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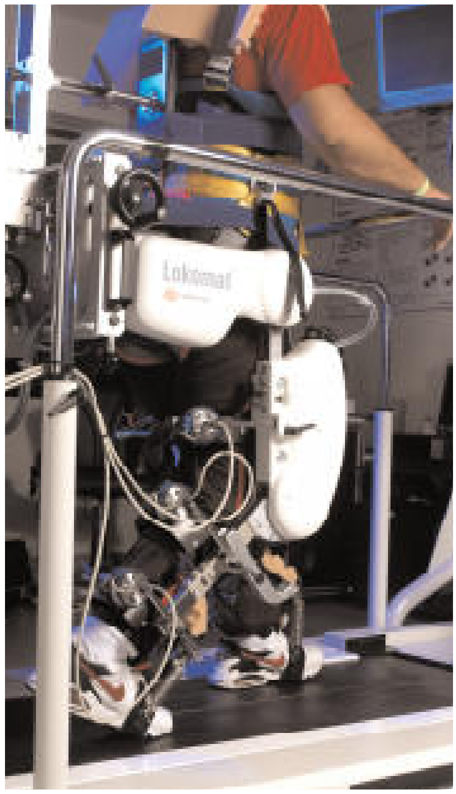
Robotic-Assessment of Walking May Enhance Therapeutic Outcomes Following Stroke and Spinal Cord Injury

Dr. Joseph Hidler, Director of the Center for Applied Biomechanics and Rehabilitation Research at the National Rehabilitation Hospital in Washington DC USA is utilizing the Codamotion (Charnwood Dynamics, UK) and Lokomat robotic gait orthosis (Hocoma AG, Volketswil Switzerland) to study gait patterns in individuals following stroke and spinal cord injury in hopes of developing better therapeutic interventions.

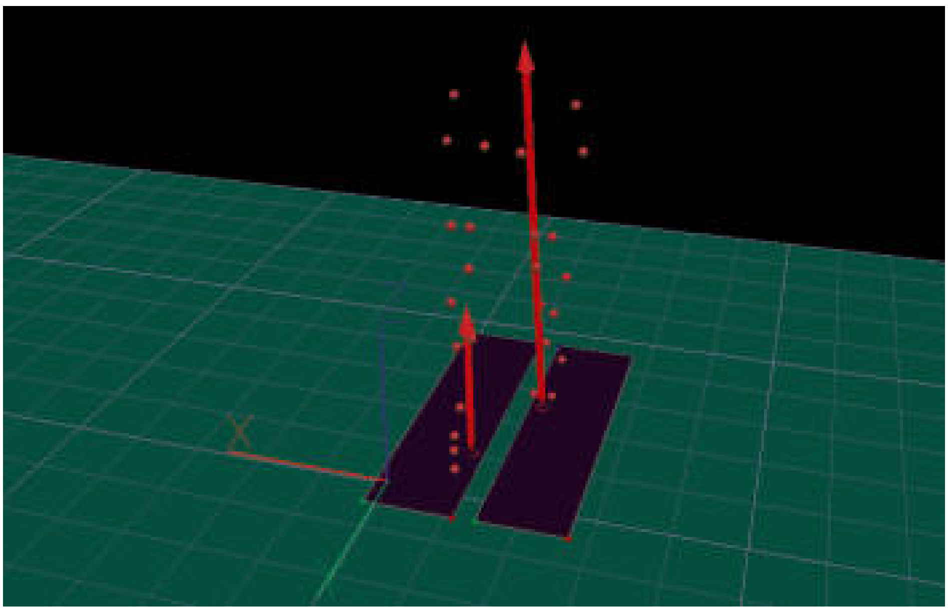
Over the last decade, the field of neurorehabilitation has seen the proliferation of new therapies, including robotic devices, aimed at enhancing walking ability in individuals with neurological disorders. The major limitation with these new therapies is that there are no guidelines as to how patients should be trained. For example, we know from extensive studies done in spinalized rats and cats that the influence of limb loading, walking speed, and limb kinematics all play a key role in how the animal steps on a treadmill. Without adequate hip extension, for instance, cats will stop stepping. Unfortunately similar knowledge remains unknown in human populations, where therapists are often relegated to using heuristic rules rather than quantitative evidence for selecting how patients are trained.

