Kinematic technique for evaluation of athletic conditioning effects on equine degenerative suspensory ligament desmitis

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The fetlock is the joint between the cannon and upper pastern bones in the front and rear limbs of horses (Fig. 1). In the horse, the suspensory ligament originates on the proximal cannon bone, inserts on both proximal sesamoid bones and has extensor branches over both sides of the pastern bone which merge with the common digital extensor tendon. The ligament provides support over the back of the fetlock, preventing hyperextension when the limb is full weight bearing. Degenerative suspensory ligament desmitis (DSLD) is characterized by degeneration of the collagenous structure of the suspensory ligament, resulting in progressive

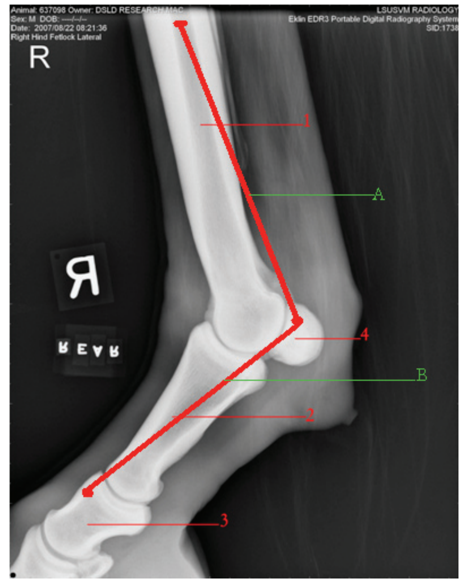

Figure 1. Radiograph of the rear limb of a horse. 1= Cannon bone, 2 = Upper Pastern bone, 3 = Lower pastern bone, 4=Sesamoid bones (superimposed), A=Suspensory ligament, B=Extensor branch of suspensory ligament

loss of its supportive function. Peruvian Paso and Paso Fino horses are frequently affected, though the condition has been reported in the majority of horse breeds. A hyperextended fetlock joint and mild to severe lameness are two cardinal signs of DSLD. The pastern bones become increasingly parallel to the ground as the disease worsens. DSLD is considered a chronically progressive disease with no known cure. Empirical and supportive treatment is not effective in halting disease progression. This study was designed to evaluate the effects of athletic conditioning on mild to moderate DSLD.

Six horses (n=2/normal; n=4/DSLD) performed 30 minutes of treadmill exercise (Fig. 2) every other day for 8 weeks. Following the exercise trial, horses were pasture rested for 4 months. Gait analysis, distal limb radiographs, and suspensory ligament ultrasound were performed prior to the exercise trial, after 4 and 8 weeks of exercise, and after 4 months of pasture rest following the exercise trial. Dynamic fetlock flexion was measured by real-time motion analysis (Codamotion, Charnwood Dynamics Ltd. Leicestershire, UK).

Figure 2. Horse exercising on a treadmill with active motion analysis markers in place to record dynamic fetlock angles.

CODA photodiode markers were attached to the skin of each animal at six anatomic positions on the left fore- and hind limbs: 1) head of the fourth metacarpal bone, 2) metacarpal attachment of the lateral collateral ligament of the fetlock, 3) proximal hoof wall over the joint between upper pastern and lower pastern bone, 4) head of the 4th metatarsal bone, 5) metatarsal attachment of the lateral collateral ligament of the fetlock, 6) rear proximal hoof wall over the joint between upper pastern and lower pastern bone (Fig. 3). The vector angle between vector 2->1 and vector 2->3 was defined as the front fetlock angle α. Vector angle between vector 5->4 and vector 5->6 was defined as the rear fetlock angle β (Fig. 4). Each data acquisition trial of 20 seconds included sufficient replicate samples of fetlock joint flexion and extension for analysis. The average maximum and minimum angles for each joint were calculated for all left fore- and hind limbs.

Figure 3. CODA photodiode marker positions for quantification of dynamic fetlock angles.

