Motion Times
Journal for the motion-capture community
Issue 1 - 06

# Successful foot-eye coordination depends on fast reactions and watching your step.

1. Reynolds,R.F. and Day,B.L., Rapid visuo-motor processes drive the leg regardless of balance constraints, Curr. Biol., 15 (2005) R48-R49.
2. Reynolds,R.F. and Day,B.L., Visual guidance of the human foot during a step, J. Physiol, 569 (2005) 677-684.

As we walk along the high street our gaze may be directed toward any number of objects, such as a desirable pair of shoes in a shop window, the retreating bus which we have just missed, or our destination further down the road. Looking down at the floor immediately in front of us may be the last thing on our mind. Indeed, if the environment around us is predictable, then normal walking may be possible without any visual input from our surroundings. However, our environment is rarely entirely predictable. Other pedestrians, un-noticed obstacles and the neighbours' cat running out in front of us may all require sudden alterations in our step. Furthermore, our environment sometimes places tight constraints on foot placement, for example when we must avoid the edge of the kerb. All these situations require us to suddenly divert attention toward the area of our next foot-fall in order to maintain our balance. In two recently published studies, we have examined the ways in which vision can be used to guide the stepping foot in such situations[1,2].

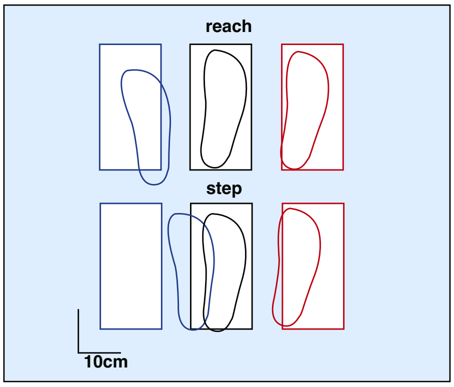


**Figure 1. Foot Replacement**
Six subjects were asked to reach or step toward jumping rectangular targets. Foot trajectories were sampled at 200Hz using 3 Codamotion mpx30 cameras. Infra-red lights were attached to the big toe and heel. The footprint was chalk-marked and digitised at the start of the experiment. The footprint could therefore be reconstructed wherever the subject placed his/her foot, given the coordinates of the two lights.

The first of these studies was inspired by findings from reaching experiments [1]. When we reach for an object which suddenly moves, we can adjust our arm trajectory to follow the object within a very short latency, around 120ms. This reaction is initiated even before we are aware of the movement, and may depend upon primitive neural pathways below the level of the cerebral cortex. We asked if the same fast tracking mechanism is available for the lower limb. Six subjects were asked to reach with their foot toward a floor-mounted target. To make our experiment analogous to the upper-limb studies, we removed the balance constraints normally present during a step by supporting the subject's body weight with hand rails. This allowed the leg to move freely without fear of falling. In 1/3rd of trials the target jumped unpredictably to the left or right by 21cm, just after the foot left the floor. The subject's task was to attempt to follow the target and place the foot upon it. They were generally successful in this task, as shown by average foot placement (see figure 1, reach condition). Furthermore, the earliest detectable deviation of the foot occurred within 121ms after the target jump (figure 2). The speed of this response clearly demonstrates that the fast visual guidance mechanism previously observed in the hand also exists for the foot. However, we wondered if this mechanism, which drags the swinging foot toward a moving visual target, could be potentially destabilising during upright stance. If this were the case, perhaps this automatic tracking mechanism would be suppressed during unsupported stance. To answer this, we repeated the experiment when subjects stepped normally, without the use of hand-rails. This placed constraints on the maximum extent to which the foot could be adjusted, particularly when the target jumped medially (see figure 1, step condition). Surprisingly, however, there was no change in the latency of the response (see figure 2) and yet no subject lost balance. This means that the leg reacts to visual input extremely quickly, regardless of balance constraints. Such fast reactions would be useful in situations where we have to suddenly change foot placement without endangering balance as a result of our own action. So when the neighbours' cat suddenly runs across our path, we can avoid it and still ensure that the foot lands in a suitable place to catch the falling body. Our findings also explain why a soccer player is capable of intercepting a fast moving ball without falling over.

