AN EMPIRICAL AND MODELING ANALYSIS OF THE AREA-ELASTIC SURFACE IN A GYMNASIUM

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The external load acting on an athlete during landing on area-elastic surfaces in gymnasiums is an important factor concerning overload injuries. Nevertheless, there is a lack of force measurements on this kind of surface. This study describes technical problems of these measurements and presents an easy method to calculate the most important characteristics of an area-elastic surface: spring and damping functions and accelerated mass. When using suitable non-linear spring and damping functions the simulations with the model of the surface lead to results, which agree very well with empirical measurements ($r^2 = .99$, $p<.001$). An accurate description of the gymnasium's surface is a first step for the aim to reduce the number of overload injuries.

KEYWORDS: surface, area-elasticity, spring, damper, force plates, landing

INTRODUCTION: In the past, many biomechanical studies deal with the measuring of external load (i.e. ground reaction force) and/or the calculation of internal load (i.e. load of joints) during landing movements in sports. This field of investigation is also important for many indoor sports activities as volleyball or handball. Here external load acting on the athlete does not depend on the landing technique only but also on the characteristics of the gymnasium's floor. If this aspect is not considered and the external load is measured under laboratory conditions on a point-elastic floor, the obtained results will not represent the gymnasium's conditions. This problem also exists concerning simulation results, if the measured external load will be used as input parameter for a model of the lower extremities - independent of the model's accuracy. So the purpose of the study is to get more information on the characteristics of gymnasium floors by measuring forces and accelerations and constructing a model of a floor.

Stacoff et al. (1987) measured vertical ground reaction forces (VGRFs) up to 2000 N under the forefoot during landing after a block in volleyball. Nigg (1988) published peak passive VGRF of 4 bw (body weight) during landing after a block and 6 bw during landing after a jump spike. De Vita and Skelly (1992) reported peak passive VGRF during forefoot-landing from 59 cm height in the time interval [15 ms; 53 rns]. VGRFs of around 4 bw during landing from 25 cm height were published by Rutkowska-Kucharska (1998). The literature search yielded no information about force measurements on an area-elastic surface in a gymnasium although the surface's characteristics have been discussed as an important factor for overload injuries (i.e. Nigg and Yeadon, 1987). In consequence, up to now investigations deal with the influence of friction attributes (Valiant et al., 1986; Yeadon and Nigg, 1988; Chesney and Axelson, 1996) or with the influence of vertical deformation of the floor (Nigg, 1988; Yeadon and Nigg, 1988). It is assumed that a higher deformation and greater deformation area result in lower external load acting on the athlete (Nigg, 1990). Nevertheless, this assumption has not been validated due to technical problems. When mounting a force platform on an area-elastic floor in a gymnasium, it has to be considered that the obtained result is influenced by the mass and geometry of the platform, because the accelerated mass and the accelerated area of the floor are changing (Peikenkamp et al., 1998). An alternative is the pressure distribution. The advantage of this measuring system is the low mass, the disadvantage the resolution (Hennig, 1998). So, either the spatial resolution is too small which makes it impossible to calculate the acting force on the basis of the pressure distribution values or the measuring frequency is only 50 Hz-100 Hz, which is insufficient for landing movements. To avoid the above mentioned problems in some studies specimens of investigated floors are fixed on a platform (i.e. Müller, 1997). This kind of study neglect the characteristics of the area-elasticity of the floor, which has a great influence as it is shown by Yeadon and Nigg (1988). They measured the vertical deformation of a floor in a gymnasium and of a specimen (2x2,5 m^2) of the same floor under the same conditions. The deformation was nearly three times higher for the specimen.

METHODS: VGRFs under one foot were measured during landing after a jump shot in handball with two platforms of different mass and geometry. One subject performed 10 trials on each platform. The platforms were fixed by screws on the gymnasium's floor. Platform 1 (PF 1) had a mass of 90 kg and both a contact area with the floor and a landing area of 60*40 cm^2, whereas platform 2 (PF 2), which was build in our laboratory (Huo et al., 1999), had a mass of 3 kg and a contact with the floor of 20'9 cm^2 and a landing area of 36'50 cm^2. The technical data of the plates are shown in Table 1.

