Towards ambulatory assessment of spinal loading in the field

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This paper presents an overview of the research that we carried out during the Master, PhD (Faber, 2010) and Post-doc projects of Gert Faber in the past decade. The main aim of this research is the development and validation of an ambulatory/wearable measurement tool for automated assessment of biomechanical loading of the joints, with a focus on the spine.

Background

Low back pain is still a major socioeconomic burden (Vos et al., 2012), and mechanical loading of the spine is regarded to be a major cause. Therefore, methods have been developed to assess spinal loading (moments/forces) in the laboratory using advanced equipment such as 3D motion capture systems and force platforms. Besides laboratory studies, accurate assessment of spinal loading is also important in field studies regarding the prevention of occupational low back pain. For instance, in epidemiologic studies investigating the relation between spinal loading and low back pain (Hoogendoorn et al., 1999; Kuiper et al., 2005; Lötters et al., 2003), and studies investigating the effect of ergonomic interventions on spinal loading at work (Lötters and Burdof, 2002; van der Molen et al., 2005).

In the first part of this paper we will provide some examples of typical laboratory studies that we carried out. In the second part some studies will be presented in which a working situation from the field was simulated in the lab and laboratory equipment was utilized in the field setting. The last section of this paper discusses more recent research about the validation of new wearable measurement technologies for the assessment of spinal loading in the field.

Typical biomechanical lab studies

Over the years we have done several typical biomechanical lab studies (Faber et al., 2009a; Hoozemans et al., 2007; Kingma et al., 2006a; Kingma et al., 2006b; Kingma et al., 2010). For example (Figure 1), in some studies we investigated the effect of lifting techniques (e.g. stoop, squat, weightlifter's and straddle techniques) on spinal loading under different conditions (varying box dimensions and lifting height & weight). The conclusion of these studies is that the most effective lifting technique is dependent on the task constraint. For example, while a squat technique results in lower spine loads then a stoop technique in case the box with handles is small enough to be lifted between the knees. However, when a box is too large to be lifted between the knees, the opposite is true.

Figure 1: Typical lab study investigating the effect of lifting technique on spinal loading

Bring field to the lab and lab to the field

Because typical lab studies are not so realistic, subject probably don't move in a natural way. Therefore, we performed a number of studies in which we brought the field to the lab and the lab to the field.

In one study (Figure 2, left) we simulated a construction lifting task in the laboratory (Faber et al., 2009c; Faber et al., 2007, 2011). One important finding was that lifting height has more effect on the spinal loading then block mass. One reason for this is that construction workers choose to lift the lighter blocks from a further horizontal position resulting in an attenuated effect of block mass.

In another study (Figure 2, right) we investigated the effect of ship motion on spinal loading (Faber et al., 2008). In this study we transported all our lab equipment to a navy ship and performed a lifting experiment with navy personnel while sailing at sea. The main finding was that spinal loading increased with increasing ship motions (due to the height of the waves and the direction and speed of the vessel), and that even highly experience personnel was unable to adjust the motion pattern to cancel out the effect of the waves on spinal loading.

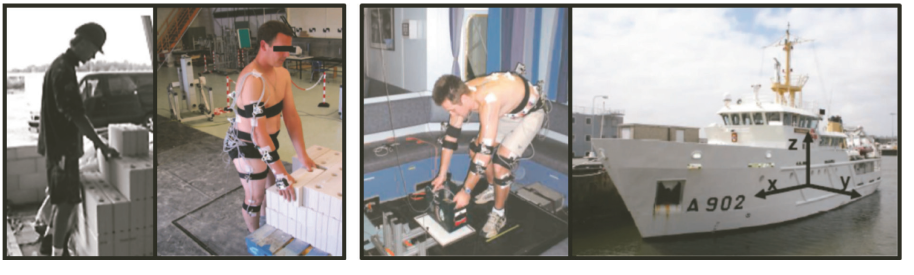

Figure 2: Left: Study with construction workers in the laboratory performing a simulated building block lifting task (bringing the field to the lab). Right: Study in which the effect of ship motion was measured on a shop at sea using lab equipment (bringing the lab to the field)

Figure 3: This figure shows how the laboratory measurement equipment could be replaced by ambulatory measurement techniques, combined in one system.

Validation of ambulatory measurement systems

Even when the work situation is accurately simulated in the laboratory, laboratory conditions may still affect natural behavior (white coat effect). The same holds when measuring with laboratory equipment in the field. It would better to study subject in their own work environment, without using equipment that limits the natural motion pattern. In the past this had been mostly done using video analysis. However, some disadvantages are that this is very laborious, there is still an external observer, and the cameras have a limited measurement volume.

To overcome these limitations, more recently we started working with wearable sensors, developed for automated ambulatory measurement in the field. We proposed to use inertial sensors for measurement of kinematics and instrumented Force Shoes for the measurement of external forces, also allowing for kinetic calculations (e.g., joint moments) (Figure 3).

In a series of validation studies we have investigated the performance of the different sub-systems. We showed that kinematics can be obtained using inertial sensors with good accuracy (Figure 4, left) (Faber et al., 2013b; Faber et al., 2013c; Faber et al., 2009b), and that ground reaction forces can be measured accurately with ForceShoes (Figure 4, right) (Faber et al., 2012; Faber et al., 2009d). In another experiment we showed that is it possible to estimate hand forces based on segment accelerations and ground reaction forces (Figure 5) (Faber et al., 2013a). In the most recent paper (Faber et al., 2015) we showed that spinal moments due to trunk motion can be estimated using an inertial motion capture (IMC) system with sufficient accuracy (Figure 6).

