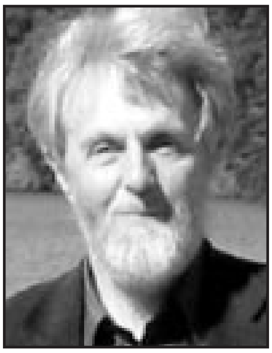
Motion Times

Journal for the motion-capture community

Theme and Variations in Repetitive Human Movements

Roger C Woledge • E-mail: r.woledge@ucl.ac.uk • UCL Institute of Human Performance RNOHT Stanmore Mddx HA7 4 LP



Human and animal movements are repetitive by nature. It is often easy to get into a rhythm of making cyclic movements and the activity can then be continued with minimal conscious effort. The movement then seems economical.

Perhaps it really is energetically more efficient than are one-off movements. It is easy too to capture by motion analysis these repeated cycles of walking or running or of arm elevation. What should we then do with these measures of repeated cycles? I hate to cut out one or a few "good ones" for further study because the bad ones illustrate just as much the behaviour of the machine we are studying and the choice of the good ones biases what we can discover. I prefer that we should include in our analysis all the data that is not technically deficient and give attention both to the mean of many cycles and to the variation of the individual cycles from the mean. Furthermore we should go beyond studying natural variations to look at small deliberate perturbations from the mean. Perhaps many labs already do these things, but that is not obvious to me from my rather too sketchy knowledge of the literature about human movement. My purpose here is to try to stimulate the appetite for such "theme and variation" studies with some examples from our CODA human motion laboratory.

The theme itself, the mean, is interesting because it reflects the basic execution plan for the movement. It is a characteristic of the individual and may be different from another person's pattern for the performance of the same task. A variation in plan could result for example from adaptation to diminished functional ability.

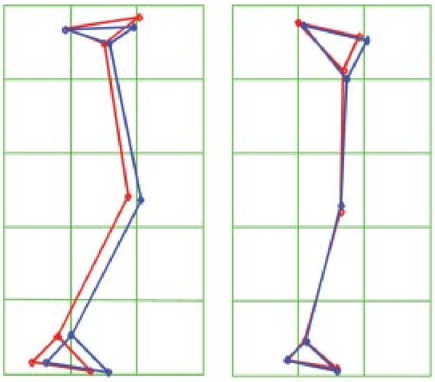


Figure 1: Averaged stick figures of left (blue) and right (red) legs during treadmill running. Two different subjects are shown. In each case the data has been time shifted to get the best match for the cycle as a whole. Each marker position is the average of between 40 and 50 observation. The grid squares are 0.2 m. The SEM of the marker positions is less than the size of the points.

Furthermore the pattern may differ between the two sides of the body. **Fig 1** is an analysis of running which demonstrates this. For two subjects we show frames from a stick figure movie made from the average of about 50 strides. We have time shifted the left side data to fit throughout the whole cycle as well as can be to the right side data. For many people, like the example on the right, the best fit is achieved with a time shift of half a cycle and gives an almost perfect fit between left and

Continued on page 2

Welcome to Motion Times

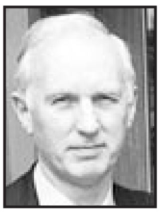
"From the 70's our technical team have been at the forefront of new techniques for automated capture, designed always with the application and the user in mind.

We are, therefore, pleased to be the sponsors of this new journal Motion Times is intended to be a vehicle for news and case studies, for an exchange of views, for an understanding of the innovative projects and technology which we are all bringing to our field.

As this is the introduction of Motion Times may I request on behalf of our editor that you support the publication by providing news, technology and application information.
A database of professionals engaged in motion capture analysis has been researched and the journal will be circulated either by email or hard copy every three months. It is our intention to make Motion Times a good read for the motion capture community and we invite you to contribute to its success."

David Mitchelson

David is the founder and Managing Director of Charnwood Dynamics Ltd. He is the pioneer of the ***Codamotion*** system of real-time motion capture and analysis.



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right throughout the cycle. However for the subject on the left the best fit required a 55 % cycle shift and is far from perfect. The differences can be seen to be statistically significant because the SEM of the position of the markers is no more than 5 mm in the anterior-posterior direction and no more than 2 mm vertically. We have not plotted the error bars because they are less than the size of the point markers. So when these markers are clearly separate the difference between left and right cannot be due to chance. It can be seen from this example that 50 strides is a convenient number to use for averaging, and it can be recorded in just a couple of minutes of running. If we used only 5 cycles the SEM would be about three times bigger and some interesting differences, up to about 20 mm, might be obscured. Averaging around 1000 strides would cut the SEM to less than 1 mm but it would probably tire the subject and change the nature of the phenomenon we are observing.

