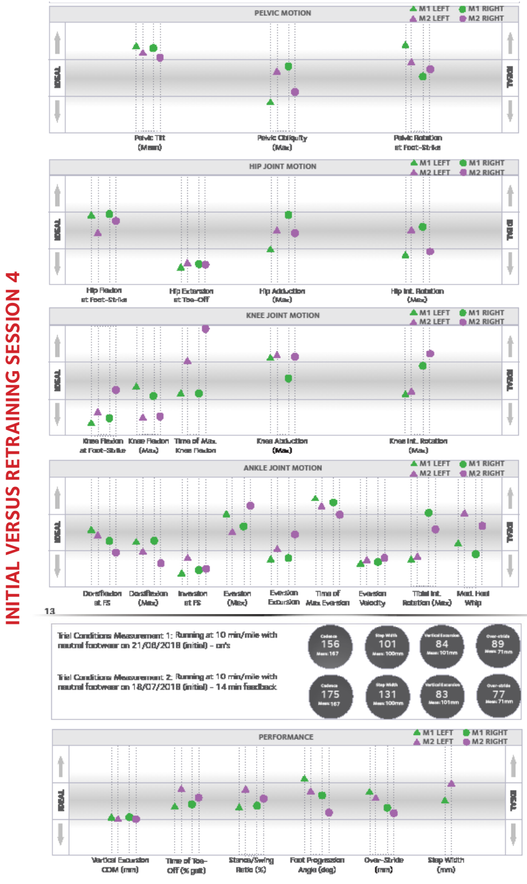


Retraining Session	TOTAL RUNNING TIME	FEEDBACK TIME	VERBAL CUES AND VISUAL FEEDBACK	KEY FINDINGS: POWER	KEY FINDINGS: CONTROL	KEY FINDINGS: ANKLE	KEY FINDINGS: GAIT PARAMETERS	COMMENTS
Retraining 3 NOTE: Changed to Mizuno wave riders for a higher drop. Patient not feeling well during this session and struggling to run properly.	15 mins	2 mins beginning 2 mins middle 2 mins end	Extend hip, quicker turnover of feet. faster feet. Feedback: Pelvic tilt, cadence.	Despite the significant increase in cadence compared to IA (173 versus 156), pelvic tilt has worsened. Patient was feeling unwell and struggling to run, this could be the reason for this abnormal trial. Peak DF has decreased, likely caused by increased drop in the Mizuno footwear compared to original ON trainers.	Improvement in transverse plane compared to IA but frontal plane kinematics reverted back to IA presentations.	Peak DF has decreased. New footwear has brought about positive change in inversion at FS and significant improvement in time to peak rear-foot eversion.	Step width has increased compared to IA.	
Retraining 4 (Mizuno Wave Rider)	15 mins	1 min start 1 min middle 1 min end	Tuck bottom under, faster turnover. Feedback: Pelvic tilt, cadence.	Mild improvement in anterior pelvic tilt, no change of hip extension compared to IA. Improvement in knee flexion at FS in right, not left.	Overall improvement in symmetry compared to baseline. Knee abduction bilaterally high	Time of peak eversion worsened again compared to Session 3, but slight improvement compared to IA.	Step-width reduced compared to Session 3 but still higher than baseline.	

INITIAL VERSUS RETRAINING SESSION 3



INITIAL VERSUS RETRAINING SESSION 4



Retraining Session	TOTAL RUNNING TIME	FEEDBACK TIME	VERBAL CUES AND VISUAL FEEDBACK	KEY FINDINGS: POWER	KEY FINDINGS: CONTROL	KEY FINDINGS: ANKLE	KEY FINDINGS: GAIT PARAMETERS	COMMENTS
Retraining 5	15 mins	1 min start	Bend left knee Soften left knee Quick turnover Extend from hip Tilt bottom under	Pelvic tilt still high, but improved compared to IA. Knee flexion at foot-strike improved but still asymmetric.	Minor changes compared to baseline but little of note.	Time of max eversion and inversion at FS improved compared to IA.	Cadence higher at 177 and maintained. FPA improved, Step width improved	

GAIT RETRAINING SUMMARY:

- **Power Generation:** The gait retraining was targeted to increase cadence, reduce anterior pelvic tilt and increase hip extension at toe-off, with the aim of reducing the ankle dominant gait that was observed in the initial assessment. A minor reduction in anterior pelvic tilt was achieved in all gait retraining sessions (apart from Session 3, which was explained by the patient feeling unwell). Further review of the kinematic curves revealed that this change was accompanied by a reduction in plantarflexion through the second-half of stance, thereby having the desired effect of off-loading the gastro-soleus complex. The minor improvements in pelvic tilt position were not coupled by increased hip extension at toe-off and it was recommended that other biomechanical factors (hip flexor tightness and glute function) need to be addressed first. Knee flexion at foot-strike increased as a result of the increased cadence, but there was clear asymmetry (right more flexed than left at FS) . Peak dorsiflexion decreased when the footwear was changed in Session 3.
- **Control:** Whilst not directly targeted by gait retraining, some minor improvements in frontal and transverse plane movements and symmetry were observed.
- **Ankle:** Rear-foot inversion at foot-strike and time of peak rear-foot eversion improved when the footwear was changed in Session 3.
- **Gait Parameters:** Cadence was increased from 156 to 166 - 177 throughout the gait retaining sessions and the patient was able to maintain this increase relatively comfortably. A slight increase in step-width and decrease in foot progression angle were observed after the new shoes were introduced in Session 3.