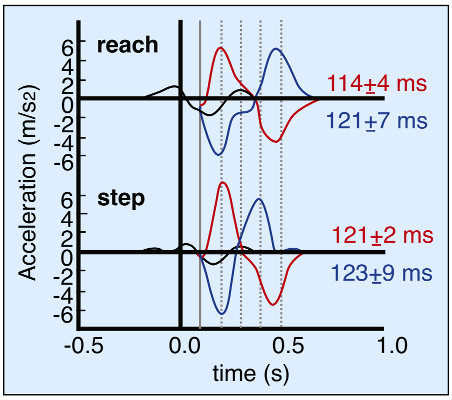


**Figure 2. Foot kinematics.**
Displacement of the toe marker was differentiated twice to derive acceleration. Red trials show lateral target jumps, blue shows medial jumps and control trials are shown in black. Estimates are given of the earliest point of deviation from control trials.

So, visual information can be used to quickly change foot placement when a planned step suddenly requires alteration due to an external event. But what about when accurate foot placement is required within an entirely static environment? One such example is a long-jumper approaching the take-off board. Video analysis of long-jumpers has shown that stride length adjustments are initiated up to four footsteps away from the take-off board. The same observation has been made for walking toward stationary targets, showing that we can use vision during locomotion to alter foot placement many steps in advance. But research suggests that for any given step, the path of the foot is pre-planned and therefore fixed once it has left the floor, with vision playing no further influence within the swing phase. To see if this really was the case, we used LCD spectacles to block vision during the swing phase of a step [2]. This intervention caused a reduction in foot-placement accuracy, compared with steps where vision was present (see figure 3). This occurred even for fast stepping, where there is less time to react. This shows that when available, vision enables subtle trajectory corrections which bring the foot closer to its target. To determine when and where these corrections were taking place we analysed individual trajectories. We derived a measure of the foot's heading as it swung through the air, by calculating the angle of its velocity vector with respect to the target position. When vision was available, heading improved as the foot came within ~8cm & 200ms of the target (see figure 4). Again, these results show that the stepping foot behaves in a similar way to the reaching hand. Both involve an initial ballistic phase to bring the limb within the vicinity of the target, followed by a visually guided honing-in phase, once it is close. These studies reveal two distinct mechanisms of foot-eye coordination. Both use vision to ensure fast and accurate control of foot placement, thus maintaining balance. They may also be utilised together, within the same step. Whilst most of the time we may be able to walk perfectly well with minimal use of vision, our results shed light on the mechanisms which maintain balance in those precarious situations which force us to pay attention to what our feet are doing.

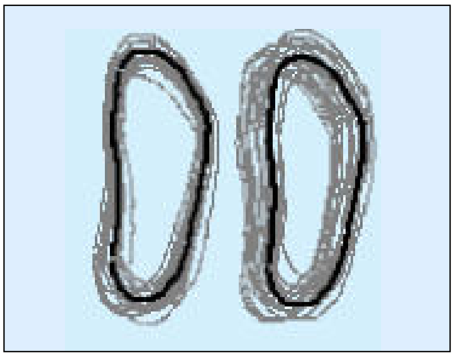

**Figure 3. Effect of visual occlusion.**
Foot placement is shown for each step for a representative subject. Target position is shown by the thick black line. In the left figure vision is always available. The right figure shows the result of occluding vision after the foot leaves the floor.

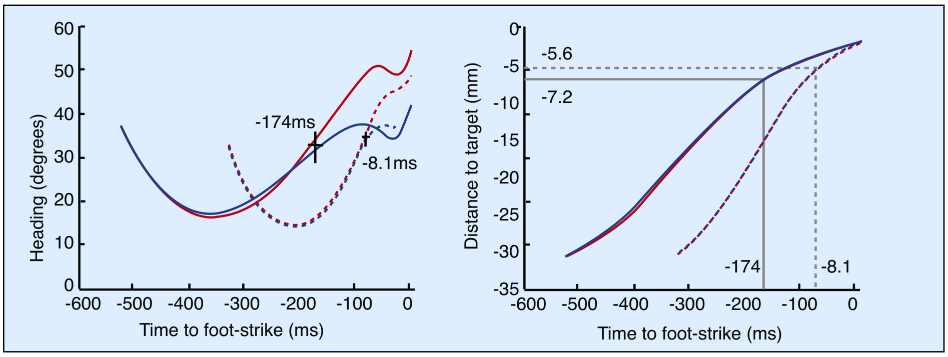


**Figure 4. Heading of the foot towards the target**
The top graph shows heading of the foot during the swing phase of a step. Dashed and solid lines show fast and slow steps, respectively. Trials with visual occlusion are depicted in red. The time points at which vision-on and vision-off trials separate are shown.
The lower graph shows the same data, but with distance of the foot trajectory plotted against time. The spatial points equivalent to the time points in the upper graph are shown.

