Muscle Shape Change During Contraction

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The timing of muscle shortening during locomotion is key in achieving optimum muscle function. During contraction of a muscle there is a complex interaction between the contractile component of the muscle and elastic elements of the muscle-tendon complex (MTC). The relative length change of each of these elements determines the force applied to the limbs, external bodies (e.g. the ground) and the subsequent motion of the limbs. However, the interaction of these elements is very complex and understanding how and why a muscle contracts the way it does is critical in understanding both human and animal movement.

We would like to know exactly how a muscle and its attached elastic elements interact to produce optimal power output and optimal efficiency. For instance, during human running, the *triceps surae* muscle group interacts with the Achilles tendon whereby up 35% of the energy used to stretch the Achilles tendon is returned due to elastic recoil where it is seen in the production of force for plantar flexion (Alexander, 2003). Therefore studying the interaction between the muscle contractile component and the elastic elements helps us to understand how we can make the movement more efficient and also how we can produce more or less force.

Studying the behaviour of muscles during movement however is inherently difficult. Sonomicrometry and ultrasound imaging are both used to determine fibre length *in vivo*, but they only give data for a slice of the muscle rather than the muscle as a whole (Tobalske *et al*, 2003, Kawakami *et al*, 2002). Maintaining probe contact and field of view

with ultrasound is also difficult during dynamic movements such as running (Kawakami *et al*, 2002). Therefore we sought another technique to study this interaction.

Muscles have constant volume; therefore cross sectional area (CSA) is inversely proportional to their length. Measurement of muscle cross sectional area could therefore be used to determine when a muscle shortens. Here we examined the *triceps surae* muscle group of subjects during a range of equivalent isometric and isokinetic contractions.

Initially, measurements of CSA were measured with CODA motion analysis, 3D ultrasound and magnetic resonance imaging (MRI) during isometric contractions of various intensities (**Figure 1**). Measurement of the cross-sectional area was done at three levels along the muscle group and it was found that the CODA motion analysis technique was sensitive to the changes in muscle CSA as a result of contraction.

Early results indicate that this technique measures equivalent CSA changes to those measured by MRI and freehand 3D ultrasound. Motion analysis of the shape changes of the same muscle group during isokinetic contractions (constant velocity) was then performed using an isokinetic dynamometer (Biodex Medical Systems), again with three rings of markers placed around the muscle group of interest.

Using this technique along with ultrasonic imaging of the muscle fibre lengths and orientations it is possible to derive a relationship between the shape changes of the muscle, the length change of muscle fibres and the length change of the associated elastic structures (i.e. tendon and aponeurosis). Custom software has been written with Matlab (Mathworks Inc.) to do both the motion analysis data calculations and the

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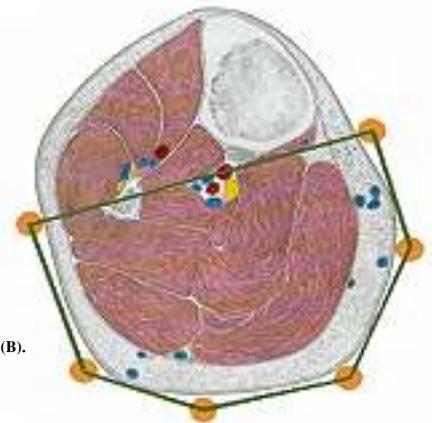
1(B).

1(C).

Figure 1: A. Setup for measurement of triceps surae muscle CSA with CODA motion analysis and synchronous ultrasonography of the muscle. **B.** Diagram of marker placement for motion analysis (adapted from Gray's Anatomy 37th Ed, Churchill Livingstone, London, 1989). **C.** MRI image of muscle CSA during contraction

ultrasound image analysis. Consistent CSA changes of this muscle group were found with isokinetic contractions, and these measurements corresponded to an equivalent active length change (**Figure 2**).

Each level of the muscle CSA that was recorded had a unique relationship to muscle length. The results found are subject-specific and therefore individual relationships between muscle CSA and active length changes must be calibrated for individuals before an assumption about length change can be made from CSA changes in the muscle.