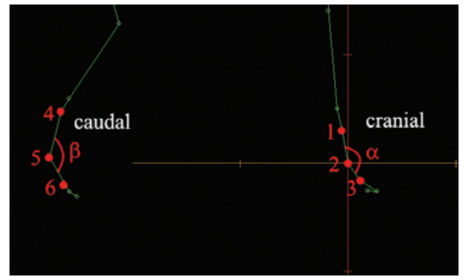

Figure 4. Stick figure diagrams of both left fore- (right) and hind limbs (left) indicating where dynamic fetlock angle measurements were taken.

This study involved state-of-the-art technology to study of equine orthopaedic disease. In addition to the markers used for quantification of fetlock joint angles, seventeen markers were attached to anatomic landmarks to include the majority of the equine skeleton (Fig. 2). Equine kinematic data collection and analysis procedures were established for this investigation. Generation of a model to characterize equine motion is currently underway. The model will be used for a number of purposes including prediction and prevention of athletic injuries and to establish a mechanical basis for therapeutic riding exercises. Use of this technology and the models generated from it has significant promise to benefit both horses and humans.

The effect of patella taping on lower limb joint movement and anterior knee pain

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Anterior knee pain (AKP) is a common condition typically exacerbated by activities that load the knee joint. Medial glide patella taping, first described by McConnell (1986), is a common adjunct to physiotherapy employed by many clinicians in the management of AKP. Despite its popular use, the mechanism behind the reported clinical success of patella taping remains unclear.

To investigate the kinematic effects of medial glide patella taping on joint angle change during a unilateral squat, and thus determine if patella taping has an effect on overall unilateral squat depth. It was a secondary objective of this study to determine if patella taping has any effect on pain during a unilateral squat.

Methods

Ten subjects with a six month history of unilateral or bilateral AKP were required to perform a unilateral squat on the symptomatic leg. A within subject repeated measures approach was undertaken to assess joint angle change and squat depth under three conditions (patella tape, placebo tape and control) using the CODA cx1 motion analysis system. A record of subjects' AKP according to the Numerical Rating Scale (NRS) under each condition was also noted.

Data Analysis

Changes were analysed using Friedman tests and Wilcoxon Signed Ranks tests.

Results

Fifteen knees were analysed in this study. A significantly greater single-legged squat depth compared to placebo tape (p=0.008) and control (p=0.0012). Statistically significant reductions in pain during a single-legged squat were found when the patellofemoral joint was taped compared to squatting with placebo tape (p=0.001) or control (p=0.001).

Conclusions

Patella taping produces significant increases in squat depth with associated significant reductions in AKP in a symptomatic population. These changes are most likely to have occurred through changes in patellofemoral joint alignment. Such changes in biomechanical alignment contribute to reduced joint loading and reduced joint stresses (Crossley et al. 2000), improving function at the joint.

Implication to Clinical Practice: MGPT will enable AKP patients to complete their rehabilitation exercises with less pain and through a greater range.

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Plymouth community benefits from motion analysis

UNIVERSITY OF PLYMOUTH

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The School of Health Professions at the University of Plymouth has been rapidly developing the range of activities based within its Human Movement and Function Laboratory (HMFL). Following on from significant capital investment the HMFL now houses a range of integrated motion analysis equipment and other supporting facilities that has extended capability. However, as well as providing a vehicle for cutting edge research the multi-professional team who support the HMFL have been able to develop important services for the local community.

The University of Plymouth is committed to ensuring that where possible its facilities, resources and expertise play a positive role in supporting the local community and that has been clearly demonstrated by one of the first initiatives supported within the HMFL. There had been concerns from surgeons based in Plymouth about the lack of a local Gait assessment service; patients referred for this service were forced to make long journeys across the UK, sometimes requiring an overnight stay. However, as a result of our investments and a positive partnership the HMFL are now offering this service; saving local people time, cost and inconvenience and providing service to those families who could not make the longer trip.