# Motion Analysis of functional upper limb movements following a stroke

Dr. Jackie Hammerton MCSP PhD Research Fellow Sheffield Hallam University
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The SMART rehabilitation project is investigating the use of accelerometer and gyroscopic technology in the home to augment upper limb therapy following stroke. Funded by the EPSRC the project combines the expertise of researchers from Sheffield Hallam University, University of Bath, University of Ulster and University of Essex.

Stroke is the largest single cause of disability in England and Wales, creating a huge burden to health care. More than 10,000 people experience a first stroke each year of which 69% will have upper limb involvement. The arm is important for both function and balance in everyday living, making it an important focus for rehabilitation. However the rehabilitation of upper limb movement is frequently neglected in the acute stages of treatment as earlier hospital discharge necessitates concentration on transfers and walking. As rehabilitation of the stroke arm often commences once the person is discharged the development of technology that may be used within the home to augment upper limb motion was chosen as the focus of the SMART study.

Researchers from Sheffield and Bath have been working closely with Charnwood Dynamics UK, to study the upper limb movement patterns of people who have had a stroke in order to identify appropriate outcome measures for the technological intervention. Motion analysis of gait is frequently used in physiotherapy, with a well established marker protocol and normative kinematic data being published. In contrast, protocols previously used to investigate the motion analysis of the upper limb have been inconsistent and normative data has not been well documented. Whilst some research had been published on upper limb movement, studies used a variety of marker protocols to record their kinematic information, furthermore subjects in these studies were generally not in the age range of most stroke sufferers so the data was inappropriate for comparison with stroke data. More importantly the damaged CNS following stroke can cause a variety of motor abnormalities which may not be recognised by existing protocols or may result in considerable marker occlusion, which limits the extent to which a full kinematic analysis of upper limb motions can be obtained.

The following research objectives were established:-

- Develop an upper limb marker protocol appropriate to the needs of the stroke user,
- Collect and analyse upper limb kinematic data for reaching post stroke,
- Collect and analyse age matched normative data for comparison.

Data were collected from a single CODA cx1 at Sheffield Hallam University and initially several upper limb protocols were developed and trialled using staff volunteers. Clinical expertise was used to predict key areas of possible movement abnormalities which subsequently resulted in the addition of the trunk into the marker set. Other body segments included were the shoulder girdle, upper arm, lower arm and hand.

During the pilot testing, limited visibility of a number of markers located on the upper limb was identified as a problem with a single scanner and occlusion during "normal" movement was resolved using wands. It was noted that scapula movement within the shoulder girdle complex could not be isolated from skin movement and was therefore not analysed separately from the gleno-humeral movement. Additionally analysis of independent head and pelvic movements that were separate from the trunk would require a considerable increase in markers. This was thought to be unacceptable to users and therefore the head and pelvis were treated as a rigid body.

The final protocol consisted of 13 markers, the details of which are shown in table 1.

| Marker number | Marker position |
|---|---|
| **1** | 3rd cervical vertebra |
| **2** | 7th cervical vertebra |
| **3** | Wand over 12th thoracic vertebra |
| **4** | Acromian process |
| **5** | Proximal end of upper arm wand |
| **6** | Distal end of upper arm wand |
| **7** | Lateral epicondyle of humerus |
| **8** | Proximal end of forearm wand |
| **9** | Distal end of forearm wand |
| **10** | Radial styloid |
| **11** | Ulna styloid |
| **12** | 3rd metacarpal |
| **13** | 5th metacarpal |

Normative data of range of movement and cycle time were collected from 8 healthy older adults and stroke data from 5 volunteers. To reduce the potential for occlusion static full visibility of all markers was collected for 5 seconds before reaching commenced. Data were collected over a maximum of a 30 second period, with individuals seated on a single plinth reaching to a cone placed at arms length on a small table. Kinematic variables of range of movement and cycle time were analysed using custom analysis routines developed by Charnwood Dynamics UK.