SUMMARY AND PLAN

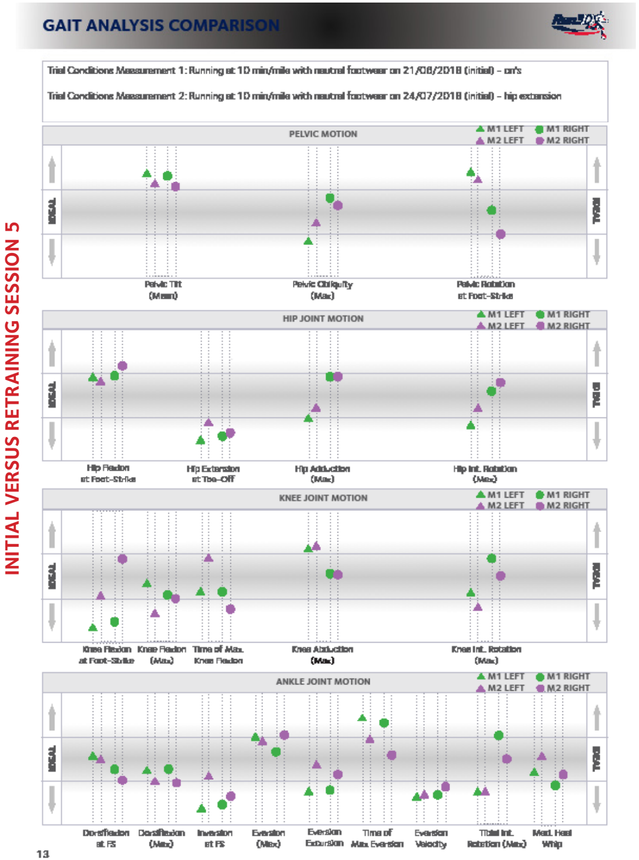
The gait retraining targeted reducing anterior pelvic tilt and increasing cadence in order to off-load the plantarflexors and reduce the patient's ankle dominant gait pattern. The patient successfully maintained an increased cadence and minor improvements in pelvic tilt, resulting in the desired effect of reducing plantarflexion through the second-half of stance. No improvements in hip extension at toe-off were achieved and the patient was advised to focus on improving hip flexor range of motion and glute function.

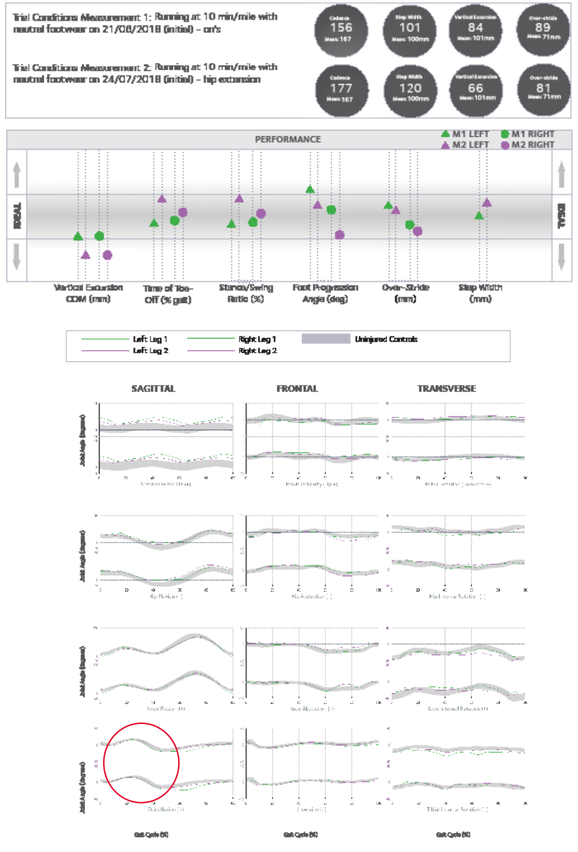
Minor improvements in control and symmetry in the frontal and transverse planes were observed and foot kinematics improved after introducing the Mizuno Wave Riders.

Patient able to run slowly, three times per week without pain following the initial gait retraining protocol. He was advised to continue with HEP and physiotherapy programme to help improve ankle dorsiflexion limitations, knee flexion, pelvic positioning and hip control (through hip flexor mobility work, and single leg balance exercise progressions).

Plan to follow-up in 1-month to review if patient is able to maintain current gait changes and improve further. Also, follow up in 6 months and 1-year (case-study to be updated as appropriate).

INITIAL VERSUS RETRAINING SESSION 5





CASE STUDY 4: YOUNG FEMALE ATHLETE WITH BILATERAL ACHILLES PAIN

BACKGROUND AND HISTORY

Female 800 m and cross-country runner. 20 yrs old at time of assessment.

Patient had previously had right-sided quadriceps pain but the reason for the Run3D assessment was to address bilateral Achilles and calf issues that had begun 6-months prior to this appointment.

No previous rehab, no previous Physiotherapy. Patient was fed-up of on-going injuries and niggles and wanted to address the underlying problems.

Patient was tested in neutral and stability shoes.

INITIAL 3D GAIT ANALYSIS MAIN OBSERVATIONS

- **Power Generation:** Good pelvic position and hip extension. Kinematic curves indicate excessive movement of ankle into plantarflexion from stance to swing, indicative of an ankle dominant gait pattern. Low knee flexion at foot-strike, in accordance with observed low cadence
- **Control:** Reduced motion on the right (hip and pelvis) and increased knee abduction bilaterally (right more than left). Good transverse plans symmetry and control.
- **Ankle:** High rear-foot eversion and eversion excursion on right. High eversion velocity bilaterally, right more than left.
- **Gait Parameters:** Low cadence and high vertical excursion.
- **Strength:** A general weakness in all muscle groups.
- **Flexibility:** This was generally good except for calf inflexibility.
- **Alignment:** Nothing of note.
- **Functional:** Knee valgus and lack of control during SLS manoeuvre, good bridge.

OPINION

The frontal plane kinematic results suggest stiffness in the right hip and pelvis, further confirmed by the single-leg squat and overall muscle weakness. Transverse plane control is good.