To solve this problem, Dr. Hidler has combined the forces of a robotic gait-orthosis called the Lokomat and the Codamotion motion analysis system. The Lokomat is an exoskeleton device that has small DC motors that actuate the hip and knee joints of the patient. Underneath the Lokomat is a split-belt treadmill (ADAL3D-COP, Techmachine, France) that has force plates under each belt. Utilizing the Lokomat to address these questions rather than simple gait analysis is necessary because many of the subjects tested cannot ambulate on their own but instead require significant assistance. To quantify this assistance, Dr. Hidler's team modified the cuffs that couple the subject to the Lokomat so that they now contain 6-axis load cells (JR3 Inc, Woodland, CA, USA). Between the Lokomat, load cells and instrumented treadmill, it is possible to identify all of the forces acting on the subject's legs at any point in the gait cycle.



The Lokomat robotic gait-orthosis (Hocoma AG, Volketswil Switzerland) is used to help guide the subject's limbs during the training sessions.

Unfortunately tracking limb motion is not as easy. As a first pass, Dr. Hidler attempted to use the potentiometers on the Lokomat to track the knee and hip angles of the subject. This turned out to be futile as misalignment of the Lokomat's hip and knee joint axes and those of the subject is a common problem. Further, the subject is not rigidly coupled to the Lokomat so there is significant movement of the leg within the device that isn't measured by the potentiometers. It became apparent immediately that the only way to track the leg motion was through motion analysis.



Perspective view of raw data from the sensor systems on the Lokomat, showing marker locations from the Codamotion system and force vectors from treadmill.

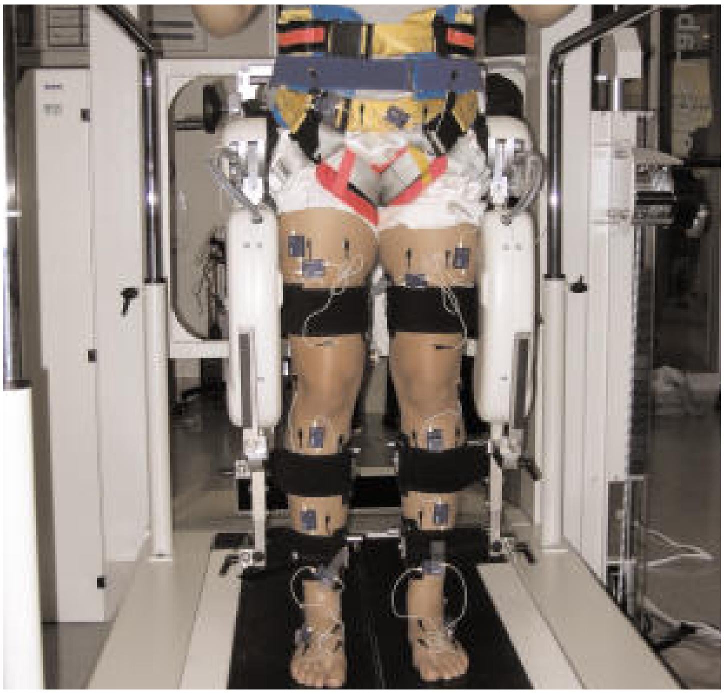
The problem with motion analysis within the Lokomat is two fold. First, there are significant reflections throughout the device that make reflective marker-based systems difficult if not impossible to employ. And secondly, losing markers due to obstructions of the device at various points in the gait cycle is difficult to avoid.

To overcome these issues, Dr. Hidler acquired a Codamotion motion analysis system. The advantages of the Codamotion system over passive systems are that reflections from the metallic surfaces of the Lokomat and treadmill are not a problem due to the active nature of the system. In addition, because the Codamotion is active, if a marker is lost during the gait cycle, it is easy to distinguish once back in view. Over the last 3 months of testing, Dr. Hidler has found that the Codamotion has worked brilliantly in the Lokomat and is now ready for full scale testing.

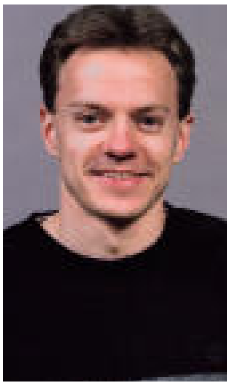
With the technological bridges crossed, Dr. Hidler and his group have now begun testing individuals with stroke and spinal cord injury where they are studying the influence of walking speed, level of body-weight support, and leg kinematics on each individual subject's gait pattern. The goal is to identify the set of training conditions through which the subject steps with the most appropriate muscle activation patterns and joint moments throughout the gait cycle. A 3-dimensional inverse dynamics model is being developed for Visual 3D (C-Motion, Rockville MD) which takes into account the Lokomat instrumentation.

Future plans include using the Codamotion and Lokomat data to develop more rigorous bio-feedback displays in Visual 3D that subjects can use during training sessions.

See us at **http://cabrr.cua.edu** to monitor the progress of this research.