It is hoped that this technique can be used to monitor CSA changes during a dynamic activity such as running so as to make inference into how the muscle is functioning during this activity. Knowledge of a muscle's length change and activity during movements such as running can allow us to predict the power output and potentially the energetic costs of muscles and how this may change with variables such as speed.
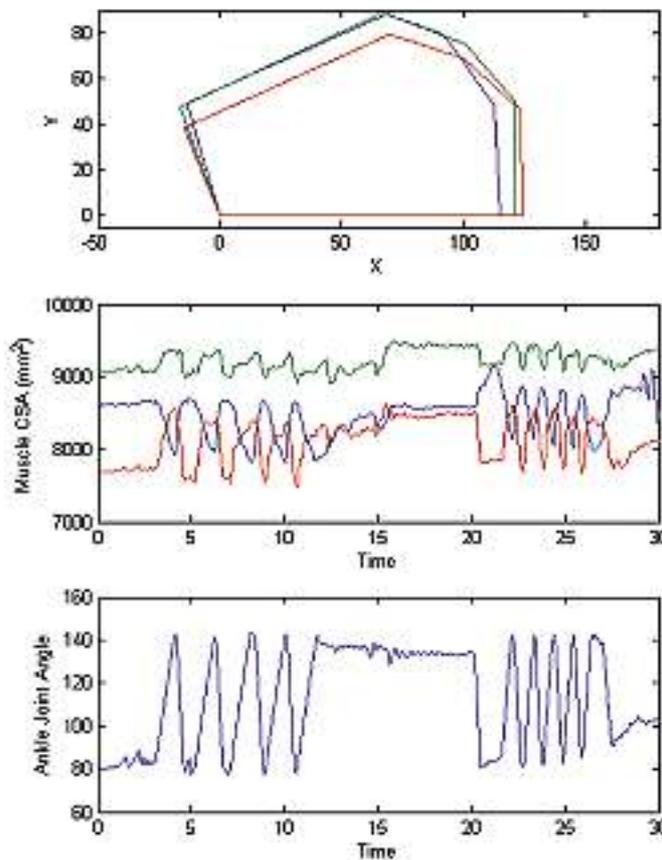
Figure 2:

2(A). Representation of 3 rings of markers (Ring 1 = blue, Ring 2 = green, Ring 3 = red) in X-Y space, embedded along the axis of two markers from each ring.

2(B). Measured muscle CSA in time for each ring (Ring 1 = blue, Ring 2 = green, Ring 3 = red) as two series of 4 plantar flexion movements are performed isokinetically (constant velocity) in time.

2C. Ankle joint angle in time corresponding to the changes in muscle CSA in figure 2B.

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Improving the eye movements of cerebellar patients improves their walking: studies combining eye tracking (ASL) and gait analysis (CODA)

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Dilwyn Marple-Horvat: "A cerebellar patient looks more accurately where he intends to step next (shown by black gaze crosshairs) after practising moving his eyes. He also steps more often on target (shadow of foot can be seen approaching the small lit square on the floor). Four steps in sequence are shown." (See images opposite)

Most walking is to some extent guided by vision; walking along a busy street, or crossing a room with children's toys left on the floor are everyday examples. In these situations, the way we move our eyes to look around is crucial.

If our eye movements are good, we perform well; if bad, our actions are badly affected. This is because the parts of the brain that enable us to walk interact with, and to some extend depend on, the parts of the brain that control our eye movements.

Cerebellar patients sometimes make bad eye movements, and when they do, their walking suffers. We reasoned that one way to help them with mobility would therefore be to help them make better eye movements, by practice or rehearsal.

Eighteen patients with ataxic gait were studied to test firstly whether eye movement rehearsal can lead to improved eye movements, and secondly whether any such improvement does indeed lead to better visually guided stepping.

We asked patients (with ethics committee approval and informed written consent) to walk along a pathway of 18 irregularly placed 'stepping stones' or footfall targets.