At the foot, there is asymmetry, with more motion observed on the right compared to left and high eversion excursion and velocity. These results will be worsened by the ankle muscle weakness.

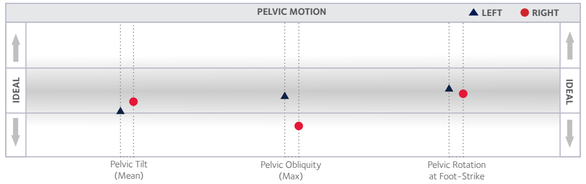
The kinematic curves reveal an ankle dominant gait bilaterally, leading to increased loading at the Achilles and calf muscles. The ankle dominant gait, low knee flexion at foot-strike, low cadence and high vertical excursion will also be increasing load at the knee and hip joints. Cadence is extremely low for this running pace. For a young athlete with high training demands and a history of injury, these gait parameters should be addressed.

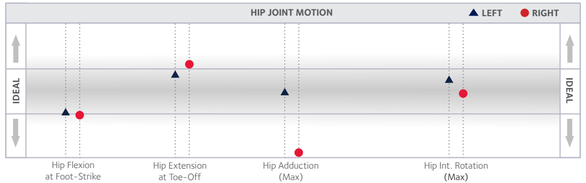
RECOMMENDATIONS

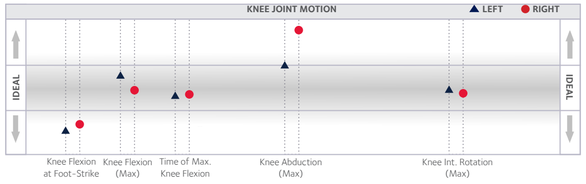
1. **Footwear:** The patient was tested in a stability shoe and based on the results, a neutral shoe is recommended. Consider also trying a more light-weight shoe for some runs in order to try and reduce the amount of knee-extension foot-strike.
2. **Orthoses:** I do not feel an orthotic device is required at this time and recommend ankle strengthening in the first instance. If strengthening alone is unsuccessful and problems persist, an orthotic will be considered.
3. **Flexibility:** Gastrocnemius and soleus.
4. **Strength and Conditioning:** The objective clinical evaluation indicates that there is a general deficit which needs attention but the key areas to target are: ankle invertors and evertors, hip abductors and external rotators, hamstrings.
5. **Neuromotor Control:** Single-leg control will be an area to target.
6. **Mobilisation:** Rehabilitation and Physiotherapy treatment is recommended for the right hip/pelvis.
7. **Gait Parameters:** Trying to increase cadence and reduce knee extension at foot-strike will reduce loading at the knees and hips. Improving gluteal function as described above should reduce the ankle dominant gait.

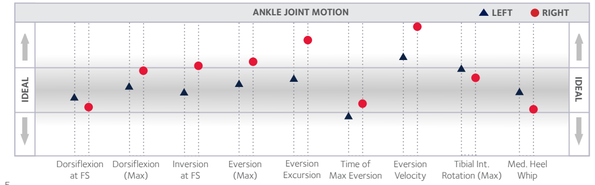
GAIT ANALYSIS KEY PARAMETERS

Trial Conditions: Running at 7 min/mile with neutral footwear on 11/06/2018 (initial)



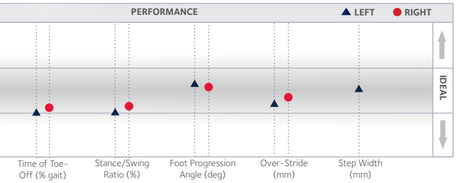






GAIT ANALYSIS KEY PARAMETERS cont'd

Trial Conditions: Running at 7 min/mile with neutral footwear on 11/06/2018 (initial)