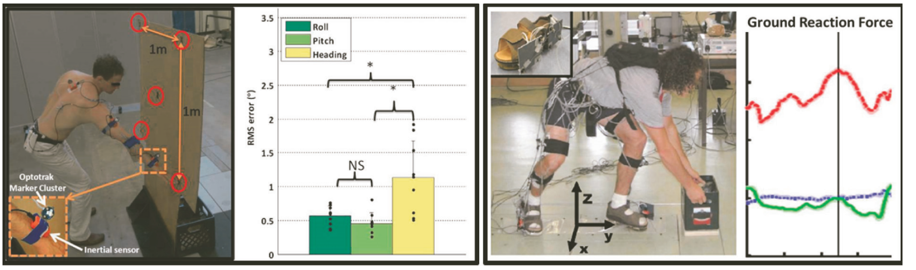

Figure 4. Left: Result of the study showing that inertial sensors can measure 3D angles with high accuracy. Right: Study showing the validity of force ForceShoes for measurement of 3D ground reaction forces: signals completely overlap with those measured by a forceplate.

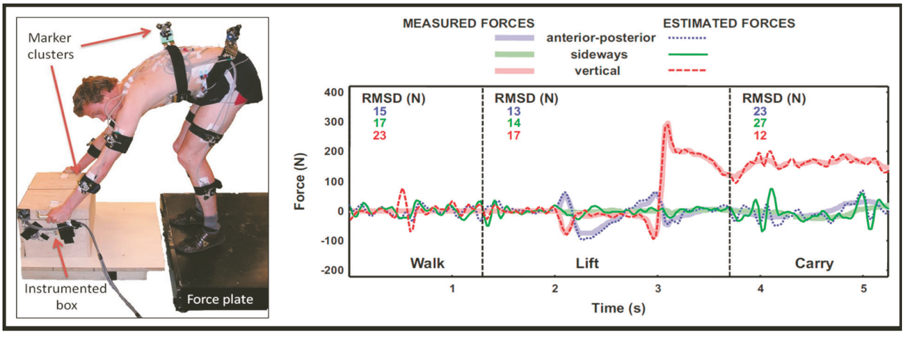

Figure 5: Typical example showing how accurately hand forces can be estimated based on ground reaction forces and full-body segment accelerations.

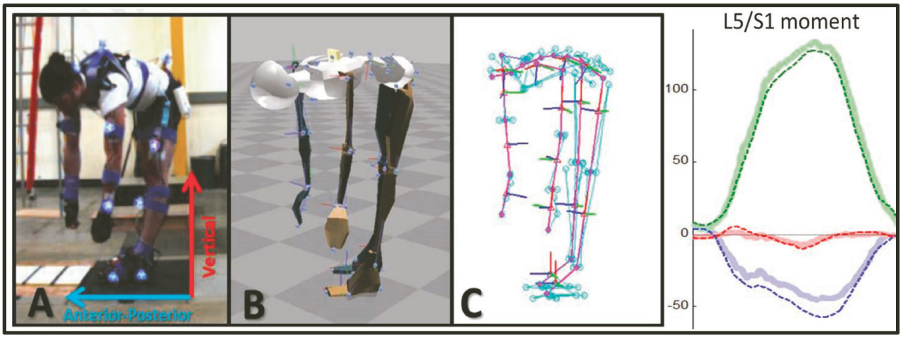

Figure 6: Proposed measurement system, combining an inertial motion capture (IMC) system and ForceShoes for estimation of spinal (L5/S1) moments using a top-down inverse dynamics model.

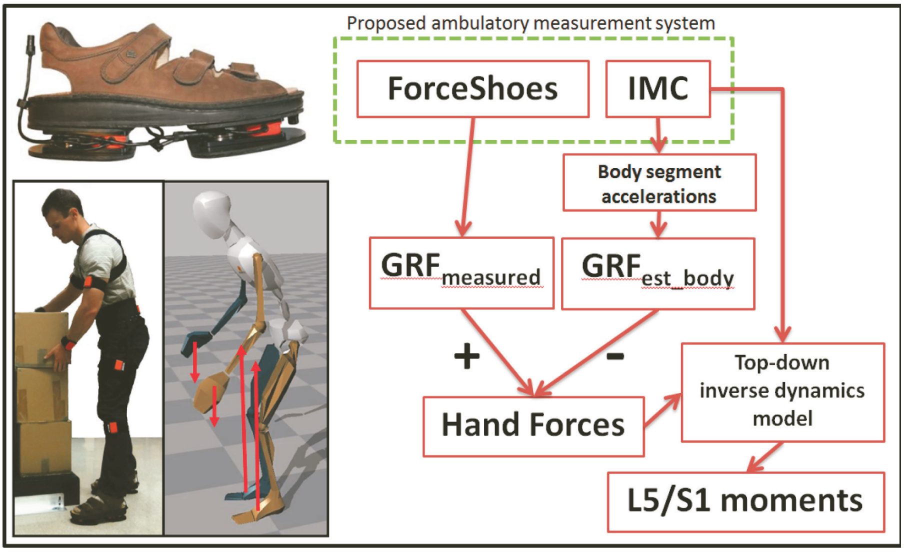

Figure 7: Typical example showing how accurately spinal moments (L5/S1) can be estimated using a full-body inertial sensor suit.

Currently we are working on combining all the sub-systems for the estimation of spinal loading due to body segment motion and external hand forces. Because it is not practical to measure hand forces in the field, we propose to estimate the hand forces based on the GRFs measure with the ForceShoes and the segment accelerations measure with the inertial sensors (see fig 7). Subsequently, a top-down inverse dynamics procedure will be applied, using hand forces plus upper body orientation and accelerations to calculate moments at the lowest lumbar vertebral level (L5/S1). After this validating this final step, we would like to apply the proposed system in future field studies.

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