We usually carry out averaging like this using a simple registration method by which individual cycles, identified by moments when the heel markers passes down through a threshold height, are cut out and then and either stretched or compressed in time to the average time for one cycle. It is these distorted cycles that are then averaged. This has the result that the Standard Deviations of marker positions are similar throughout the cycle, rather than increasing steadily from the point at which different cycles are superimposed. It is also important to eliminate net motion of the body, which does occur of course even with our subject on a treadmill. This is done by expressing each of the marker positions with respect to the mean position of all of the markers before we do the averaging.

The variations from the mean are interesting for several reasons. Obviously they can be used in a rather boring statistical sense, as we have just done, to decide whether two sets of data are different systematically or differ just by chance. Also the size of the variations tells us about the success or otherwise of the control mechanisms in the body which try to ensure that each movement cycle is the same. As an example **Figure 2** shows some motion data obtained in floor walking over the central 5 m of an 8 m track.

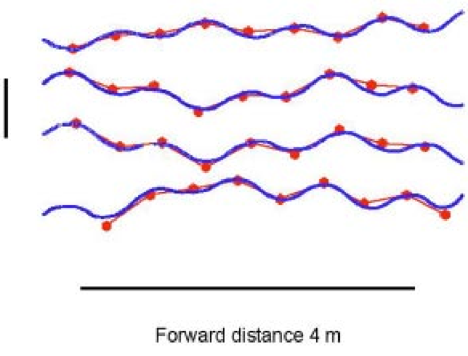

Figure 2: Blue lines are the paths followed in the horizontal plane by the thorax during four walks by the same subject. The red points mark the positions of both ankles during the stance phase of each step. Red lines join up the successive stance positions.

It shows (blue lines) the paths followed in the horizontal plane during four walks by the centre of the thorax (obviously this is a "virtual" marker). Also, shown in red, is a line joining the successive positions during stance of the two ankles (medial malleoli). This is the path of the base of support. We are interested in how closely the thorax follows the ankles and how the deviations between these two paths may change with age. We define therefore an error signal, which at each moment is the medio-lateral distance between these two paths. The RMS value of this error signal is greater in a group of elderly subjects than in a group of young subjects, but the difference is not statistically significant. However this error signal for each subject contains a mean path and a departure from the mean. **Fig 3** shows that when we cut the error signal into strides and superimpose them there is a regular pattern, part of the planned movement we presume, as well as a variation between strides.

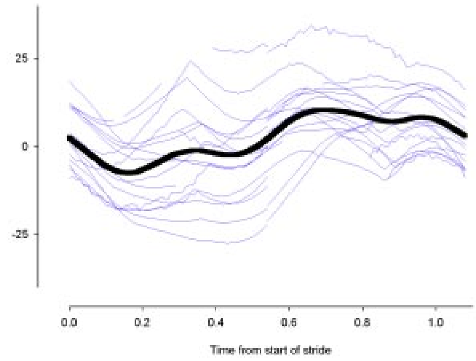

Figure 3: The thinner lines show the deviations between the blue and red lines in Figure 2 have been divided into individual strides. The thick line is the average.

Now we can reconstruct from this mean signal the path of the thorax in a hypothetical perfect walk in which the deviation between thorax and base of support paths has the same pattern in each stride. Taking this from the original error signal we can obtain the departure from the planned path. When we compare the RMS value of this random part of the error signal we see a very clear and statistically significant difference between the age groups and can identify which individuals can be said to have the less good control of the walking. Hypothetically these are the individuals at risk of falling, but this needs testing on a much bigger and more diverse group.

A possible reason for one person to have movements more variable than another's would be a diminished ability to respond to perturbations, which disturb the movement plan. We would like to find out by experiment whether this is actually the reason.

A candidate experiment for the task is the perturbation of treadmill walking. This uses a very nice feature of the CODA system, the ability to provide a real time trigger pulse. We have our subject walking on a treadmill with a light tape attached to the back of each shoe. Suitable rubber bands keep these tapes just taut all the time and they are not a hindrance to regular walking. We set the CODA trigger to fire each time one heel rises above a preset level. At random, about once in a hundred strides, we use this trigger pulse to activate an electric brake that impedes the forward motion of the foot that has just begun. This lasts about a quarter of a second and is hardly noticed by the subjects if they are suitably distracted by interesting conversation.