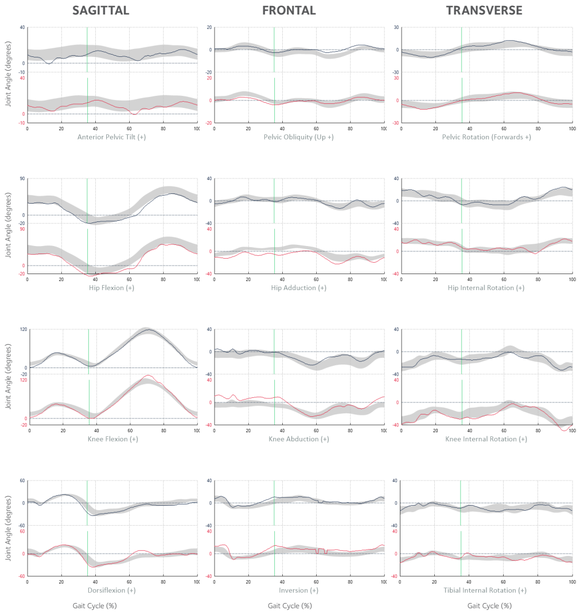


PARAMETER Units in Degrees Unless Specified Otherwise	YOUR RESULT (Mean (STD)) L | R		CONTROLS (Mean) L | R	
Pelvic Tilt (mean stance)	5.7 (0.9)	7.9 (0.8)	11.4	11.1
Pelvic Obliquity (max stance)	3.2 (0.8)	2.9 (0.8)	3.9	6.3
Pelvic Rotation at Foot-Strike	-3.3 (1.4)	-5.5 (1.2)	-3.8	-4.7
Hip Flexion at Foot-Strike	29.9 (1.2)	28.3 (1.7)	39.5	40.0
Hip Extension at Toe-Off	-20.0 (1.4)	-24.8 (1.5)	-11.7	-11.7
Hip Adduction (max stance)	7.2 (0.7)	-1.2 (1.0)	7.3	7.0
Hip Internal Rotation (max stance)	19.9 (1.3)	20.4 (1.2)	16.5	20.9
Knee Flexion at Foot-Strike	0.3 (1.4)	2.4 (1.8)	12.5	14.2
Knee Flexion (max stance)	46.9 (0.8)	44.7 (1.3)	44.3	45.6
Time of Max Knee Flexion (% gait)	16.3 (0.7)	15.8 (0.8)	16.7	16.3
Knee Abduction (max)	6.2 (1.5)	15.1 (1.1)	0.2	0.8
Knee Internal Rotation (max)	-6.1 (1.0)	-13.3 (1.1)	-5.5	-11.7
Dorsiflexion at Foot-Strike	1.8 (0.9)	-1.9 (0.9)	4.4	4.9
Dorsiflexion (max stance)	22.4 (0.9)	23.5 (0.8)	21.9	20.8
Dorsiflexion at Toe-Off	-25.9 (1.5)	-28.1 (2.1)	-21.6	-22.1
Inversion at Foot-Strike	7.6 (1.1)	13.2 (1.6)	8.0	8.3
Eversion (max stance)	9.1 (1.3)	12.1 (0.9)	8.1	8.3
Time of max eversion (% gait)	10.7 (0.8)	11.1 (0.7)	14.5	12.8
Eversion Excursion	20.8 (1.6)	28.0 (1.6)	18.5	17.9
Eversion Velocity (degrees/second)	552.3 (77.3)	1036.8 (85.7)	369.9	383.6
Tibial Internal Rotation (max)	-0.4 (0.3)	-0.4 (0.2)	-3.2	-1.4
Medial Heel-Whip	1.8 (5.8)	-7.4 (1.4)	2.3	-0.7
Static Vertical Off-Set Angle	8.4 (0.0)	13.3 (0.0)	10.5	9.5
Vertical excursion centre of mass (mm)	108.2 (6.0)	108.7 (5.8)	86.8	86.6
Time of toe-off (% gait)	35.1 (0.7)	35.4 (0.7)	37.3	37.4
Stance/Swing Ratio (%)	54.0 (1.7)	54.7 (1.6)	59.8	60.5
Foot Progression Angle	24.0 (1.2)	21.7 (1.6)	21.5	20.5
Over-Stride (mm)	130.8 (10.8)	144.9 (12.4)	156.8	156.7
Step-Width (mm)	81.78 (18.91)		80.24	
Cadence (Steps/Minute)	153.46		186.26	

GAIT ANALYSIS GRAPHS

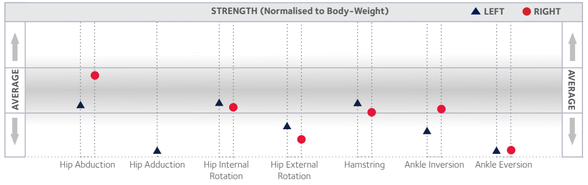
Trial Conditions: Running at 7 min/mile with neutral footwear on 11/06/2018 (initial)

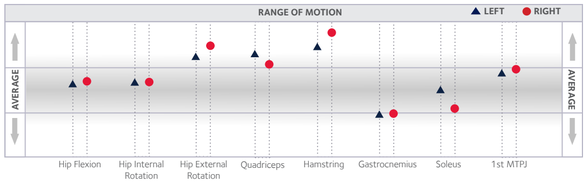
Left Leg | Right Leg | Uninjured Controls



CLINICAL EXAM PARAMETERS

Trial Conditions: MSK Basic on 11/06/2018





PARAMETER (Units) Please note that your clinician will have used his/her clinical judgement to select the combination of clinical tests most appropriate for you.	YOUR RESULT (Mean (STD)) L | R		CONTROLS (Mean) L | R	
STRENGTH (Normalised to BW)				
Hip Abduction	10.6	14.1	12.3	12.8
Hip Adduction	139		276	
Hip Internal Rotation	13.8	12.2	15.6	14.0
Hip External Rotation	14.2	13.6	17.7	18.5
Hamstring	18.9	18.0	21.7	22.7
Ankle Inversion	11.3	16.9	19.8	21.1
Ankle Eversion	13.3	6.7	28.8	26.2
RANGE OF MOTION (Degrees)				
Hip Flexion (Thomas Test)	77	76	79.4	79.4
Hip Internal Rotation	47	54	44.1	46.3
Hip External Rotation	56	58	42.2	40.7
Quadriceps	0	0	3.8	2.7
Hamstring	2	3	18.0	18.8
Gastrocnemius	35	35	41.9	42.3
Soleus	42	35	42.1	41.4
1st MPTJ	90	90	77.5	74.8
FUNCTION AND STRUCTURE (Units as Specified)				
Leg Length (mm):	862	863	-	-
Calf Raises:	15	17	19.1	20.3
Bridge (secs): Normal | Left Leg Up | Right Leg Up	30.0 | 30.0 | 30.0		Target 30 secs each	
Single Leg Squat Left (observations noted)	Shift in the position of the trunk. Contralateral pelvic drop. Medial knee dive.			
Single Leg Squat Right (observations noted)	Contralateral pelvic drop. Medial knee dive.			

SUMMARY AND PLAN

Based on the results of the gait analysis and clinical exam, rehabilitation will focus on the following areas:

- Rehabilitation programme to strengthen ankles and functional hip control
- Physiotherapy to help mobilise hips and progress programme
- Running re-education to increase cadence and increase knee flexion at foot- strike

Patient was given the following exercise to perform daily:

- Ankle inversion with a theraband
- Ankle eversion with a theraband
- Intrinsic arch lifts
- Single-leg-squat
- Foam rolling calves

Update on progress to follow:

CASE STUDY 5: YOUNG FEMALE ATHLETE WITH KNEE AND GLUTE PAIN

BACKGROUND AND HISTORY

Female, cross country (4 km) and track (1500 m) runner, 14 years at time of assessment.

