Challenges in Measuring Small Joint Movements: Hand Biomechanics and Health Technology Assessment

Dr Cheryl Metcalf, School of Health Sciences, University of Southampton

1. INTRODUCTION

Using motion capture techniques to measure gait has been well-established since the end of the 19th century[1,2]. Over the past 40 – 50 years, with advances in motion capture technology, the field of human gait analysis has been formed in which collaborations across many disciplines (clinical, engineering and biomechanical) has given rise to clearly defined standards and protocols, accepted methods of validation and progress within the field. Standards now exist for marker placement, marker topology, axes definition/rotation and even graphical representation of results.

The cyclic nature of gait lends itself to standardisation; activities are highly repeatable and therefore easy to compare within an individual's gait and across a participant sample. Variations from 'normal' are also easily recognisable and gait analysis is often used as a tool for clinical diagnosis[3,4].

Traditional motion analysis laboratories are designed to capture movements of larger joints and gross movements. However, if your interest in motion capture is anything other than gait analysis, you are forced to start from the beginning; developing and validating the techniques in your own area of research that will ultimately give credibility to the field.

2. MEASURING SMALL JOINT MOVEMENTS

Over the past 8 years, advances in commercial motion analysis systems' technology, particularly camera resolution, has allowed capture of small joint movement; leading to new fields, and in particular, hand biomechanics. Several systems are now capable of capturing small joint movement, for example the CODA system (Charnwood Dynamics Ltd., UK) is an active motion capture system, using infrared LED markers that are powered by drive boxes (Fig 1).

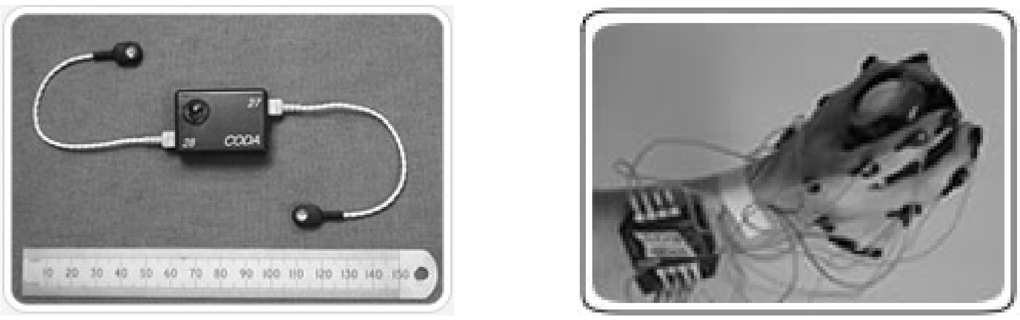


Fig 1: Markers for the CODA motion capture system and illustrated for hand motion capture as used by MOBILAB[5] at the Central Research Laboratory for Biomedical and Rehabilitation Technology, Belgium.

This type of motion capture technology is useful for assessment ergonomics with unimpaired participants, however may be limited in its application with various patient groups, for example the cables may interfere with the movements of those with joint deformity or spasticity.

An alternative to this type of technology is passive motion capture technology, such as those available from Vicon (Oxford, UK) and the Motion Analysis Corporation (Santa Rosa, CA USA), where infrared cameras are used to detect reflective markers placed on the body (Fig 2).

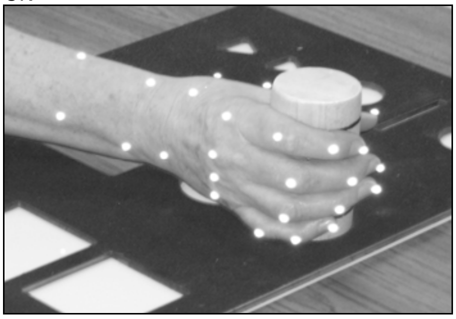


Fig 2: Markers for the Vicon motion capture system and illustrated for hand capture as used by the ARM Research Programme at the University of Southampton, UK.

Many systems are in use throughout clinical research centres in the UK and most, if not all, are capable of capturing smaller joint movements due to increased resolution of these systems.

2.1 Practical Issues of Capturing Small Joint Movements

The recent release of the Vicon T-Series has meant that motion capture laboratories can keep cameras in relatively few configurations for all types of captures and, consequently, fewer adjustments are needed for small joint volume capture size. For example, the biomechanics laboratory at the University of Southampton has optimised the camera placement and resolutions to successfully capture both gait analysis and hand capture using the same camera placement. This has resulted in a considerably larger volume capture space for hand capture trials (Fig 3) and optimises the practical use of multiple user laboratories.