Five control walks (before rehearsal) were followed by a first batch of eye movement rehearsal during which subjects stood still at the start of the walkway and rehearsed by looking in sequence at the first 6 targets for stepping. They rehearsed the sequence 5 times without interruption, then made 3 test walks (after 1st rehearsal).

A second batch of eye movement rehearsal followed, and finally a further 3 test walks (after 2nd rehearsal). Eye movements and gaze were recorded (using an ASL head mounted eye tracker) together with a signal indicating successful foot contact with a target, and kinematic data provided by a CODA mpx30 system for full gait analysis.

Walking was compared before and after eye movement rehearsal. Rate of progression, step phase durations, proportion of successful steps onto targets and stepping accuracy were calculated.
The proportions of accurate saccades to footfall targets (rather than hypometric and additional corrective saccades) were also calculated before and after rehearsal.

Almost everyone's eye movements improved after rehearsal (17/18). They made good, accurate eye movements more often, and
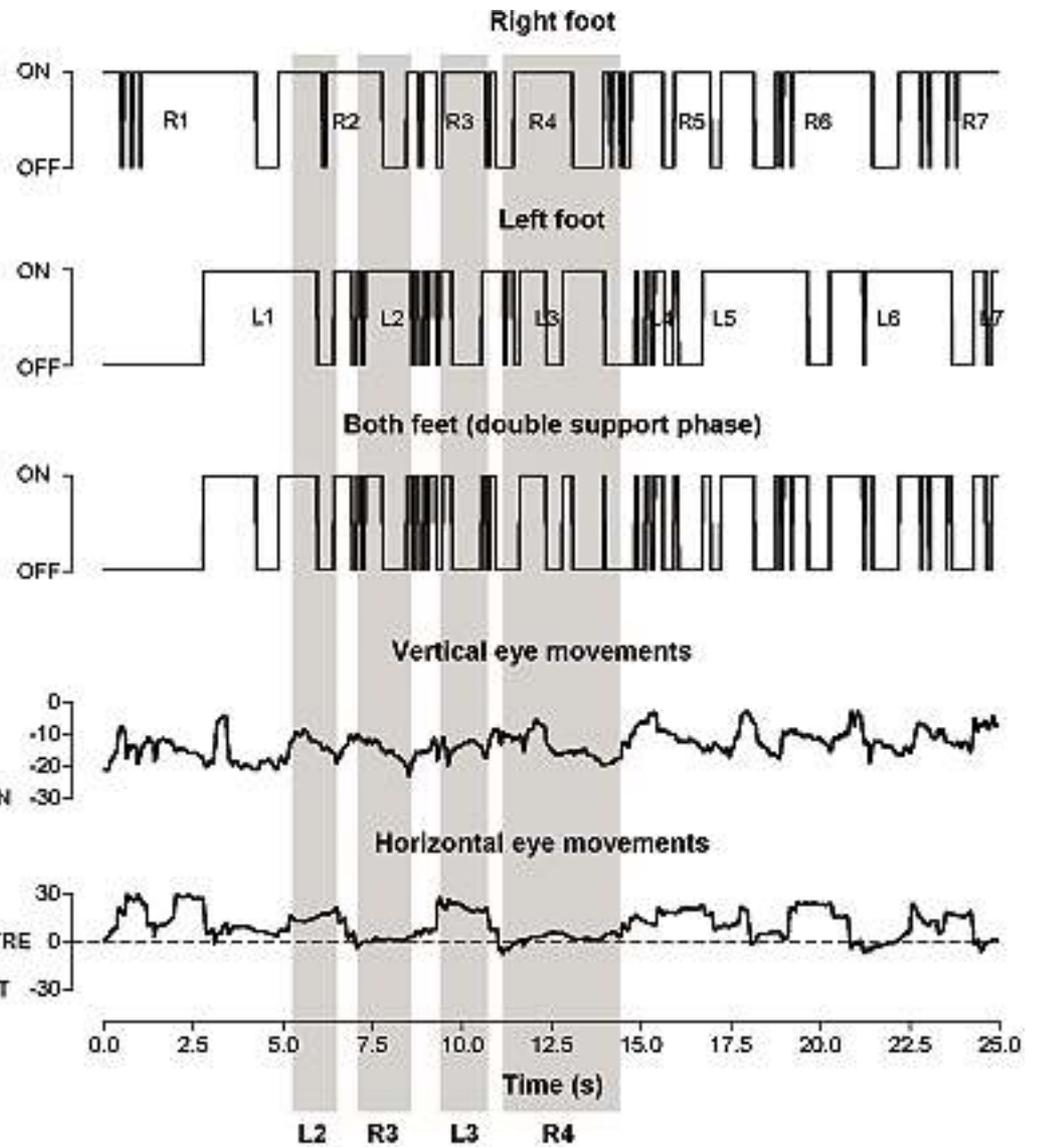
fewer bad (too small) eye movements. Some patients' eye movements ended up as good as those of a healthy individual.

