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# Real-time visual biofeedback during weight bearing improves therapy compliance in patients following lower extremity fractures

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ABSTRACT

*Background:* Individuals with lower extremity fractures are often instructed on how much weight to bear on the affected extremity. Previous studies have shown limited therapy compliance in weight bearing during rehabilitation. In this study we investigated the effect of real-time visual biofeedback on weight bearing in individuals with lower extremity fractures in two conditions: full weight bearing and touch-down weight bearing.
*Methods:* 11 participants with full weight bearing and 12 participants with touch-down weight bearing after lower extremity fractures have been measured with an ambulatory biofeedback system. The participants first walked 15 m and the biofeedback system was only used to register the weight bearing. The same protocol was then repeated with real-time visual feedback during weight bearing. The participants could thereby adapt their loading to the desired level and improve therapy compliance.
*Results:* In participants with full weight bearing, real-time visual biofeedback resulted in a significant increase in loading from 50.9 ± 7.51% bodyweight (BW) without feedback to 63.2 ± 6.74%BW with feedback (P = 0.0016). In participants with touch-down weight bearing, the exerted lower extremity load decreased from 16.7 ± 9.77 kg without feedback to 10.27 ± 4.56 kg with feedback (P = 0.0718). More important, the variance between individual steps significantly decreased after feedback (P = 0.018).
*Conclusions:* Ambulatory monitoring weight bearing after lower extremity fractures showed that therapy compliance is low, both in full and touch-down weight bearing. Real-time visual biofeedback resulted in significantly higher peak loads in full weight bearing and increased accuracy of individual steps in touch-down weight bearing. Real-time visual biofeedback therefore results in improved therapy compliance after lower extremity fractures.

## 1. Introduction

The weight bearing regime after surgery of lower extremity fractures is controversial and mainly experience based instead of evidence based [1]. Early weight bearing is preferable, as it has beneficial effects on fracture healing. It causes micromovement at the fracture site, which triggers a cascade of cellular events, resulting in the process known as mechanotransduction [2–4]. Furthermore, weight bearing increases bone metabolism and has a positive effect on muscle mass and bone mass [4]. Despite the beneficial effects of early weight bearing, it is avoided in many indications for reasons of safety, for example to protect the mechanical construct or maintain fracture reduction [1]. However, unloading an extremity induces negative effects, such as skeletal muscle atrophy due to decreased transient receptor potential canonical type 1 (TRCP1) protein [5] and loss of bone mineral density [4,6]. The treating physician has to determine the optimal weight bearing regime, while balancing between increasing bone growth and muscle mass and protecting the mechanical construct at the fracture site.

Visual biofeedback could improve weight bearing compliance during gait training [7–9]. From previous studies it is known that, in the absence of biofeedback, individuals often experience difficulties in following the prescribed weight bearing regime. This results in limited therapy compliance in full weight bearing, partial weight bearing and touch-down weight bearing [10–14]. In full weight bearing, individuals often underload the fractured extremity due to factors such as pain, anxiety or uncertainty. This could negatively affect the process of mechanotransduction and cause a delay in fracture healing. For partial

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**Fig. 1.** The SensiStep system. Real-time visual biofeedback was shown on the tablet as a green bar (i.e. target weight) with grey step curves (actual weight). Both the participant and the physical therapist had insight in weight bearing during the feedback session. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

weight bearing, low therapy compliance results in potentially unsafe conditions by overloading the affected extremity, possibly inducing fracture displacement or mechanical failure. Others have already shown that variance in loading in partial weight bearing is wide, resulting in higher peak loads than anticipated [10,14,15].

The positive effects of biofeedback were previously shown in healthy volunteers using haptic feedback [14] and in individuals with lower extremity injuries using auditory feedback [16,17]. Visual feedback was shown to be effective in Parkinson's disease, in the late period after stroke and after cerebral palsy [7–9]. Still, evidence on effectiveness of biofeedback systems in weight bearing is limited and currently available systems have significant drawbacks, either technological or functional. Many systems are not capable of providing real-time feedback, have not been validated for correct detection of loading, or are not available outside a laboratory setting [18]. The SensiStep (Fig. 1, Evalan BV, Amsterdam, The Netherlands) has previously been validated in static and dynamic situations and is able to provide real-time visual feedback in the ambulatory setting [19].