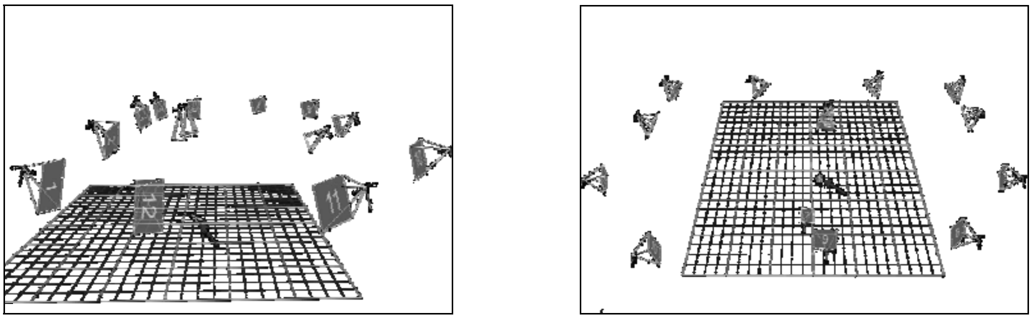


Fig 3: Large volume capture area using a Vicon T-Series 12-camera system.

Until recently, the practical issues surrounding small joint motion capture were centred on the problem of data integrity; that is, in order to gather complete datasets arduous pre-analysis processing in order to analyse their output, researchers were often forced to use small, restrictive volume capture areas and have cameras very close to the participant during assessment (Fig 4).

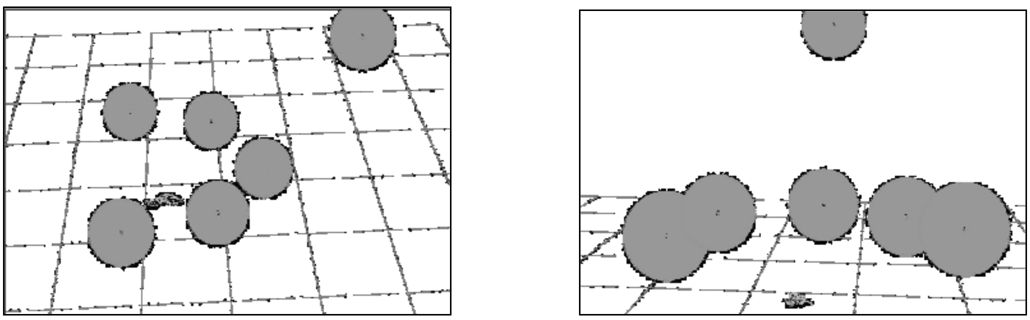
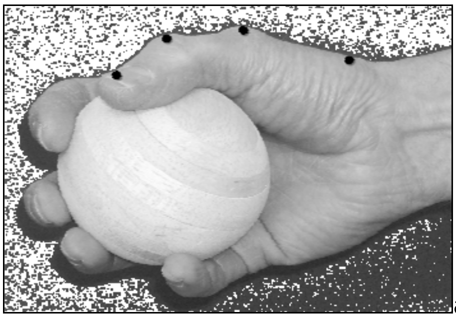


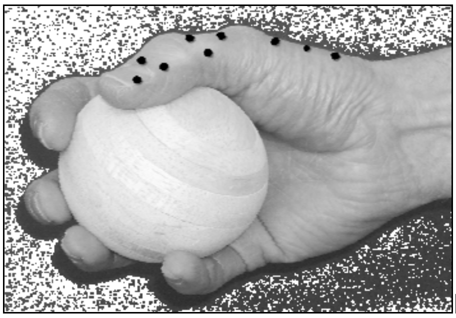
Fig 4: Small volume capture area using a Vicon VCam 6-camera system.

In addition to capture volumes, marker sizes have also added to practical considerations of adopting motion capture as a tool for analysing the movements of small joints. Vicon, for example, can capture markers as small as 3mm diameter, which is very useful for small joint capture.