But the walking pattern is changed in a specific and repeatable fashion. We compare the average of about six such perturbed strides with the average of about 20 or more normal strides. Although the response of the

Figure 4: The time course of forward velocity of the foot during swing in treadmill walking. Red line is the average of 25 normal steps. The Blue line is the average of 5 steps in which the forward motion was impeded by a brake activated during the period marked by the bar Grid is 200 ms by 1 m/s.

whole body is interesting we show here what happens to the forward speed of the foot we impeded. Subjects show one of two clearly different strategies in response to this experiment. The subject shown increases the speed of her foot as soon as the brake releases and makes up most of the lost ground within the same step. Other subjects however immediately give up on the impeded stride, and have to compensate later. Our discovery of these two different strategies has distracted us so far from working out how to measure how "good" or "bad" the response to the perturbation may be and comparing this with the regularity of unperturbed walking.

We average EMG signals too. No need after that to smooth them in any other way. **Fig 5** shows some examples from a rowing ergometer study. I show this to introduce a negative aspect to averaging. This is that sometimes the average looks nothing like any of the individuals that went into the average. This is the case with these emg records, but not for the other examples I have shown here. Averaging can obscure an essential feature of records; in this case the spikiness of the emg records is not suggested by the average because the spikes occur at different places in different cycles. It is possible to carry out averaging in a way that does respect and preserve identified features by more elaborate registration in which a number of landmarks are identified and the times between them stretched of compressed in each record to the average value. But what are the landmarks to be? That question gives us pause.

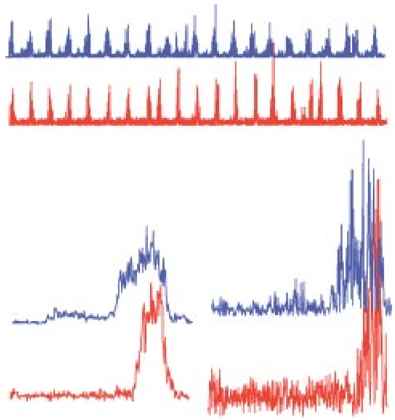

Figure 5: Emg records from lattisimus dorsi muscles during rowing on an ergometer at 20 strokes per minute. Red from the right and blue from the left side of the body. The top panel shows the rectified records as they were recorded. One cycle is shown on a larger scale bottom right. The average of about 50 cycles is shown (bottom left) on the same scale as the expanded example.

My thanks to the following for their roles in gathering and analysing the data shown here *T. Christopher, S.Bruce, D.Birtles, D.Skelton, H.Gentles, J.Wooley.*

Motion Capture on the Move

The advanced *Codamotion* system really is motion capture on the move as a new level of portability has been designed into a system already widely accepted as a benchmark for accuracy, reliability and now, technology.

What makes this advanced system so flexible, transportable and easy to use is the redesign of the main sensor unit, the CODA cx1. It now contains an advanced level of processing capability previously carried out by the main computer. This important development means that the computer specification to operate the system has been reduced from an industrial requirement to that of a standard laptop or host PC.

The CODA cx1 can now be operated using an inbuilt, rechargeable 12 volt battery, so accurate motion capture with the *Codamotion* system is now possible wherever it is required.

The fact that the system is precalibrated means that it is the most user-friendly system available and can be set up and operating in a matter of minutes.

The advanced system means that motion capture in the field is now easier than ever before, whatever the location. Sporting activities spring to mind as a perfect application example to benefit widely from the new features. Multi location organisations also gain great advantage as the system can be taken to wherever it is required and operated instantly without the need for a dedicated laboratory set-up.

No 'spaghetti' either as the power and computer wiring is now contained within a single cable. This is not only a lot neater but also contributes to the ease of the new set-up.

High quality advanced components and the introduction of new digital marker technology means that real-time is just that. It now takes less than 1 millisecond for the marker position data to be output, so multi-channel, tightly coupled, control of external devices is now possible at this same low latency.

The advanced digital marker boxes contain crystal controlled counters that provide enhanced precision in the timing of the flashing LED's, adding further to the high level of accuracy and the low latency of the system.

Medicos Biomecanica in Santiago, Chile

"We have evaluated other systems but our dual *Codamotion* set-up, which is housed in a dedicated laboratory, is the best way we have found to capture, analyse and evaluate the motion in all of the activities that we are involved in."

Work is the operative word in this case as Medicos Biomecanica in Santiago, Chile, uses the many real-time features of the *Codamotion* system to study the interaction between jobs and health, and the effect of illnesses on the ability to work. Motion capture plays a large part in the research and diagnosis of the effects of employment on health and the real-time *Codamotion* system is in daily operation.

