contributions to the regulation of posture, with more (less) regularity reflecting in(de)creased cognitive involvement. To investigate this 'strategy hypothesis', dynamical measures that determine the active degrees of freedom (dimensionality) and local stability (largest Lyapunov exponent) of postural sway are necessary and will be implemented in the future.


### REFERENCES

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## Prothetics

## P48

### DISPLACEMENT PATTERNS AT A COMPLIANT ADAPTER IN A TRANS-TIBIAL PROSTHESIS


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### SUMMARY

This study quantifies the displacement patterns at a compliant adapter that allows transverse rotation (TR) and longitudinal translation (LT) during stance phase with a trans-tibial prosthesis. TR was similar in pattern to that of non-amputees, but smaller in magnitude. LT was similar in pattern to that of vertical ground reaction forces (GRFs), but greater in magnitude than specified by the manufacturer of the adapter. In-socket forces were reduced due to compliance at the adapter.


### CONCLUSIONS

A trans-tibial prosthesis that incorporates a compliant adapter provides the residual limb with increased freedom for TR and LT, thus accommodating for at least some of the residual limb's natural tendency to displace during stance phase. The adapter compliance led to reduced loading rates on the residual limb and therefore reduced in-socket force measurements, as the resistance from the socket of the prosthesis against residual limb displacements was smaller than without adapter compliance.

### INTRODUCTION

During stance phase with a trans-tibial prosthesis, the loads from weight-bearing are transmitted onto the residual limb in transverse and longitudinal direction, due to multi-directional GRFs. Unlike a rigid shin tube, as is commonly used for inter-connecting the socket and prosthetic foot [1], a compliant adapter should have the capacity to reduce the loads transmitted onto the residual limb, because adapter compliance allows the magnitude of GRFs to increase gradually rather than abruptly. This study quantified both TR and LT patterns at a compliant adapter as well as in-socket forces during straight walking to establish if adapter compliance reduces the loads transmitted onto the residual limb.

### PATIENTS/MATERIALS AND METHODS

Ten male, trans-tibial amputees (mean age 44, range 27–71) volunteered to walk at a self-selected speed during gait tests. Four types of test conditions were used to establish the effect of TR and LT separately by permitting them in isolation, in combination and with neither of them. Each of the four test conditions was recorded ten times. The parameters to be obtained were quantified with six FlexiForce sensors (Tekscan, USA) for in-socket forces and with an electro-mechanical device [1] for TR and LT at the adapter.

### RESULTS

The pattern for TR was similar to that found by [2] for non-amputees, but 64% smaller in magnitude. LT was similar in pattern to M-shaped vertical GRFs, but 14% greater in magnitude than the manufacturer's specifications for average adapter displacements during straight walking. Each TR and LT were greater and in-socket forces smaller in magnitude when TR and LT were permitted in combination compared to when they were permitted in isolation or particularly when neither of them were permitted (Fig. 1).

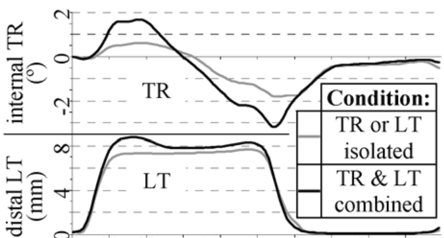


Fig. 1. Pattern of TR and LT at the adapter (displacement of the socket relative to the foot).

### DISCUSSION

Following amputation, the residual limb length is reduced, which may be the reason why TR was smaller in magnitude for amputees compared to non-amputees. A resemblance between the pattern of LT and vertical GRFs indicates that vertical GRFs appear to have a direct influence on the magnitude of LT at the adapter. Also, TR and LT only occurred during stance phase, as the adapter is a passive device that requires GRFs to displace it, which were absent during swing phase. As in-socket forces were smaller when TR and/or LT increased, it appears that compliance at the adapter seemed to have a positive effect on the residual limb.


### REFERENCES

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## Technology

## P49

### DEVELOPMENT OF AN INSTRUMENTED POLE TEST FOR USE AS A GAIT LABORATORY QUALITY CHECK


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### SUMMARY

This paper describes a new pole-based, gait laboratory quality check. It differs from previous designs in that it incorporates a 3D force transducer. Data are presented showing the successful detection of simulated error conditions.

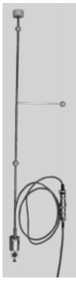

### CONCLUSIONS

The pole test provides a useful daily spot check for detecting gait laboratory system failures. Tests such as this are important for any quality system, either general (ISO 9000), or discipline specific.

### INTRODUCTION

A 3D gait laboratory contains complex measurement systems. These systems are integrated so there is a risk that sudden equipment failure, of a slow deterioration in performance can go undetected. Full calibration tests have been designed (eg Hall et al. [1]), but these are generally too time consuming to perform on a daily basis. What is needed is a quick check to verify the position measurements from the cameras, the 3D force output from the force plates and the relative alignment of the different co-ordinate systems.