2.2 Clinical Issues Requiring Consideration for Capturing Small Joint Movements

Marker size, and particularly the marker topology used, can often play an important part in the acceptability of motion capture when it is used as a tool for clinical assessment. There are several types of marker system topologies used in hand biomechanics research (for a comprehensive overview, see reference 6), such as single surface markers, surface marker clusters (or technical marker sets) and rod clusters (Fig 5).


a)


b)

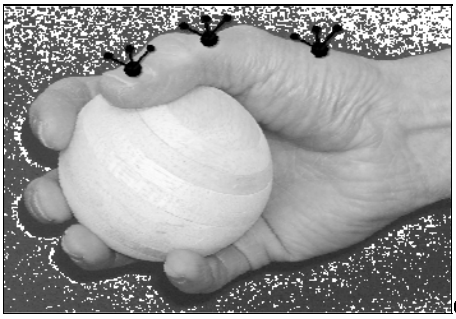

c)

Fig 5: Various marker topologies used for hand biomechanics. In each case, in order to measure all degrees of freedom of the wrist, hand, fingers and thumb, the marker system will need to be replicated on the dorsum of each finger, the hand and wrist.

Such marker topologies are useful and each has its place in hand biomechanics research. However, when working with impaired participants, the cumbersome nature of marker types b) and c) in Figure 5, may interfere with the natural movement response of the joints. For example, asking a person with a neurological impairment to ‘ignore’ complex marker systems and complete a task as they would do naturally at home is impractical. Complex marker systems can often be a hindrance in clinical biomechanics research due to the close proximity of the markers in relation to one another, particularly on the fingers and on adjoining fingers. Potential problems of proximity can often be compounded by joint deformity or spasticity. Care must be taken when selecting the most appropriate methods for the intended participant sample.

There are many issues surrounding standardisation of marker placement, axes definition/rotation that has already been established for gait analysis, but requires updating for upper limb motion capture. The introduction of standards for upper limb motion capture as presented by the International Society of Biomechanics will help resolve these issues[7].

Other considerations for measuring small joint movement include capturing valid normal, functional movements that result from representative activities an individual would usually undertake at home. Previous studies have investigated shoulder, elbow and wrist movements during tracking tasks and cited the redundant degrees of freedom in the upper limb to justify constraining the activity to a repetitive task, thus mimicking the cyclic nature of lower limb gait analysis[8,9]. However, results from tasks that constrain upper limb movement at the expense of analysing a truly functional approach will ultimately be limited in its relevance[10]. In motion capture, the activity should standardise the movement; the movement should not be standardised at the expense of the functional activity.

3. SMALL JOINT MOTION CAPTURE AND ASSISTIVE TECHNOLOGY

The University of Southampton has many recent and ongoing projects using motion capture of smaller joints in such areas as validation of kinematic methods, assessing the effectiveness of clinical interventions and assessing variability in movement strategies following neurological impairment using assistive technology.

3.1 Validation and Reliability

A marker placement protocol and associated computational algorithms were developed specifically for capturing and analysing small joint movements of the wrist, hand, fingers and thumb. This method is comprehensive and provides all the degrees of freedom from the distal joints, and it has been tested for validity and reliability[6] and is used in many clinical research projects.

3.2 Assessing the Effectiveness of Clinical Interventions

In a recent project, the effectiveness of a novel splinting technique to correct swan-neck deformity of the proximal interphalangeal joint of the finger was investigated. Swan-neck deformity is a typical symptom in rheumatoid arthritis and produces hyperextension of the proximal interphalangeal joint with flexion of the distal interphalangeal joint of the finger. The use of silver ring splints was investigated within this clinical context and was shown to be effective by significantly improving the amount of hyperextension at the proximal interphalangeal joint[11,12].

3.3 Assistive Technology

In an ongoing project, the ARMEO® gravity-compensating robot is being used to assist stroke patients with their upper limb rehabilitation. Markers are placed on the hemiplegic wrist, hand, fingers and thumb. Patients are then instructed to interact with a virtual game on a computer screen, while the movements are recorded using a Vicon motion capture system. This project will characterise the kinematics of hand opening in reach-to-grasp activities.

4. CONCLUSION

Small joint motion capture is a challenging and relatively new area of research. Motion capture of the small joints is a powerful tool and has been used successfully in a series of clinical research projects in the ARM Research Programme at the University of Southampton, spanning the musculoskeletal and neurological domains. The complexity of the methods adopted for these studies, such as marker topology and identifying a suitable activity, should be clinically relevant and not interfere with preferred strategy of movement or constrain function.

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