Patient had slight left knee pain and left glute tightness at onset of running, but this did not affect her ability to train consistently four times per week. No other injuries to note but her parents wanted to ensure that these presentations did not worsen.

INITIAL 3D GAIT ANALYSIS MAIN OBSERVATIONS

- **Power Generation:** Good sagittal plane movement.
- **Control:** Notable asymmetry in the frontal plane with more movement on the right compared to left (without orthotics). The asymmetry in pelvic obliquity and hip adduction improves when orthotics are worn. Pelvic rotation at FS low on right, resulting in high hip rotation (R) (both with and without orthoses). Good knee motion.
- **Ankle:** Generally good. High eversion velocity on left.
- **Gait Parameters:** Patterns of note are a very low step-width and low foot progression angle on left.

OPINION

Based on the results of the 3D gait analysis and a selection of clinical tests, there is stiffness in the left hip/pelvis and lack of control on the right. The orthoses improved frontal plane motion but a specific strengthening programme will be recommended to try and reduce the need to wear these for the long-term. Trying to run with a wider step-width might help address the asymmetry in pelvic rotation at foot-strike and improve mobility at the hips.

RECOMMENDATIONS

1. **Footwear:** Neutral shoe recommended.
2. **Orthoses:** Keep using the existing orthoses in the short-term as they improve frontal plane pelvis and hip joint motion.
3. **Flexibility:** Left glute stretching.
4. **Strength and Conditioning:** Key areas to target are: hip control, pelvic stability, glute strengthening (min, med and max).
5. **Neuromotor Control:** -
6. **Mobilisation:** -
7. **Gait Parameters:** Try to increase step width.

SUMMARY

Overall, lower-limb kinematics are good. However, the gait analysis revealed some areas for improvement that could be linked with the knee and glute pain that you are experiencing when you start running:- a low step width and asymmetry at the pelvis and hip in the frontal and transverse planes.

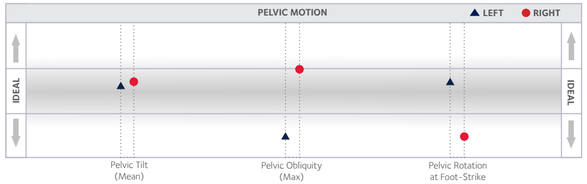
The asymmetry we see at the pelvis and hip will be addressed with a rehabilitation programme to improve functional single leg control and hip/pelvis stability. Ankle strength and control will be included later.

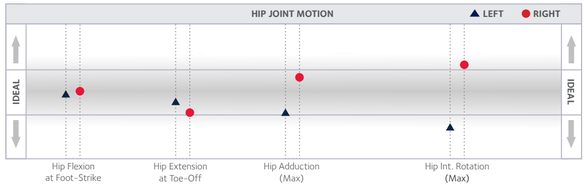
To address the narrow step width, try consciously running with your legs further apart. This will feel strange initially but will gradually start to feel more 'normal'. We could implement a gait retraining programme to address this if your pain worsens. Increasing step-width might also improve your pelvis and hip joint motion, but we did not test for this during this base-line assessment.

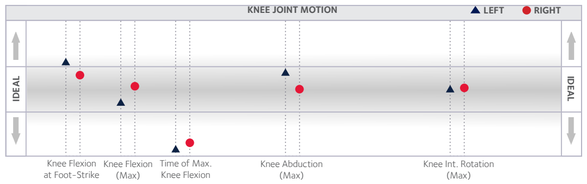
The orthoses had a positive effect on frontal plane pelvis and hip joint motion and I recommend continuing to use them until these areas have been strengthened through the targeted rehab programme described above. We can re-evaluate whether or not they are still required at a later date.

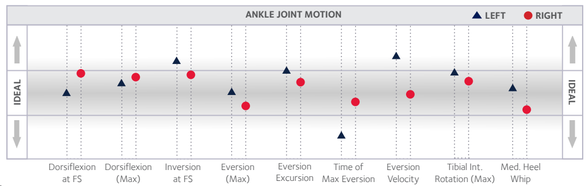
GAIT ANALYSIS KEY PARAMETERS

Trial Conditions: Running at 9 min/mile with neutral footwear on 13/02/2018 (initial)









GAIT ANALYSIS KEY PARAMETERS cont'd

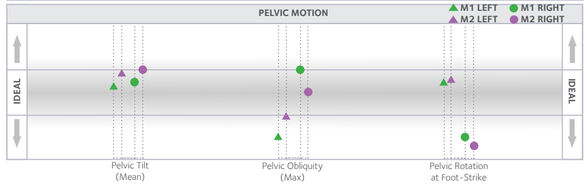
Trial Conditions: Running at 9 min/mile with neutral footwear on 13/02/2018 (initial)