As well as this positive outcome the HMFL provides fantastic access for students to research equipment for project work within their course and has supported other services including product testing for a new range of foot orthoses. Access to facilities within the HMFL has also been critical in the school obtaining initial approval to commence a Knowledge Transfer Partnership focused on the development of new innovative products for the sports injury market.

This range of exciting developments is testimony to how investment in a range of motion analysis and support technologies, combined with the right personnel and a dynamic innovative approach, can lead to exciting opportunities and positive outcomes. The HMFL is always looking to explore new opportunities to enhance its services and as well as applying for a variety of research funds is exploring the range of services it can provide to assist sports performance, injury prevention and rehabilitation.

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Evaluating the performance of a vision-based human motion capture system mounted on a humanoid robot

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The beginning of the 21st century has witnessed an increasing interest by the robotics community in the analysis and modelling of human motion. Applications range from social human-robot interaction to more complex learning-by-imitation tasks. In this context, vision-based systems mounted on the robot are often preferred. They can be assumed to provide the most natural way of interaction between people and robots. Recently, many markerless approaches have been proposed, differing in the number, type, and arrangement of the sensors incorporated, real-time applicability, the ability to perceive 2D or real 3D motion, and the smoothness of the output trajectories. Compared to other invasive human motion capture systems, these visual-based approaches have the disadvantage that the provided position and orientation information is usually affected by significant errors, which only can be reduced by increasing the computational cost associated to the employed algorithms. In this paper, the performance of a non-invasive, vision-based approach for gesture perception is evaluated taken as reference a CODA motion capture system.

Humanoid robots are expected to interact and cooperate with people in everyday situations. Given the dynamic nature of the environments in which these robots are expected to work, they will need to be flexible to adapt to changes and able to learn new motor skills continuously, as they are expected to carry out a huge variety of different tasks. Therefore, one main trend of research for the robotics community is focused on the perception system of these humanoid robots. It is usually assumed that, in order to learn how to perform new tasks, the robot should first be able to sense and interpret a wide range of communicative modalities and cues (Calinon, 2007).

Specifically, in order to interact with people, the humanoid robot must be able of autonomously detecting their presence and tracking their activities. Capturing the articulated motion of a person can be a useful tool to understand and imitate his/her activity if required. Doing so from an autonomous robot in reasonably unconstrained indoor scenarios presents several challenges: i) the task of understanding human motion must share the computational resources of the robot with other tasks (and thus should not be computationally expensive); ii) it should be performed using the robot's own sensors (should not rely on sensors mounted on the ceiling, for example); and iii) should not impose important restrictions on the appearance of the subject or the background. Following these guidelines, the ISIS research group at the University of Malaga have developed a vision-based (markerless)upper-body motion capture system, whose first versions have been presented in several publications (Bandera et al, 2008; Bandera et al, 2007; Molina-Tanco et al, 2005). The system detects and tracks the positions of shoulders and hands. Once these positions are estimated, a pose estimation method computes the whole set of joint angles using a constrained inverse kinematics algorithm and an internal 3D model of the human upper-body. The analytic nature of this method allows it to offer the required joint angles in real-time. These obtained angles will be the output of the capture system, and can be used to make a 3D avatar imitate the human pose. The pose estimator method also filters incorrect or noisy upper-body human postures, as it intrinsically applies kinematics relations and physical constraints to the inputs obtained from the vision module. The constraints of such a system are very restrictive: it should only use resources that can be built into a robot; it should function in real-time; it should provide sufficiently accurate data in order to allow the robot to learn by imitation; and it should be robust enough to recover from disturbances such as partial or total occlusions of the demonstrator, expected to occur in real scenarios.