The Codamotion system (Charnwood Dynamics, UK) is used to track limb segment motion during Lokomat trainings



Dr. Joseph Hidler received the B.S. degree in Mechanical Engineering from the University of Massachusetts, Amherst, MA in 1994, and the M.S. and PhD. degrees in Biomedical Engineering from Northwestern University, Evanston, IL in 1996 and 2001, respectively.

He is currently an Assistant Professor in the Department of Biomedical Engineering at Catholic University and the Director of the Center for Applied Biomechanics and Rehabilitation Research (CABRR: http://cabrr.cua.edu) at the National Rehabilitation Hospital. His research focuses on neural control of movement, musculoskeletal modeling, and understanding the mechanisms underlying motor impairment following stroke and spinal cord injury. He is a member of IEEE, BMES, ASB, and the Society for Neuroscience, serves on the Scientific Advisory Board for the Paralyzed Veterans Association (PVA) and is an Associate Editor for the IEEE Transactions on Neural Systems and Rehabilitation Engineering. His research is funded by the Whitaker Foundation (Arlington, VA), NIDRR, NIH, and the Department of Defense.

A comparison of normal data between two clinical gait analysis labs.

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Different clinical gait analysis labs use different equipment, place markers in different locations and have different "models" for finding joint centers. To what extent are the results obtained comparable ? To begin an investigation of this question we here compare two sets of normal data for children between 3 and 8 years old. One set was collected using CODA equipment and software in the Motion Analysis Laboratory of the Royal National Orthopaedic Hospital Trust in Stanmore, the other at the One Small Step Gait Laboratory at Guy's Hospital, using Vicon equipment and software. The Stanmore data is for 12 children, and the Guy's data is for 17 children, each group has a mean age of 5.4 yrs. Data was not different between left and right legs, and so all legs within each group were combined. For technical reasons records for two legs from the Guy's set were rejected. Each leg provided signals for twelve kinematic variables, rotations about three orthogonal axis of the pelvis, the hip, the knee and the ankle; however coronal plane rotation at the ankle is not yet satisfactorily analysed at the time of writing this abstract.

Each signal was divided for analysis into two components: "position" and "movement". The position is the mean value through the gait cycle and movement = signal – position. Fig 1 illustrates this dissection. This was done for two reasons: (1) work with the Stanmore normal data set has shown that, for many variables, a large part of the variation between subjects is due to variations in position rather than movement; (2) differences between labs in modelling centers of rotation would be expected to influence position more than movement.

The movements recorded by the two labs were very similar. For most variables there were no statistically significant differences between the two data sets. Only the rotations of the hip and the knee were significantly differentfor part of the gait cycle. These differences were largely during swing. In contrast the positions recorded by the two labs were statistically different for 6 of the 11 variables examined. It is possible to explain these differences , at least qualitatively, as due to the different modelling of joint centres between the two laboratories.

It is hoped to extend this work in the future by including:
• more age groups; so that a large combined data base can be age stratified;
• data from other laboratories;
• kinetic variables; these may be more model dependent that kinematic variables.

Clinical laboratories with normal data are invited to participate in this project by contacting
r.woledge@ucl.ac.uk

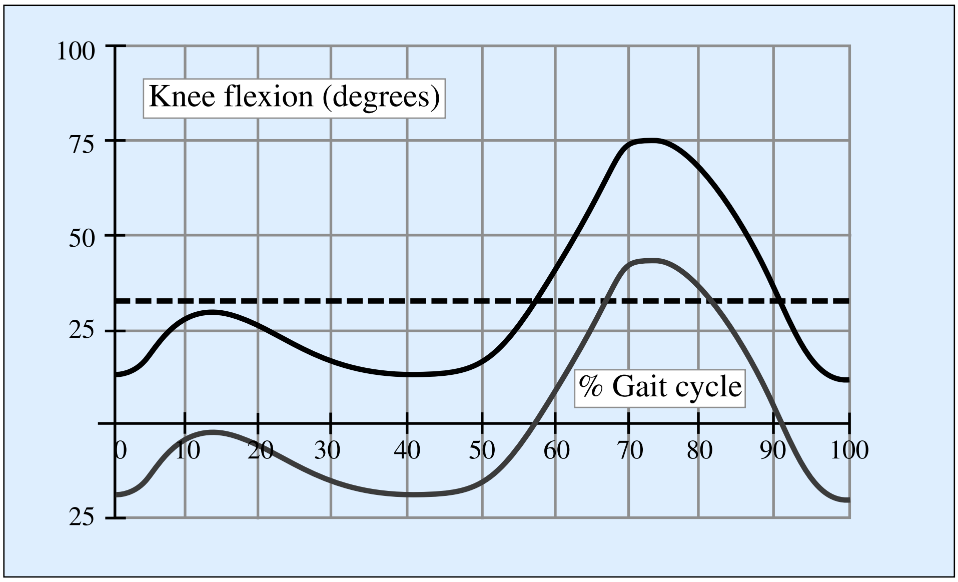

Figure 0. A typical motion analysis signal dissected into position and movement. The full line is the signal for the knee flexion through the gait cycle. The horizontal line is its mean, here called "position" and the lower dotted line is the "movement" i.e. the difference between this signal and position.