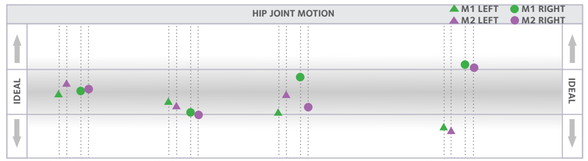
PARAMETER Units in Degrees Unless Specified Otherwise	YOUR RESULT (Mean (STD)) L | R		CONTROLS (Mean) L | R	
Pelvic Tilt (mean stance)	11.5 (1.2)	12.2 (1.4)	10.2	10.0
Pelvic Obliquity (max stance)	-3.0 (0.9)	7.3 (1.0)	3.4	5.3
Pelvic Rotation at Foot-Strike	-2.5 (1.9)	-14.5 (2.3)	-4.5	-3.7
Hip Flexion at Foot-Strike	32.8 (1.4)	34.2 (2.1)	33.4	33.7
Hip Extension at Toe-Off	-7.7 (1.8)	-2.6 (2.0)	-11.5	-11.1
Hip Adduction (max stance)	0.8 (1.1)	8.3 (1.2)	5.1	6.6
Hip Internal Rotation (max stance)	6.2 (2.3)	26.0 (1.9)	17.0	19.9
Knee Flexion at Foot-Strike	17.4 (2.1)	15.7 (2.0)	10.5	11.9
Knee Flexion (max stance)	38.9 (1.4)	43.0 (1.4)	41.9	42.3
Time of Max Knee Flexion (% gait)	12.4 (1.8)	12.6 (1.2)	17.4	17.0
Knee Abduction (max)	4.3 (1.0)	-0.7 (1.2)	0.4	-0.6
Knee Internal Rotation (max)	-7.8 (1.7)	-13.4 (1.4)	-7.7	-13.6
Dorsiflexion at Foot-Strike	3.8 (4.2)	12.7 (3.4)	3.5	5.0
Dorsiflexion (max stance)	22.6 (1.2)	22.7 (1.1)	21.4	20.8
Dorsiflexion at Toe-Off	-12.8 (2.1)	-14.1 (3.2)	-22.1	-21.3
Inversion at Foot-Strike	13.0 (4.8)	10.4 (2.9)	6.9	7.3
Eversion (max stance)	6.6 (1.7)	5.1 (1.7)	6.4	6.6
Time of max eversion (% gait)	8.1 (2.8)	12.6 (3.4)	16.0	14.1
Eversion Excursion	19.9 (5.0)	17.0 (3.1)	15.6	14.9
Eversion Velocity (degrees/second)	492.1 (77.6)	320.2 (96.9)	302.2	327.5
Tibial Internal Rotation (max)	-0.2 (0.1)	-0.3 (0.6)	-3.4	-1.9
Medial Heel-Whip	1.8 (7.0)	-6.2 (6.7)	0.1	-1.9
Static Vertical Off-Set Angle	20.0 (0.0)	20.3 (0.0)	10.5	9.5
Vertical excursion centre of mass (mm)	87.8 (5.9)	87.2 (6.5)	96.0	95.9
Time of toe-off (% gait)	35.6 (1.5)	37.2 (1.5)	41.5	41.0
Stance/Swing Ratio (%)	55.3 (3.7)	59.4 (3.8)	73.1	69.8
Foot Progression Angle	9.1 (4.9)	19.8 (4.1)	17.4	17.2
Over-Stride (mm)	40.9 (12.3)	75.8 (15.2)	103.9	103.2
Step-Width (mm)	62.22 (32.71)		95.46	
Cadence (Steps/Minute)	171.9		176.49	

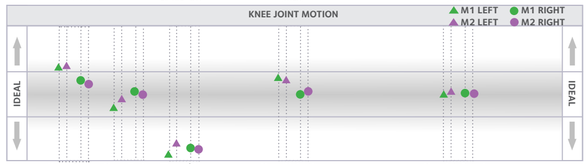
GAIT ANALYSIS COMPARISON

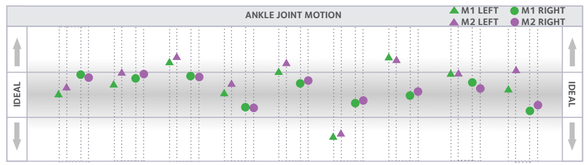
Trial Conditions Measurement 1: Running at 9 min/mile with neutral footwear on 13/02/2018 (initial)

Trial Conditions Measurement 2: Running at 9 min/mile with neutral footwear with orthotics on 13/02/2018 (initial)





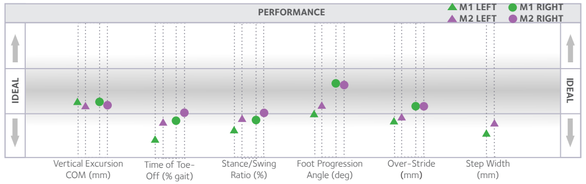




GAIT ANALYSIS COMPARISON cont'd

Trial Conditions Measurement 1: Running at 9 min/mile with neutral footwear on 13/02/2018 (initial)

Trial Conditions Measurement 2: Running at 9 min/mile with neutral footwear with orthotics on 13/02/2018 (initial)