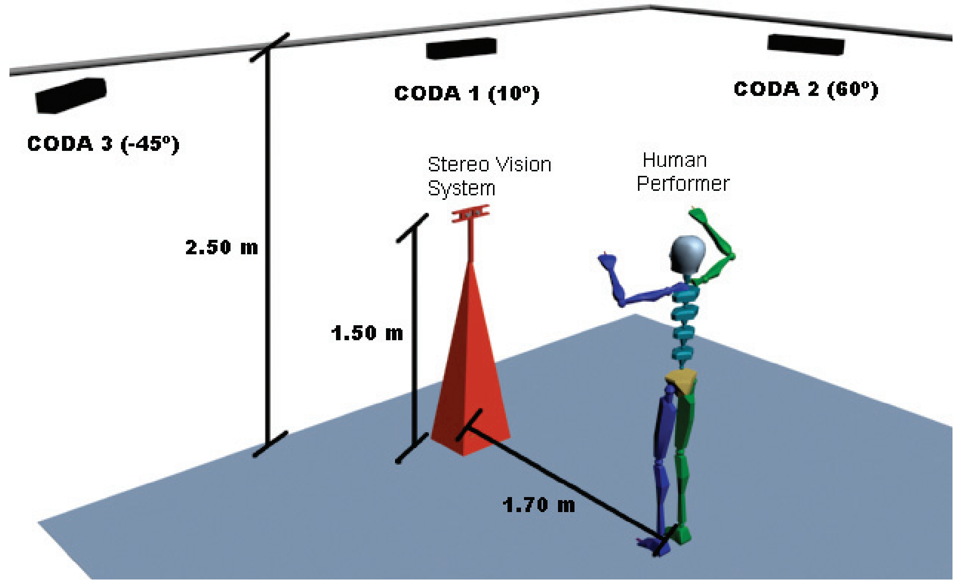


Figure 1. a) The experimental setup

In the following sections we describe the experimental tests which have been recently conducted at the Centre for Vision, Speech and Signal Processing (CVSSP) at the University of Surrey in order to evaluate the performance of the proposed upper-body motion capture system. The CVSSP has created the Visual Media Laboratory for research in real-time video, audio processing and visualisation, and is owner of three Codamotion units.

Experimental results

The proposed vision-based gesture capture system has been implemented using a STH-DCSG-VARX stereo system and the Small Vision System software, provided by Videre Design (www.videredesign.com). This visual perception system captures and preprocesses stereo pairs. In our case, the size of left and right images is 320x240 and, therefore, the resulting disparity map has also a size of 320x240. The 3D virtual model used to reproduce perceived gestures is rendered and animated using OpenSceneGraph, an open source graphic engine available at www.openscenegraph.org. The whole system runs on a 2 GHz Pentium IV computer running the Linux operating system. The proposed gesture capture system is able to deal with different demonstrators moving in a non-controlled environment, the only requirement being to wear long sleeves and non-skin colour garments. Demonstrators are told to stay at a distance from the robot cameras between 1.50 and 2.5 meters. This ensures that most of their upper-body motion will be confined in the field of view of the cameras. It is also a reasonable distance in human-to-human interaction processes.

In this particular case, experimental tests are performed in a controlled environment, where the CODA motion capture system is installed. The layout of this environment is illustrated in Fig. 1a and 1b. Fig. 1b also shows the distribution of visual markers attached to the body of the human demonstrator. A more detailed description of the number and position of the employed visual markers can be observed at Fig. 1c. Different demonstrations were performed in front of the two motion capture systems. A specific gesture will be used to synchronise the trajectories captured from both systems.

The vision system estimates trajectories for head and hands positions. The centre of mass of these positions is used to fit the human demonstrator silhouette onto an intrinsic model, which generates positions for virtual markers artificially distributed over this model to match the corresponding real markers (see Fig. 1c.). Finally, real CODA markers are compared to our model virtual markers to evaluate the goodness of our method.

Discussion

In this work, the CODA Motion capture system has been used to test the performance of a non-invasive, vision-based motion capture approach. Several gestures have been performed by different demonstrators at the same distance from both capture systems. In all cases, errors are bounded in a small range, showing that the proposed capture system is robust to variations of the physical dimensions of the human demonstrator, and to variations in illumination conditions.