Fluctuations in knee angular acceleration in young and older adults during functional tasks

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Lower limb muscle steadiness has been shown to be greater in younger than old people during isometric (Tracy and Enoka 2002) and isotonic (Hortobagyi et al. 2001) contractions, but no studies have examined steadiness during functional tasks in these two age groups.

40 young (29.3+_0.6 (mean + SEM, range 19-41 years) and 42 older (75.9+_0.6, range 70-86 years) adults participated in the study. The CODA motion analysis system was used to track bilateral markers placed on the ankle, knee and hip of participants during stepping up and down on a 20cm high box and during standing up and sitting down on a 42cm high armless chair. A stick figure of each leg was created, and the angular acceleration of the knees was measured during the tasks. The standard deviation of angular acceleration was calculated as the measure of steadiness.

When analysed according to both the most and least steady legs, the elderly were less steady than the young when standing up on the most steady and down on the least steady leg. During standing and sitting there were no differences between the two groups (Table)

Standard deviation of knee angular acceleration (rad.sec -2) during functional tasks. *= significant difference between groups (P<0.01) for the most and least steady legs.

Task	Young			Older		
	n	Mean	SE	n	Mean	SE
Stand up						
Most	39	4.14*	0.42	42	5.82	0.42
Least	39	5.53	0.94	42	9.06	0.93
Sit down						
Most	39	3.83	0.36	42	4.97	0.40
Least	39	5.91	0.55	42	9.82	1.71
Step up						
Most	40	4.62	0.39	38	5.62	0.40
Least	40	7.29	0.94	38	10.31	0.98
Step down						
Most	38	5.37	0.51	34	5.55	0.48
Least	40	7.42*	0.42	38	11.35	1.33

These CODA measurements are a useful tool in measuring functional steadiness and show some age related changes. Functional steadiness may be a factor in medically unexplained falls in older people and it remains to be seen whether steadiness is reduced in this group compared to people of a similar age with a history of such falls.

Mapping Musical Movement:

The Physical Expression of Musical Individuality

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This project measures how movements made while playing a piece on the cello differ during the progression from sight reading for the first time to performing the piece from memory. Some movements (defined in this study as 'local') will be minimally required to execute 'the notes' of a given piece while others (defined as 'global') are associated with and enable the projection of musical expressiveness and individuality.

Our initial hypotheses are:

1. local movements become more consistent as performers become familiar with a piece and in better technical control of the instrument;

2. there is comparatively little variability between the expert performers in relation to the movements necessary for technical control;

3. global movements increase as performers work toward a performance and the individual variability between performers become greater;

Five cellists were studied; each performed four unfamiliar cello pieces on three occasions: sight-reading (SR) intermediate session (IS) memorised performance (MP). In each session each piece was recorded 4 times. Measurements were made at 50 Hz with the CODA MPX30 motion analysis system; three markers were placed on each of these eight segments: pelvis, thorax, head, right upper arm, right lower arm, right hand, the bow, and the cello.

Segment position at each time point is defined as the mean of the positions of the three markers and mean position is the average over the recording period. Segment movement at each moment (a scalar) is defined as the distance of the segment from its mean position. Mean movement is the average over the recording period. Mean speed, mean angular rotation and mean angular rotational speed were similarly defined. So far the results for only one piece have been analysed: J.S. Bach: Menuet I from 'Seventh Suite' (arranged and edited by D. Kadarauch).

Results for the four recordings of the piece within each session were highly repeatable. Mean movement in sight-reading is less than in any other session; there is significant increase for all segments except hand and bow in the progression from SR session to IS+MP sessions. The differences between IS and MP are individual (perhaps related to the amount of practice?). Thus, the amount of local movements (hand and bow) changes little whereas segments participating in a more global way (expressive) change more. Bow and hand move faster than head, thorax, pelvis, upper arm, with lower arm intermediate. Speed generally increases from SR to IS and MP. Thus, speed of local movements increases (related to accuracy?) whilst that of global movements (expressive?) changes little.

For future work one may aim to examine the reasons for these trends in greater detail.

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