The marker protocol was found to be easy to apply to the stroke patients, requiring approximately 30 minutes to configure. Range of movement for flexion, extension, abduction, adduction and rotation at all upper limb joints and segments was examined. Data were successfully collected and analysed from both stroke and age matched healthy individuals. Significant differences in movement kinematics were found between the two groups, indicating that the protocol is sensitive to abnormalities in movement following stroke. It would therefore appear that motion analysis of functional upper limb movement following stroke may be able to identify key kinematic abnormalities to guide therapeutic input. In addition it is possible that these same variables may be of use in measuring the outcome of that therapy.

It is planned to collect a more extensive database of the upper limb kinematic parameters for stroke and healthy age matched individuals in order to validate these initial findings. Further review of the protocol may enable reduction of the number of markers without losing clinically important data, which could be an advantage in the clinical setting given the time constraints of NHS staff.

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Dr. Jackie Hammerton MCSP PhD Research Fellow Sheffield Hallam University

*Dr. Jackie Hammerton qualified as a Chartered Physiotherapist in 1984 from the Middlesex Hospital School of Physiotherapy in London. Following a move to the regional spinal injuries centre in Sheffield she developed an interest in rehabilitation of patients with neurological conditions. This interest led to further post graduate study in neurological rehabilitation and a focus into treatment following stroke. In 1995 she established a community rehabilitation service for stroke patients in Sheffield and work in this area provided the basis for her PhD - Investigating the influence of age on recovery from stroke with community rehabilitation. In 2001 she joined Sheffield Hallam University as a Senior Lecturer in the Faculty of Health and Well being and in 2003 was seconded as a Research Fellow to the SMART rehabilitation study. Jackie has a keen interest in the use of motion analysis in stroke rehabilitation, particularly in its use in the home environment to aid patients in the ability to guide their own rehabilitation programme.*

Dr. Marianne Gittoes PhD Lecturer University of Wales

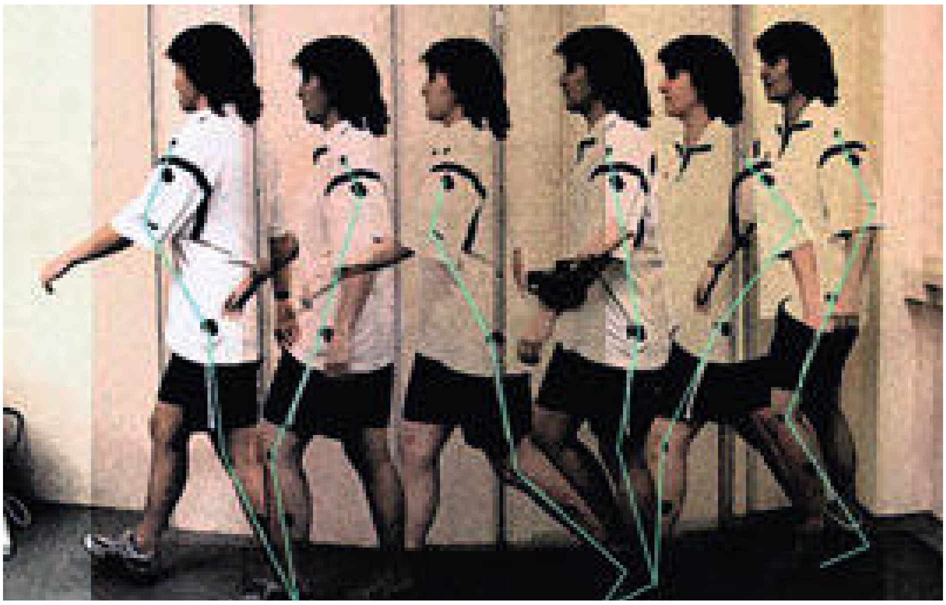
*Marianne's PhD on 'Contributions to Impact Loading in Females during Vertical Drop Landings' was obtained at the University of Bath in 2004.*
*Her current research interests enhance her simulation modelling skills and include the use of computer component inertia modelling of soft and rigid human body tissues and simulating wobbling mass models of human impact landings. In 2004 she won the British Association of Sport and Exercise Sciences Biomechanics Award at the National Conference in Liverpool. Prior to joining the fulltime staff at UWIC, she was employed as a post doctoral research assistant on an EPSRC Equal project specialising in developing CODA(tm) protocols for the 3D tracking of post stroke recovery patients. Marianne has also contributed to two sports science projects; Gloucester Rugby Club on the kinematics of line-out throwing and the Cardiff School of Medicine on the mechanics of the golf swing in post-operative knee replacement older adults.*