The experiments show that the error associated to the whole visual-based capture system is practically the same as the one associated to the stereo vision system. This error is not equally distributed over the entire image, but it increases when the tracked item is close to the image border. This is illustrated in Fig. 2, which shows the differences between the positions estimated using both systems for two different items A and B. Item A is moving near the image center and item B is performing a similar movement near the border of the image. Although the calibration software provided by Videre design allows taking into account the radial and tangential distortions of the lens, obtained results show that these distortions still affect to the correct estimation of the 3D position of perceived points.

(a)

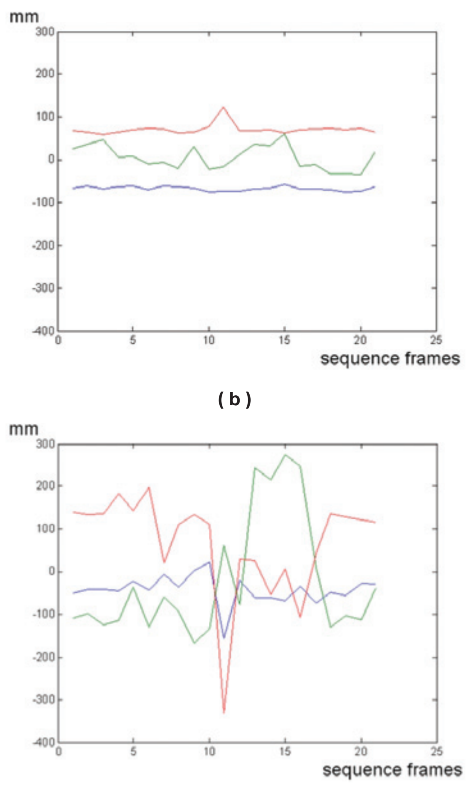
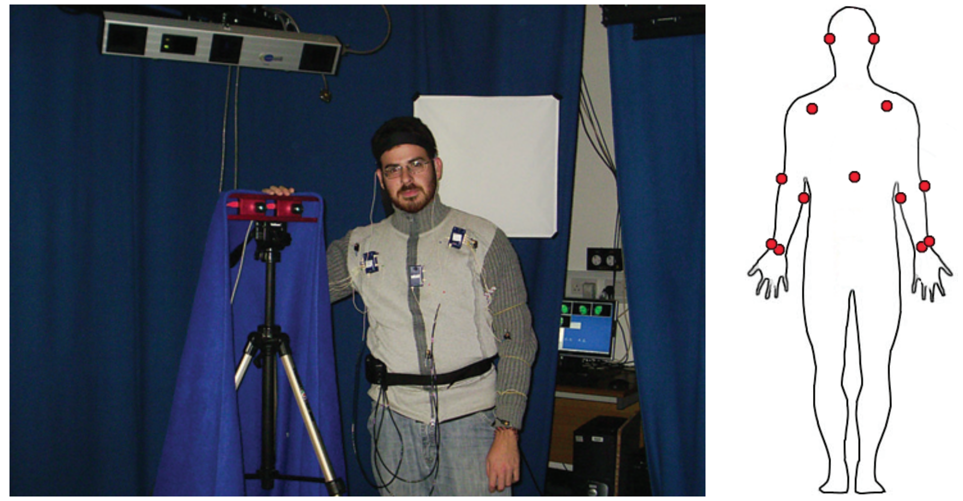


Figure 2. Differences between positions estimated from both capture systems associated to a virtual marker which is located: a) near the image center; and b) near the image border (red, green and blue lines show the differences in the x, y and z coordinates, respectively)



(b) (c)

Figure 1. b) the stereo vision system STH-DCSG-VARX from Videre Design and the CODA Motion system at the Centre for Vision, Speech and Signal Processing, at the University of Surrey; and c) distribution of virtual markers

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The intra-rater reliability of a 3D motion analysis system for use as a measurement tool in FES evaluation studies

