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Case study

CAREN (computer assisted rehabilitation environment): a novel way to improve shoe efficacy
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Abstract
A new technical system, CAREN (computer assisted rehabilitation environment), is described, which makes it possible to do a total body movement analysis in a virtual environment. The virtual environment is reproducible and as close to natural environment as possible. In a case study it proved possible with this system to test different shoes and get insight in the movement problems. The importance of whole body analysis is demonstrated in this case study. The adjustments made in the shoes could be tested for their efficacy.

Introduction
Prescribing and designing shoes is often experience based although, through technical assessment, insight in the biomechanics and material interface is improving. Often used methods are for example force platforms (Chaudhuri and Aruin 2000), 2 or 3 dimensional gait analysis with or without markers (Finlay et al., 1999), Stacoff et al. 2001; Sandrey et al., 2001) or in-shoe data acquisition (Morley et al., 2001). Walking however is an activity involving the whole body with the shoes as an element in the biomechanical chain. It is therefore preferable that data can be acquired from the whole body at the same time. It is even more preferable that the persons tested can move as naturally as possible, in their natural environment and not in a laboratory environment. This is made possible with CAREN.

Technical equipment
Computer Assisted Rehabilitation Environment (CAREN) combines virtual reality with a total body movement analysis system. CAREN measures movements simultaneously in the x, y and z-axis by means of body markers, thus creating a comparison in time in 3 dimensions of whole body movement. Sampling is at 120 Hertz and the system has a standard error of 1-millimetre (range 0.5-1.4). The obtained data are digital, thus statistical analysis is possible. CAREN is composed of a large screen (on which the virtual environments are projected, e.g. the visual environment), a 6 degree of freedom moving platform (for the physical environment input)(Micro motion system), an optical marker system (tiny reflecting balls, monochromatic lights and detecting cameras in a large ring above the person) (Vicon 6 Precision Motion Analysis System) and a Silicon Graphics Octane computer (Fig. 1). The software is specially designed and contains self-threaded algorithms and the human body model developed by E. Otten (Eerden et al., 1999). This makes it possible that the person interacts in real-time with his environment.

Patient
A young woman was referred for advice after a long period of experience with different
customised shoes. She was born with a left fibula aplasia, operated frequently in her youth with continuous physiotherapy. Her left ankle was stiff (arthrodesis) and her left knee was unstable in lateral and forward/backward direction when passively tested, but close to stable when activated by muscle. She had a normal walking pattern, although her walking speed could be regarded as high. She complained of pain in her left forefoot that started while walking and this reduced her walking distance. By the time of referral the pain would not go away even after stopping walking. She had a customised shoe in which her foot was placed in neutral position with a rocker bottom sole. She preferred however to walk on a cast (comprising her foot, lower leg up to her knee).

The authors tested her dynamic standing balance on the so-called road-environment in which there are bends and bumps (thus vertical and horizontal disturbances). Movement analysis showed that her whole left body side moved differently from normal. Figure 2 is an example of the differences in movement patterns of her shoulders (right normal, left more divergence). The difference was most obvious in her left knee, that was extremely unstable (Fig. 3A). Also a large difference could be noticed between bare-foot test and cast test situation (Fig. 3B), in which the left knee was more stable in cast test situation. This difference could also be noticed between old shoe test and cast test situation (Fig. 3C), in which again the cast gave more stability in the left knee. Based on these data a new shoe was made:

her forefoot was put more in the equinus position that forced the knee in slight hyperextension (remember her fixed ankle) and the shank of the shoe was made higher (to give her more sensory input on her lower leg, since in fibula aplasia not only the bone is missing but also muscle and nerves). When tested the new shoe displayed an increase in stability at least comparable to that of the cast, and it also showed that in both knees the stability improved with the new shoes (Fig. 4). In practice while wearing the shoe the pain disappeared, her walking ability improved and her normal social life was again possible.

Discussion

It this study two major points concerning movement analysis are accentuated: movement involves the whole body and movement is an interaction between the whole body, the task and the environment (Perry, 1998). To study these two aspects of movement the use of the CAREN system was of utmost importance: the ability to study whole body movement in interaction with a virtual environment. Furthermore the system proved to be sensitive enough to detect different testing circumstances (footwear) in a standardised environment: the different footwear under the same testing conditions gave different movement curves.

Usually movement analysis is either performed with markers on body parts and not on the whole body or is done in a laboratory environment, which is rather different from the
Fig. 3. Graphical representations of the movement on the left knee marker in the sagittal plane. The curves are superimposed by means of synchronising the sampling frames (X-axis). On the Y-axis the movement of the body marker in millimetres, except for Figure 3A, where a relative scale is used.

A: vector representation of the movement directions in the left (lower line) and right knee (upper line) in barefoot circumstances: notice the instability in the left knee compared to the right knee.

B: comparison of the left knee movements barefoot (thin line) and with cast (thick line): notice the stability with cast which can be seen as fewer disturbances of the movement line.

C: comparison of the left knee movements with old shoe (thin line) and with cast (thick line): notice that the cast gives a more stable pattern in the left knee than the orthopaedic shoe.
natural environment and the normal tasks in the natural environment. In natural environments motor patterns are normally autonomous patterns, while in unnatural (laboratory) environments the movement can be regarded as a process of learning new (unnatural) motor skills, in which cognitive influence is much higher. Therefore movement analysis must be as close as possible to natural movement patterns or natural motor programmes in a person’s own environment. Most testing circumstances for balancing or walking are focused on the accomplishment of the movement task, although double tasks are introduced (such as counting); still the testing situation is very unnatural. It is very unlikely that the movement patterns recorded thus are totally autonomous patterns. Testing a person in their natural environment is technically possible but very time and money consuming. Virtual reality is an intermediate solution.

The importance of studying the whole body is demonstrated in this study: the whole left body side moved differently from normal and the largest divergence could be detected in the left knee. Thus CAREN has proved helpful in analysing the movement disorder: although the pain in the forefoot was the reason for visiting the rehabilitation physician, the problem seemed to be originating in the position and stability of the knee. Furthermore the sensitivity of the system allowed testing the adjustments in her new shoes for efficacy.

The limitations of the CAREN system are the voluminous setup and costs of the system. It is therefore not to be expected that every department has its own setup and uses it routinely for every patient, but that the system is available in collaboration. However, CAREN is a useful addition for analysing and evaluating therapy in selective use.

Conclusion
Movement analysis involves the whole individual and its environment; the CAREN system provides the opportunity to study this. CAREN has the potential to assess the efficacy of shoes, orthoses, prostheses and therapy in respect of dynamic balance and the influences of environments on the dynamic balance. CAREN is therefore a powerful instrument to increase insight in biomechanical mechanisms and design.

REFERENCES