The system is used mainly to help to predict the risks involved in a number of working situations and the promotion of the necessary actions for their reduction or elimination.

Dr Sacha Bittelman explained further:
"The main area of concentration for Medicos Biomecanica is segmental biomechanical analysis of the locomotor system. If the patient has a lower back pain or a discal hernia, we do a lumbar test. If the patient has a knee problem we do a knee biomechanical analysis using the *Codamotion* system.

"Testing of the lower limbs also includes gait analysis with a plantar pressure system (RSSCAN) and the *Codamotion* system, and then motion analysis using *Codamotion* and Surface EMG.

"For back problems, a very common work-related problem, we do the same. In the upper extremities and cervical spine we again carry out motion analysis and Surface EMG. Medicos Biomecanica works mainly with the Mutual de Seguridad an organisation that deals with worker-related injuries and is also based in Santiago.

Outsourcing Movement Analysis in Sweden

the cost-effective solution offered by BML and *Codamotion*

Sweden's Biomechanics Laboratory (BML) is situated in Linköping, one of Sweden´s leading high-technology cities. It is owned by Team Ortopedteknik Scandinavia AB, one of Sweden´s largest suppliers of technology and products related to orthopaedic science. The main objective of BML is to provide clinicians with a cost-efficient alternative to building their own laboratories. The biomechanics laboratory services offered are designed to combat the difficulties some may encounter in raising funds for an in-house movement analysis laboratory, and as a result would only be able to carry out limited analysis. With the BML solution, a full biomechanics laboratory service is conveniently available for referring clinicians.

The equipment used in the biomechanics laboratory is a full bilateral *Codamotion* motion capture and analysis system, a single Kistler force-plate and 8-channel telemetric EMG. For optimum performance, BML uses the *Codamotion* Analysis and Report Generator software to acquire and compile data.

"BML is the only working movement analysis laboratory in Sweden using equipment as sophisticated as *Codamotion* with its active marker system. Our patients come by appointment from clinicians all over Sweden," confirmed CPO and laboratory manager Kjell-Åke Nilsson.

"We make an appointment for the patient, collect and compile movement data and present it in a way preferred by the clinician. We work with physiotherapists and orthopaedic surgeons with interest in movement analysis, taking care of the data interpretation. All work is then discussed in a regional group of specialists such as surgeons, occupational therapists, physiotherapists and rehabilitation doctors as well as orthotic/prosthetic and biomechanics professionals. Suggestions for future action regarding the patient come from the whole group."

He continued: "The lab was originally designed and built to be a movement analysis laboratory. A supply room and a dressing room were cleared and rebuilt. Our goal was to make a laboratory in which patients would feel more like being at home than being in a hospital. Most of our analysis subjects are children with varying degrees of cerebral palsy (CP) and they have a need to feel secure. Some of them are reluctant to go to the hospital due to previous experiences. We believe that we have succeeded in our efforts to provide our analysis subjects with a friendly and aesthetically pleasing atmosphere in our laboratory."

Current work

In addition to the clinical acquisition of gait data in children with CP, BML has taken part in work regarding certain movements within the shoulder complex and a study on the effect of axial shock absorber units on the gait in transtibial amputees.

Kjell-Åke Nilsson continued "Since the laboratory is owned by a company that specialises in orthopaedic technology, there is no problem in having special jigs or straps made for the laboratory. Special carbon-fibre jigs for the application of markers on the upper limbs and torso have been manufactured at the Department of Orthopaedic Technology in Linköping.

"The shock absorber study needed additional information on torso movement. This was achieved through the use of specially designed arm jigs, on which markers were placed. This made it possible to record the full movement of the subjects´ bodies as they walked and ran in the laboratory."

Codamotion in Orbit

CODA units specially qualified for space flight have been designed for MIT in preparation for flight in the International Space Station. In the space-borne experiments, astronauts will wear VR headsets. Their head and hand movements will be tracked by the *Codamotion* system and the data fed back in real-time to a host computer which controls the visual scene presented to the astronaut via the headset.

A series of perceptual-motor tests will be undertaken by the astronauts. The results from these experiments are expected to shed more light on fundamental mechanisms mediating perceptual – motor skills.

In particular researchers will be seeking a better understanding of the functioning of the vestibular system and how the nervous system interprets and uses conflicting information from vestibular, visual and proprioceptive inputs.

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tel: 00 44 1422 833950 fax: 00 44 1422 833950

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