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Stroke is the most common cause of acquired physical disability worldwide, second only to dementia as the most expensive illness in health and social care costs, with these costs exceeding those of either cancer or ischaemic heart disease (Irish Heart Foundation, 2003). "Drop-foot", a condition which contributes significantly to the residual disabilities incurred as a result of stroke, is typically characterised by a weakness or absence of the ankle dorsiflexors, which assist in clearing the foot during the swing phase of gait but also control plantarflexion of the foot on heel strike (Lyons et al., 2002). Dropped-foot is most commonly treated using a custom-moulded ankle foot orthosis (AFO) or by using Functional Electrical Stimulation (FES). The treatment of drop-foot post-stroke is the focus of this author's thesis which is currently being completed. In general, subjects with post-stroke drop-foot are seen to walk at a slower speed with a reduced cadence, step and stride length compared to age-matched healthy individuals (Lamontagne et al., 2007). Subjects with stroke are also reported to spend longer time in stance and double support phase on the affected side also (Olney and Richards, 1996).

Three dimensional (3D) gait analysis systems, such as the CODA, are considered the "state of the art" in providing quantitative information on how kinematic and spatiotemporal parameters are affected by FES. Establishing the degree of variation of a particular analysis system between test is a necessary precursor to evaluating an intervention on patients using the analysis system. The investigator must be confident that any detected changes are as a result of the intervention and not by measurement error.

Previous literature has established the intra-rater reliability of the CODA using a normal healthy population (Monaghan et al., 2007). Studies involving stroke patients have also employed the CODA as an outcome measure (Lennon et al., 2006, Tyson, 1999) however data on the reliability of CODA in a stroke population has not been addressed. Hence this study aimed to address this gap in the literature by establishing the intra-rater reliability of the CODA motion analysis system in a chronic stroke population. The study also aimed to determine how many walks subjects must complete to optimise the reliability of the system in measuring spatiotemporal (speed, step length, % stance time, double support time) and kinematic parameters (ankle angle at heel strike and toe-off in the sagittal plane) with their shoes on, using their usual mobility aids. The study also aimed to determine how many walks subjects must complete to optimise the reliability of the system in measuring spatiotemporal (speed, step length, % stance time, double support time) and kinematic parameters (ankle angle at heel strike and toe-off in the sagittal plane) with their shoes on, using their usual mobility aids.

Methodology

A sample size of ten chronic stroke patients were recruited for this study. Patients were required to meet the following criteria for inclusion;

1. Patients who had a stroke over one year previous to the time of recruitment. This time-frame was selected as it is established that the probability of gait changes at this stage post-stroke are unlikely without therapeutic input (hence improvements due to natural recovery were thought would not occur during the week between testing);
2. Patients also had to be living at home and able to walk a distance of 10m independently (with or without a mobility aid or ankle-foot orthosis/AFO);
3. Able to give informed consent;
4. Not currently receiving an intervention that may affect their gait.

Gait analysis data was collected using the CODA system at a 200 Hz sampling rate using the standard setup for bilateral gait acquisition. A chartered physiotherapist experienced in functional anatomical landmark attainment, who had received formal training by a Charnwood Dynamics team member tested all subjects. One full stride for each respective leg was marked sing gait cycle marks. For example, heel-strike, toe-off and next heel-strike of the left leg of subject one were marked using the "Drop Left Cycle marks (green)" command. The file was then re-saved as a Movement Data Report file (.MDR) which is similar to the .MDF file but includes the analysis data needed to generate the "cycle symmetry" (or spatio-temporal) data. The phase between the marked toe-off and heel-strike events were then isolated using the appropriate functions and converted to Microsoft Excel file format by converting the number of output samples to "100 + 1" in the Data export Option of CODA software. The first and last values were extracted as the toe-off and heel-strike value respectively for each gait recording. Data for trials 1–3, 1–5, 1–10, 1–15, and 6–15 for each subject were subsequently derived.