Most patients also walked better (14/18). Walking improved in several ways. Half the patients (9/18) were able to walk more quickly. Most improved the regularity of their walking; their walking rhythm improved, and they staggered less (14/18). More than half (10/18) managed to step more often where they wanted to (on the stepping stones) – there were fewer misses.

This is a technique that improves the way patients move their eyes, and demonstrates that this improves their mobility – specifically

their ability to use what they can see to step where they want to.

The technique is free – involves no drugs or surgery – and takes just a few minutes to yield significant improvement. The work was funded by Action Medical Research.
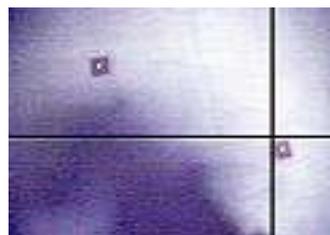
For further information, see
1. Crowdy KA, Hollands MA, Ferguson IT, Marple-Horvat DE (2000) Experimental Brain Research 135:
437-454.
2. Crowdy KA, Kaur-Mann D, Cooper HL, Mansfield AG, Offord JL, Marple-Horvat DE (2002) Experimental Brain Research 146:
244-247.

L2   R3   L3   R4

Hip force direction during running and walking

R. Delaney and R. Woledge
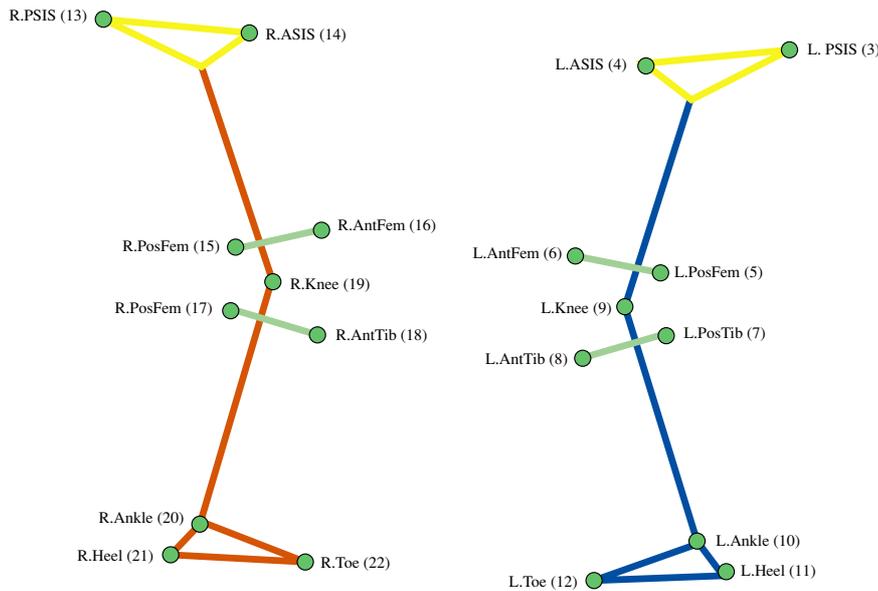UCL Institute of Human Performance, RNOHT Stanmore.

Diagram 2: Model used to calculate the internal forces acting through the hip joint to the pelvis.