# Recovery of postural control and head activity in the early stages of recovery post-stroke.

Malcolm Burnett & Janet Lawrence

Impaired postural control is common post-stroke and is caused by a complex interplay of motor, sensory and cognitive impairments. Sitting balance is an important prerequisite for early functional activities following stroke and often the focus for early therapy. Most research studies in this area have explored the asymmetry of trunk and limb movements, but have yet to describe head movement. This study will investigate the recovery of movement patterns of the head and trunk over a 12 week period following stroke. This study forms Phase I of a planned feasibility study exploring an intervention to promote early return of sitting balance post stroke.
A head and trunk movement assessment protocol that is acceptable to people with acute stroke has been developed. For the main study we will explore the recovery of head and trunk movement during the first 12 weeks post stroke. We aim to recruit people up to 65 people with stroke, collect baseline data and carry out a number of assessments including measures of mobility, balance and attention. Recovery of head and trunk movement will be explored using (CODA) three dimensional movement analysis systems and (HAT) an observational head movement assessment tool. Assessments will take place at one, three, six and 12 weeks post stroke. In addition we aim to recruit 20 healthy controls who will be assessed on three separate occasions.

*The Stroke Association Rehabilitation Research Centre is based at Southampton General Hospital and run by a team of researchers from the University of Southampton and clinicians from the NHS Trusts in Bournemouth, Christchurch and Southampton. The programme is based on a multidisciplinary approach to recovery after stroke and the reduction of disability. This comprehensive programme - the first of its kind in Britain - was made possible by an award of £500,000 over five years by The Stroke Association.*
*The focus of the Centre is on investigating and understanding which rehabilitation interventions are most effective, ultimately, creating a model of treatment that benefits patients directly and informs the future development and delivery of clinical services across the UK.*
*Professor Ann Ashburn of the University's School of Health Professions and Rehabilitation Sciences is leading the research: 'Our distinctive research programme brings together experts from a range of professions at the University of Southampton with senior clinicians currently working with people with stroke. Through this partnership we will explore the process of rehabilitation and identify therapies that will most benefit people with stroke.'*



# Analysis of postural sway to determine the balance strategy utilised in normal and anterior cruciate ligament reconstructed subjects

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This study analyses postural sway to determine if normal healthy and anterior cruciate ligament reconstructed (ACLR) subjects, predominately control their balance solely about the ankle (ankle strategy) [1] or use movement about other joints.
Three-dimensional movement, using the CODA motion analysis system, was obtained in 21 age-matched healthy (9 males) and 18 ACLR subjects (10 males, median time post surgery = 7yrs). During a 15s, one-legged standing task postural sway was recorded, at 100 Hz by two sensor units from 22 light emitting diodes placed on specific anatomical landmarks.
The data was exported and analysed in Mathcad 2001i and SPSS 11.5 to identify which balance strategy was predominately utilized to control balance in the coronal (medial-lateral) and sagittal (anterior-posterior) planes. The Mann-Whitney U test found a significant difference between the groups for strategy utilised on the dominant ($p = 0.02$) and non-dominant ($p = 0.005$) legs in the coronal plane. A larger proportion of ALCR subjects (83%) were found to utilise ankle strategy compared to healthy controls (38%) on the non-dominant leg in the coronal plane.
This study found a greater proportion of the ACLR subjects utilised less movements about the other joints to accomplish postural control. Ankle strategy predicts that ankle movements alone act to accomplish balance control; this may be a compensatory strategy due to ACL injury and subsequent reconstruction. The evidence found may significantly influence the rehabilitation of clients after ACL reconstruction.

[1] Winter DA. Human balance and posture control during standing and walking. Gait Posture 1995;3:193-214.

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