Subject	Sex	Age (yrs)	Weight (kg)	Height (m)	Timesince stroke (yrs)	CVA Type (From medical notes)	Type of mobility aid
1	F	72.92	59.70	1.42	1.08	R MCA infarct	Stick
2	M	73.13	97.20	1.77	9.00	Multi-infarct (L sided weakness)	Rollator frame
3	M	69.71	100.20	1.88	1.92	L internal capsule	None
4	M	71.94	79.30	1.61	1.00	R internal capsule	Stick
5	F	77.65	57.60	1.51	1.25	L thalamus	None
6	F	52.13	84.50	1.52	1.58	R temporoparietal haemorrhage	AFO
7	F	79.14	67.50	1.57	1.25	Unclear (R sided weakness)	None
8	M	66.90	86.40	1.80	1.33	Pontine (R sided weakness)	None
9	M	84.50	68.20	1.68	5.33	L internal capsule	AFO & Tripod
10	M	55.54	97.40	1.73	2.25	Unclear (L sided weakness)	None

Table 1: Details a demographic profile of the subjects. **Abbreviations**: CVA, cerebrovascular accident; MCA, middle cerebral artery; AFO, ankle foot orthosis.

Using the "Motion Analysis Database" software, each file was opened separately and with the "Report" function a ".PDF" file of all spatio-temporal data was generated. Using the "Copy gait parameters to clipboard" button, data was extracted to an excel file. The parameters of interest, Speed, Step length, Percent stance and Double Support time were calculated for trials 1–3, 1–5, 1–10, 1–15, and 6–15 for each subject. Analysis was repeated on day two for the same parameters.

Figure 1. Subject set-up for bilateral gait acquisition.

Results

Data for nine chronic hemiplegic subjects was analysed as it was not possible to analyse the data acquired for one of the subjects who mobilised with the aid of a tripod. This result is a note of caution to researchers allowing subjects to walk with their usual mobility aid as it would appear that the CODA cannot successfully acquire data (particularly ankle angle data) from a subject using a tripod. The results of the study indicate that the CODA system has good reliability with all parameters (except ankle angle at heel strike using trials 1-3) in returning an ICC > 0.75. Spatio-temporal parameters exhibited less test-retest variability in comparison to kinematic parameters, a result which concurs with previous research (Monaghan et al., 2007, Cowman et al., 1998).

Parameter	Degree of Variability
Ankle angle at toe-off (degrees)	16.73
Ankle angle at heel-strike (degrees)	24.12
Speed (m/s)	0.14
Step length (m)	0.08
% Stance Time (%)	1.60
Double Support Time (s)	0.04

Table 2: Number of trials recommending for various parameters from these results.

Parameter	No. of trials
Speed	1-15
Step Length	6-15
%Stance	1-5
Double support time	1-15
Ankle angle at toe-off	6-15
Ankle angle at heel-strike	1-10

Table 3: Degrees of variability for parameters examined.

For kinematic parameters, this study advocates the use of ten trials representing the mean in order to optimise reliability between sessions; the first ten when determining the ankle angle at heel strike (1-10) and the last ten of fifteen (6-15) in the case of ankle angle at toe-off (Table 2).

For spatio-temporal parameters the variability, indicated by the range of LOA is acceptable; however the variability indicated for kinematic measures is too large to be considered clinically feasible (Table 3).

Conclusion

In a sample of chronic stroke patients, the 3D motion analysis system, CODA exhibited excellent intra-rater reliability (ICC > 0.75) for all spatio-temporal and sagittal plane kinematic parameters, except for the ankle angle at heel strike when the mean of trials 1-3 were analysed. In line with previous research, spatio-temporal parameters exhibited less test-retest variability in comparison to kinematic parameters. The number of trials advocated for each parameter in order to optimise reliability is presented in the table above.

The objective of completing this study was to inform future work by this investigator using the CODA system for FES clinical evaluation. It is expected that the information gained from using such an analysis system will add to our knowledge regarding the orthotic and especially therapeutic effect of FES for post-stroke drop foot correction. It is expected more literature on how movement patterns are altered as a result of FES will facilitate refinement of the current selection procedures for appropriate patients. Such developments should facilitate clinicians adopting FES as a more first-line treatment (where appropriate).

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