PARAMETER Units in Degrees Unless Specified Otherwise	M1 (Mean (STD)) L | R		M2 (Mean (STD)) L | R	
Pelvic Tilt (mean stance)	11.48 (1.16)	12.24 (1.39)	14.6 (1.01)	15.31 (0.88)
Pelvic Obliquity (max stance)	-2.98 (0.89)	7.28 (0.97)	0.13 (0.97)	5.22 (1.14)
Pelvic Rotation at Foot-Strike	-2.5 (1.86)	-14.53	-1.93 (2.52)	-16.78
Hip Flexion at Foot-Strike	32.76 (1.39)	34.23 (2.15)	37.44 (1.65)	35.12 (1.52)
Hip Extension at Toe-Off	-7.74 (1.79)	-2.57 (2.04)	-5.9 (1.56)	-1.5 (1.67)
Hip Adduction (max stance)	0.81 (1.1)	8.29 (1.18)	4.65 (1.5)	4.96 (1.09)
Hip Internal Rotation (max stance)	6.21 (2.33)	25.95 (1.85)	4.94 (1.9)	25.21 (1.43)
Knee Flexion at Foot-Strike	17.36 (2.09)	15.72 (2.04)	17.75 (2.61)	14.65 (1.78)
Knee Flexion (max stance)	38.93 (1.37)	43.05 (1.37)	40.85 (1.4)	41.98 (1.32)
Time of Max Knee Flexion (% gait)	12.43 (1.79)	12.59 (1.21)	13.4 (2.07)	12.47 (1.44)
Knee Abduction (max)	4.3 (0.97)	-0.71 (1.19)	3.76 (0.84)	-0.11 (2.2)
Knee Internal Rotation (max)	-7.75 (1.73)	-13.43	-6.87 (1.72)	-13.57
Dorsiflexion at Foot-Strike	3.79 (4.2)	12.69 (3.45)	6.45 (4.69)	11.54 (3.76)
Dorsiflexion (max stance)	22.57 (1.15)	22.69 (1.15)	23.84 (1.12)	23.2 (0.99)
Dorsiflexion at Toe-Off	-12.75	-14.09	-14.5 (1.71)	-16.53
Inversion at Foot-Strike	13.04 (4.78)	10.42 (2.93)	14.09 (3.89)	10.26 (2.31)
Eversion (max stance)	6.58 (1.71)	5.11 (1.75)	7.53 (2.03)	5.03 (1.57)
Time of max eversion (% gait)	8.06 (2.8)	12.63 (3.38)	8.73 (2.23)	13.05 (3.45)
Eversion Excursion	19.86 (4.95)	16.96 (3.07)	21.63 (4.88)	17.5 (2.34)
Eversion Velocity (degrees/second)	492.11	320.19	477.67	341.98
Medial Heel-Whip	1.8 (7.0)	-6.22 (6.66)	7.98 (5.09)	-4.72 (5.4)
Tibial Internal Rotation (max)	-0.21 (0.12)	-0.26 (0.58)	-0.17 (0.1)	-1.1 (1.15)
Static Vertical Off-Set Angle	20.04 (0.0)	20.25 (0.0)	18.44 (0.0)	20.19 (0.0)
Vertical excursion centre of mass (mm)	87.84 (5.86)	87.19 (6.46)	84.62 (5.62)	84.59 (6.37)
Time of toe-off (% gait)	35.56 (1.52)	37.23 (1.48)	37.81 (1.57)	38.33 (1.12)
Stance/Swing Ratio (%)	55.27 (3.73)	59.39 (3.77)	60.9 (4.06)	62.2 (2.94)
Foot Progression Angle	9.14 (4.87)	19.8 (4.09)	12.22 (4.99)	19.22 (3.96)
Over-Stride (mm)	40.9 (12.3)	75.8 (15.2)	50.2 (15.3)	75.6 (10.2)
Step-Width (mm)	62.22 (32.71)		70.79 (25.59)	
Cadence (Steps/Minute)	171.9		172.38	

CASE STUDY 6: MALE WITH LOW-BACK PAIN AFTER 3KM RUNNING

BACKGROUND AND HISTORY

Male, aged 56 at time of analysis. Patient presented to clinic complaining of low-back pain after running any distance more than 3km. His goal now is to run 5km, he has run half-marathons in the past.

L3/L4 discectomy in January 2018.

He had been advised by his Physio to have a gait analysis to assess whether his gait was the cause of pain during running. Other than that he was self-managing the pain with home exercises including pilates and yoga.

INITIAL 3D GAIT ANALYSIS MAIN OBSERVATIONS

- **Power Generation:** High anterior pelvic tilt, resulting in low hip-extension at toe-off and high hip flexion at foot-strike. Low knee flexion at foot-strike (landing with a straight knee) and reduced peak dorsiflexion bilaterally.
- **Control:** Asymmetry in frontal plane pelvis with more movement on the right and notable stiffness on left. Pattern is transferred to frontal plane hip. Pelvis and hip rotations (transverse plane) good. Notable asymmetry in tibial internal rotation and heel-whip (left high, right low).
- **Ankle:** Difference in foot-strike pattern, with tendency towards mid-foot strike on right and heel-strike on left. Reduced peak dorsiflexion bilaterally. High inversion at foot-strike bilaterally (right more than left, in keeping with difference in DF at FS). Low peak eversion.
- **Gait Parameters:** Some asymmetry in stance/swing time, increased on left compared to right, in keeping with increased DF at FS on left. Vertical excursion and cadence good. Wide step width. Asymmetry in foot-progression angle (more toe-out on left) ties-in with increased tibial internal rotation and heel-whip on left compared to right.

OPINION

The patient is holding a position of high anterior pelvic tilt and forward lean for prolonged periods during running, which increases loading on the lumbar spine. Furthermore, the hip extensor muscles are less effective in this position and the lumbar spine, hamstrings and calves are used for propulsion instead, thereby increasing loading in these areas. The fact that the low-back pain occurs after 3 km of running further suggests that it is being caused by musculoskeletal overload and that reducing load at the lumbar spine during running will be of benefit.

During the assessment, we attempted some gait retraining to 'tuck the bottom under' and 'run taller' to try and improve the position of the pelvis. A mild improvement in pelvic position was observed, resulting in a small increase in hip extension.

Rehabilitation will also address the frontal plane asymmetry at the pelvis and hip.

Both feet are relatively stiff, landing in high inversion at foot-strike and exhibiting reduced peak eversion. Interestingly, inversion at foot-strike reduced (improved) during our gait retraining to reduce anterior pelvic tilt.

RECOMMENDATIONS

1. **Footwear:** Neutral shoe recommended.
2. **Orthoses:** Not recommended.
3. **Flexibility:** Not tested.
4. **Strength and Conditioning:** Based on these gait results and some strength testing during your assessment, key areas to target are: single leg strength and control.
5. **Neuromotor Control:** Single leg control, upper limb/trunk position.
6. **Mobilisation:** Not tested
7. **Gait Retraining:** Try to 'run tall' and 'tuck pelvis under'.