### MATERIALS AND METHODS



A simple test was designed using a long metal pole, with 3 retroreflective markers mounted. The overall design and use is similar to that proposed by Holden et al. [2]. The main difference is that a 3D force transducer is incorporated into the body of the pole. To conduct the test the end of the pole is pressed against the surface of the force plate, while the pole is rotated slowly, transcribing a cone shape. This is repeated at five points across the surface of the plate. Software was produced to automate the data processing. A simple output report gives both detailed information and simple pass/fail indicators based on pre-set thresholds. The functioning of the pole was checked by collecting data sets with the lab operating correctly and under 14 simulated error conditions.

### RESULTS

| | | | |
|---|---|---|---|
| Normal function | Pass | Err 8: camera scaling error | Fail |
| Err 1: force plate Fx failure | Fail | Err 9: co-ordinate system 5 mm (x) out | Pass |
| Err 2: force plate Fy failure | Fail | Err 10: co-ordinate system 10 mm (x) out | (Fail) |
| Err 3: force plate Fz failure | Fail | Err 11: co-ordinate system 15 mm (x) out | Fail |
| Err 4: force plate partial Fz failure | Fail | Err 12: co-ordinate system 5 mm (y) out | Pass |
| Err 5: transducer Fx failure | Pass | Err 13: co-ordinate system 10 mm (y) out | (Fail) |
| Err 6: transducer Fy failure | Pass | Err 14: co-ordinate system 15 mm (y) out | Fail |
| Err 7: transducer Fz failure | Fail | | |

### DISCUSSION

The results show that when the lab is functioning correctly the pole test gives a pass. The majority of the failure modes are detected correctly. The failure to detect a transducer Fx or Fy fault is not critical, or surprising, in this configuration. The ability of the system to detect co-ordinate system shifts depends on the pass/fail threshold set. The pole test is simple enough to perform at each patient assessment. This allows the quality of an individual set of patient data to be defended and gives confidence to the clinician when analyzing patient results. The incorporation of the force transducer removes the need to assume an idealized force system and allows the magnitude, as well as the direction, of the force plate output to be verified.


### REFERENCES

[1] Hall, et al., 1996, J Biomech, 29, 659–65.

[2] Holden, et al., 2003, Gait Posture, 17, 205–13.


## P50

### CAMERA-MARKER AND INERTIAL SENSOR FUSION FOR IMPROVED MOTION TRACKING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**SUMMARY**

A method for combining a camera-marker based motion analysis system with miniature inertial sensors is proposed. It is used to fill gaps of optical data and can increase the data rate of the optical system.

**CONCLUSIONS**

Inertial sensors provide accurate position tracking in case of optical data failure. The errors will grow with the gap time, but off-line analysis significantly reduces the errors. During high dynamic movements, big errors were observed using a standard spline function; however, the inertial sensors measured the trajectory correctly.

**INTRODUCTION**

Optically based systems offer accurate position tracking of body segments. However, the line of sight from marker to camera can be blocked resulting in incomplete data. Miniature inertial sensors like accelerometers and gyroscopes have been proposed as an alternative to camera-based systems [1]. They do not suffer from line-of-sight problems or high costs related to the optical systems, but they are prone to errors due to integration drift. In this study, an optical system was used to update the inertial position estimates and correct drift errors.

**METHODS**

To blend the available data from the inertial sensors and optical system, a complementary Kalman filter was designed in which position, velocity, acceleration and orientation errors were computed based on the measurements of the gyroscopes, accelerometers, optical system and their models [2]. In an offline analysis, a smoothing algorithm [2] was used in which the data was also processed reverse in time. An optical marker was attached to an inertial sensor module (MT9-B, Xsens) and a 6 camera Vicon 470 system was used to capture the trajectory of the marker. The module with marker was moved through the lab by hand in 20 trials (1–2 min).

**RESULTS**

Fig. 1 shows an example of a simulated gap in the optical data from 7 to 9 s in the lab's z-direction. The 3D measurements from the Vicon system were assigned as unavailable for this period and the Kalman filter estimated the 3D position changes based on the inertial sensor data. The dashed line in the upper graph is the connection between the last and first available optical frames by a standard spline function. The maximum error plotted is 12.1 cm compared to the original Vicon data. The drift errors of the inertial sensors in a forward (real-time) Kalman filter increased with time to a maximum of 1.1 cm, however in the smoothed filter (off-line) the error is limited to 0.38 cm (lower graph). The average error using the smoothed filter after a gap of 0.5 s was 0.1 cm (S.D. 0.03) and increased to 0.25 cm (S.D. 0.12) with a gap time of 1 s.

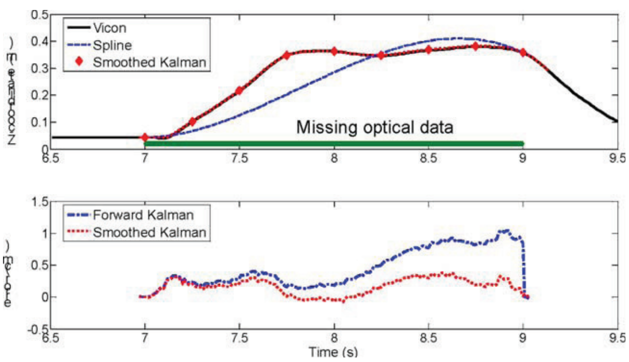


Fig. 1. Two seconds of gap filling with a spline function and inertial data (upper) and the Kalman errors (lower).