Diagram 1: CODA marker placement used to collect data for walking and running.

Running is a complex activity that requires the body to accommodate high forces to be transmitted through the joints of the lower limb. The magnitudes of these forces during the running and walking gait cycles are well documented. However, the actual direction of the forces with respect to the pelvis, to our knowledge, has not been documented.

This pilot study looks at the direction of the forces acting through the hip during the walking and running cycles and compares these directions. Provisional results suggest that here is a difference in the direction of the force vectors between the two cycles. There appears to be an anteriorly placed area in the hip joint, through which forces are transmitted during walking and not when running.

CODA mpx30 motion analysis was used to collect bilateral gait data using the standard gait marker placements. Each subject was then instructed to walk or run along a 12m pathway that had two force-plates embedded half way along. Data was analysed off line. External force throughout the hip joint was calculated from the vertical and anterior-posterior force data, as measured on the force-plate by subtracting for each of the three segments the product of the segments mass and its acceleration (including gravitational acceleration). Internal force (that is the force due to muscles acting across the hip joint) was calculated by modelling the rectus femoris and hamstring muscles around the hip at an angle of 15º to the thigh segment.

These muscles were used, as they are the principal muscles involved in the sagittal plane movement around the hip during the gait cycles. The hip movements obtained from the gait analysis program were then used to calculate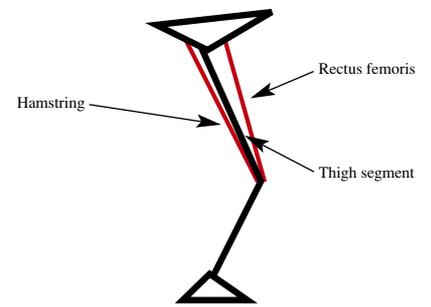 the magnitude and direction of the muscle forces acting through the hip on the pelvis. The vectors in the sagittal plane representing these external and internal forces were added and then transformed into the frame of reference provided by the pelvis model from the gait analysis.

Data from eight legs has been collected and analysed. All subjects have been heel strikers during the walking and running cycles. The graphs comparing the direction of force through the hip when walking and running have shown an area anterior to the hip joint that does not have forces transmitted through it during running but does when walking. This has been the case for each subject. The range of movement occuring at the hip during running is known to be greater than that during walking. These results suggest that it is not simply the range of movement at the hip that affects the force at the hip joint but also the position of the pelvis.

The idea for this experiment came from a clinical observation. Patients often describe pain in the hip when walking but not running. These results suggest a possible explanation for this observation. If this pattern of pain is described to the clinician during consultation, further investigations can then be anatomically focused to the anterior aspect of the hip joint.
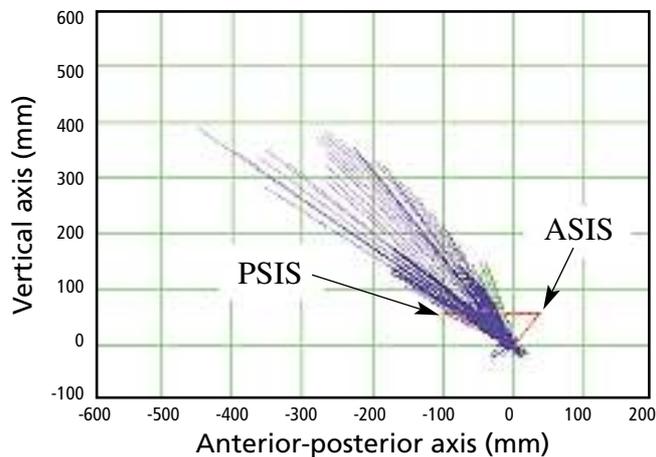
Walking data
Running Data

Diagram 3: Sagittal view of the data from one subject demonstrating the area anterior to the hip joint that has force transmitted through it during walking (green lines) but not during running (blue lines). In this diagram each line represents a force vector at a particular point in the gait cycle. The red lines are the pelvis model.

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