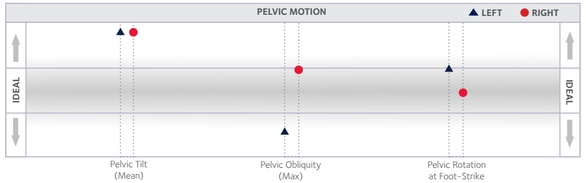
SUMMARY AND PLAN

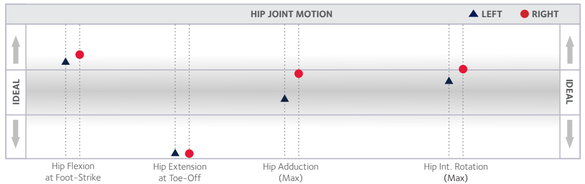
The results indicate that your anteriorly tilted pelvis position and forward trunk lean during running are leading to increased loading of the lumbar spine and subsequent pain. I recommend focussing on running taller and tucking your pelvis under, as we tried during your assessment. This will enable your glutes to function to extend your hip, thereby off loading the lumbar spine, calves and ankles. As discussed during your assessment, do this in conjunction with the exercises summarised below:

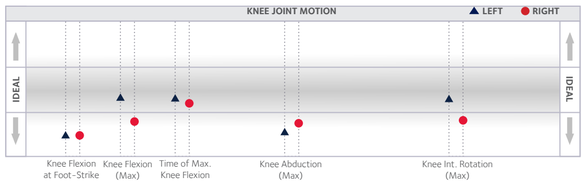
1. Pelvic tilts lying, sitting and standing.
2. Focus on tilting pelvis under when walking and running slowly.
3. Posture - try and keep your trunk straight when doing any exercise or movement.
4. Single-leg knee bends keeping knee over toes, hips level and trunk upright.
5. Hip abduction at a 45 degree angle with a theraband (3 x 15 daily).

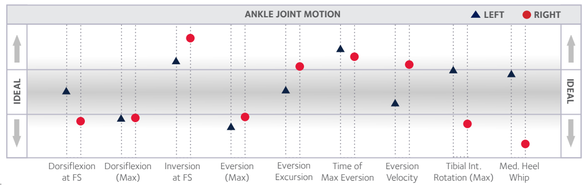
GAIT ANALYSIS KEY PARAMETERS

Trial Conditions: Running at 10 min/mile with neutral footwear on 11/09/2018 (initial)



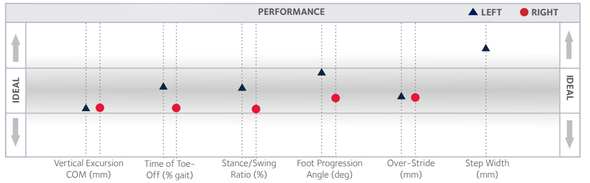






GAIT ANALYSIS KEY PARAMETERS cont'd

Trial Conditions: Running at 10 min/mile with neutral footwear on 11/09/2018 (initial)



PARAMETER Units in Degrees Unless Specified Otherwise	YOUR RESULT (Mean (STD)) L | R		CONTROLS (Mean) L | R	
Pelvic Tilt (mean stance)	19.0 (0.6)	19.2 (0.5)	4.2	4.2
Pelvic Obliquity (max stance)	-1.8 (0.4)	7.5 (0.6)	4.0	5.0
Pelvic Rotation at Foot-Strike	2.2 (1.2)	-2.7 (1.1)	-1.3	-2.4
Hip Flexion at Foot-Strike	34.3 (0.7)	36.8 (0.7)	24.4	24.5
Hip Extension at Toe-Off	6.8 (1.1)	9.0 (1.2)	-15.6	-14.3
Hip Adduction (max stance)	5.4 (0.6)	10.7 (0.7)	6.6	7.9
Hip Internal Rotation (max stance)	16.4 (1.3)	24.8 (1.5)	14.3	19.4
Knee Flexion at Foot-Strike	-2.3 (1.1)	-0.2 (1.2)	10.6	11.7
Knee Flexion (max stance)	36.1 (1.0)	31.3 (1.2)	37.6	38.2
Time of Max Knee Flexion (% gait)	17.6 (0.7)	16.7 (1.0)	18.3	18.2
Knee Abduction (max)	-6.8 (0.5)	-6.6 (1.4)	-0.1	-0.5
Knee Internal Rotation (max)	-14.0 (0.8)	-27.6 (1.5)	-11.8	-18.2
Dorsiflexion at Foot-Strike	5.1 (1.5)	-1.5 (2.0)	4.7	5.6
Dorsiflexion (max stance)	16.8 (0.9)	16.5 (1.4)	20.4	20.4
Dorsiflexion at Toe-Off	-24.0 (1.8)	-18.6 (1.9)	-18.3	-17.8
Inversion at Foot-Strike	13.6 (1.4)	15.1 (1.0)	8.9	8.1
Eversion (max stance)	1.4 (0.8)	3.4 (0.7)	5.8	6.5
Time of max eversion (% gait)	21.2 (2.4)	19.8 (3.1)	13.4	13.5
Eversion Excursion	16.1 (1.7)	19.2 (1.2)	15.8	15.7
Eversion Velocity (degrees/second)	319.0 (64.6)	463.8 (50.5)	361.2	355.1
Tibial Internal Rotation (max)	-0.2 (0.1)	-8.9 (1.5)	-3.4	-3.9
Medial Heel-Whip	-1.7 (3.8)	-15.1 (3.3)	-5.0	-5.2
Static Vertical Off-Set Angle	20.0 (0.0)	18.2 (0.0)	11.9	11.5
Vertical excursion centre of mass (mm)	86.6 (3.9)	86.4 (3.9)	100.9	100.9
Time of toe-off (% gait)	44.7 (1.0)	41.2 (1.0)	44.2	44.1
Stance/Swing Ratio (%)	81.0 (3.3)	70.1 (3.0)	79.7	79.6
Foot Progression Angle	20.8 (1.6)	11.7 (2.1)	14.7	14.3
Over-Stride (mm)	61.8 (10.5)	54.5 (9.1)	70.8	66.4
Step-Width (mm)	163.55 (16.4)		100.32	
Cadence (Steps/Minute)	173.69		166.76	