**DISCUSSION**

The combination of an optical system running at a relatively low rate combined with low cost inertial sensors sampled at high frequencies can provide an alternative for expensive high-speed cameras and the offer the possibility to measure accelerations of body segments directly instead of differentiating the optical data.

**REFERENCES**

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[2] Brown, Hwang, 1997, Introduction to random signals and applied Kalman filtering, John Wiley.

## P51

### TOWARDS PATIENT TRAINING BY AMBULATORY MONITORING AND FEEDBACK OF POSTURAL LOAD EXPOSURE

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**SUMMARY**

Research goal: To examine the possibilities of training people to minimize their mechanical joint load (e.g. in the low back) by applying automated feedback of orientation based parameters, or by automated assistance of coaching by ''clinicians-on-a-distance''. A prototype system has been developed. Inertial sensing is used for the ambulatory measurement of dynamic 3D orientation, and ICT applications are developed for online monitoring, generating feedback, and support for coaching. The measurement method was tested with healthy subjects in an ergonomic assessment. Current work consists of experiments with patients in specific rehabilitation programs, verifying if the system can function as an aid in changing behaviour. This poster tries to rise discussion on what protocols might be most effective for training. Research questions in this practical part of the study vary from basic learning principles, to acquiring relevant parameters of posture and guidelines for thresholds of feedback, and will build up progressively towards the development of treatment protocols.

**CONCLUSIONS**

It is technically possible to ambulatory assess posture statistics in terms of accurate 3D body segment orientations, while monitoring the stream of data over standard internet facilities. It is still unclear to what extend, or in what way the automated feedback of posture will lead to a change in behaviour.

**INTRODUCTION**

Within the ExO-Zorg framework knowledge is gained considering modelling, design and control of ambulatory health care processes, with the help of ICT applications focused on supplying direct automated feedback, and giving the opportunity for professional support on a distance. For the area of postural load a prototype system has been developed.

**MATERIALS AND METHODS**

The proposed method consists of 3D inertial motion sensors, custom calibration protocols for translating sensor to body segment kinematics, applications for the ambulatory measurement of posture and online streaming of data to a server, server-side online analysis, and online monitoring software which can be assessed by a clinician with a standard web browser from anywhere on the internet.

**RESULTS**

Some first measurements have taken place with healthy subjects in an ergonomic assessment, to test the several functional parts of the system. Calibration of sensors to body segments showed errors less than 2° for thorax and head, to 5–7° for the upper arm. Currently the system supplies feedback based on ergonomic guidelines, but relevant parameters can be adjusted as needed. Current work focuses on applying the method as a coaching assistant for patients suffering from low back pain.

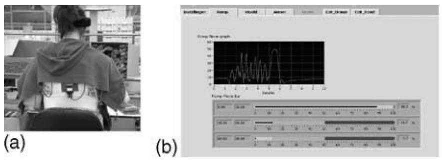


Fig. 1 (a) Subject wearing the system. (b) Output of monitoring software, orientation is distributed over time and categories of posture, thresholds for risk are indicated with colours green, orange and red. (c) Example of a visual feedback modality. Segments will change colour when values are above threshold.

**DISCUSSION**

Discussion is required on: (1) Relevant parameters and amount of information. (2) Acquiring appropriate guidelines and protocols for applying feedback. (3) Basic learning principles (frequency, modality of feedback (visual, sound, vibration), automated feedback or coaching by a clinician, obligatory or compulsory feedback.

**REFERENCE**

[1] Chris T.M. Baten, Ambulatory low back load exposure estimation, in: Proceedings of the IEA 2000, 2000, San Diego.

# Toxin

## P52

### HOW DO REPEATED BTX-A TREATMENTS CHANGE THE WALKING PATTERN IN CHILDREN WITH CP? A LONGITUDINAL EVALUATION

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**SUMMARY**

The effect of repeated botulinum toxin A (BTX-A) treatment session on gait in young children with cerebral palsy (CP) was evaluated, with an averaged follow-up period of 2.3 years.

**CONCLUSIONS**

The present study demonstrates that improved gait can be achieved after repeated multilevel BTX-A treatment. The most significant changes were seen at the ankle joint. The score for Physician Rating Scale (PRS) significantly increased after each treatment session.

**INTRODUCTION**

Positive short-term outcomes with BTX-A have been described in a large number of studies. However, there is a lack of long-term outcome studies of BTX-A treatment in children with CP. Perfectly timed repeated multi-level BTX-A treatments, started at an early age, combined with casting and physiotherapy, may influence the natural history of the child with CP. The purpose of the study was to evaluate the effect of repeated BTX-A treatments in young ambulant children with CP.

**PATIENTS/MATERIALS AND METHODS**

Twenty-six children with CP (22 with diplegia and 4 with hemiplegia) were included in this retrospective study according to the following inclusion criteria: predominantly spastic type of CP,