The SensiStep was used to investigate the effect of real-time visual biofeedback on weight bearing in the ambulatory, clinical setting in two conditions: full weight bearing and touch-down weight bearing. We hypothesize that therapy compliance can be improved using visual biofeedback in individuals after lower extremity fractures. Ideally this should result in higher peak loads during full weight bearing, and decreased variances in peak loads during touch-down weight bearing.

## 2. Materials and methods

### 2.1. Inclusion and exclusion criteria

In a level I trauma center, individuals who underwent surgery of the lower extremity after trauma were asked to participate. Surgery was either performed within days following a fracture (fresh fractures), or late to treat long term complications, e.g. a non-union or a malunion (revision surgery). The participants were allowed either full weight bearing or touch-down weight bearing following the surgical procedure at the discretion of the treating physician. Exclusion criteria were 1) weight > 120 kg, 2) cognitive impairment or 3) inability to achieve dorsiflexion of the ankle joint, as the position of the sensor in the SensiStep system requires a neutral foot posture. This research protocol was approved by the medical ethics review board of the institution (approval number 11-317/C).

### 2.2. Study design

The participants received either conservative treatment or underwent surgical procedures for fixation of a lower extremity fracture or revision of previous posttraumatic injuries. The first day of conservative treatment or after the surgical procedure, participants started mobility exercises under direct supervision of an experienced physical therapist according to standard institutional protocol. This protocol included training exercises to walk safely, if needed with the use of walking aids. All physical therapists involved in this study were qualified for orthopedic and trauma rehabilitation. They were appointed solely to these departments. The standard institutional protocol for mobilizing the participants was repeated daily. The study protocol started at the day the participants were able to walk safely, as determined by the physical therapist. The participants were instructed to walk 15 m in a straight line with SensiStep without feedback, meaning that neither the participant nor the physical therapist had direct insight in weight bearing. Immediately thereafter, in a return walk, the participant and the physical therapist received real-time visual feedback on loading, with the desired level of loading indicated on the tablet. The order of walking without feedback followed by walking with feedback was deliberately chosen to avoid the potential influence of a learning effect. Previous studies are inconsistent about the learning effect of biofeedback and an immediate effect cannot be ruled out [20]. Feedback was provided using a tablet with graphic real-time representation of each step. The applied weight of individual steps was directly visualized, as well as the desired target weight, which was illustrated as a green bar in the same graph (Fig. 1). The healthcare professional, also looking at the tablet, verbally assisted and motivated the participant to improve weight bearing. For participants with full weight bearing, the target load was set at 100% bodyweight (BW) (range: ± 10 kg). For participants with touch-down weight bearing, the target load was set at 10 kg (range: ± 5.0 kg), as previously defined by others [10,12,14].

### 2.3. Data analysis

All raw data were encrypted and stored on a secured server. The raw data were analyzed with MATLAB 2014a. Data from full weight bearing sessions were analyzed separately from data from touch-down weight bearing sessions. Specific Matlab routines were developed to convert the raw data into the parameters of interest, the peak load and the loading rate. The peak load of a single step was previously defined as the maximum peak during the entire gait cycle of a step [21]. Per participant, the mean peak load per session was calculated by taking the average peak load of all single steps. The results are shown in percentage bodyweight (%BW) for full weight bearing and in kilograms (kg) for touch-down weight bearing. The loading rate was defined as the steepness of the curve and shown for both weight bearing regimes in kilograms per millisecond (kg/ms). The mean loading rate per session was used for statistical analysis. Both parameters have previously shown a clear relation with rehabilitation progress in elderly with hip fractures [21]. It is expected that both peak load and loading rate will increase when the participants reach the endpoint of rehabilitation [21].

### 2.4. Statistical analysis

The D'Agostino-Pearson omnibus test was used to confirm normal distribution of the datasets. Then, the paired Student's *T*-test in Prism 7.02 (GraphPad Software Inc., La Jolla, CA, USA) was used to determine differences in weight bearing parameters between the training with and without feedback from SensiStep. To compare variance of the data, specifically in touch-down weight bearing, the F-test was used. All data are shown as mean ± standard deviation (SD). Significance was set at $\alpha < 0.05$.

## 3. Results

Between August 2015 and February 2016, a total of twenty-six consecutive individuals were eligible for inclusion. Three of these were excluded; one was unable to achieve dorsiflexion of the ankle joint and in two cases technical failure of the tablet occurred. Eleven participants