Table 1 Technical data of the force plates

	PF 1	PF 2
non-linearity	< 1%	< 1%
nature frequency	> 200 Hz	> 150 Hz
cross-coupling	< 3%	< 3%

The measurements were done to get an impression of how strongly the measured forces are influenced by the different masses and geometries. Moreover, the vertical acceleration of the floor during impact with a shot (mass of 2 kg) from a constant height (0.38 m) was measured with a I-dimensional accelerometer. The overall measuring frequency was 1000 Hz. The reason for the acceleration measurements is to obtain input parameters for a 1 mass - 1 spring - 1 damper -model of the gymnasium's floor (Figure 1).

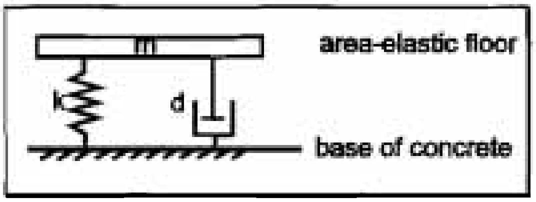

Figure 1 — Model of the area-elastic floor in the gymnasium

The mathematical description of the model is

$$m\ddot{x} + dx + kx = 0$$

where
- m is the accelerated mass of the floor
- k is the spring function with deformation as independent variable
- d is the damping function with velocity of deformation as an independent variable

The simulations with this model should give information about
- the swinging characteristics of the floor, expressed by the spring function k and the damping function d
- the accelerated mass m of the floor
- the accelerated area of the floor

RESULTS AND DISCUSSION: Figure 2 shows typical VGRFs measured on the area-elastic surface in the gymnasium with the two platforms PF 1 and PF 2.

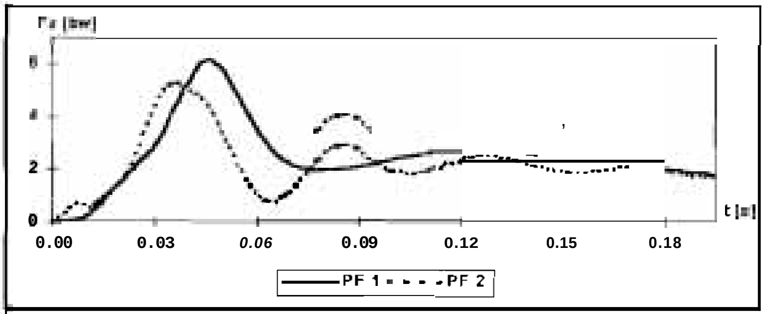

Figure 2 — Measured VGRF with PF 1 and PF 2 during landing after a jump shot in **handball**

The curve measured with PF 2 shows 'swinging characteristics' which means that the curve consists of more local maxima compared to the curve measured with PF 1. The different shapes of the curves indicate that the measured VGRF is clearly influenced by the mass and geometry of the force platform.

Figure 3 shows the measured acceleration on the floor during the impact with a shot (measured) and the calculated acceleration of the model (Figure 1) with varying accelerated masses.

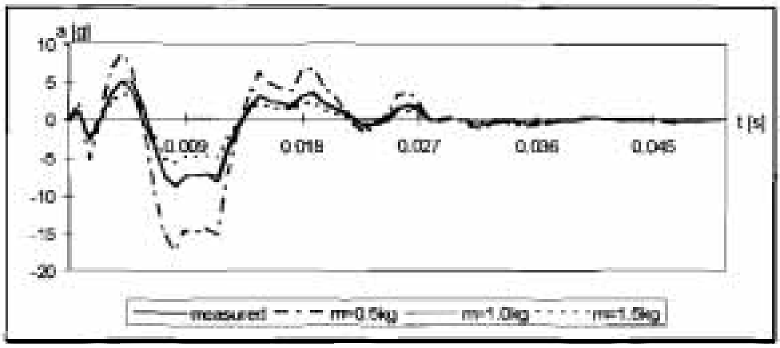

Figure 3 — Comparison of measured acceleration and calculated acceleration using different masses

The figure shows that the measured acceleration and the calculated acceleration for m = 1.0 kg are very similar ($r^2 = .99$, $p < .001$). Provided that the wooden floor's density is about 0.6 **gr/cm^3** and the thickness of the floor is 3 cm, the accelerated area A is about 555 cm^2. This corresponds to a circle with a radius of 13 cm, if it is assumed that the acceleration is the same at each point of this area.

In Figure 4 the measured acceleration (measured) is compared to the calculated acceleration using linear (k,d lin) and non-linear (k,d nlin) spring and damping functions.

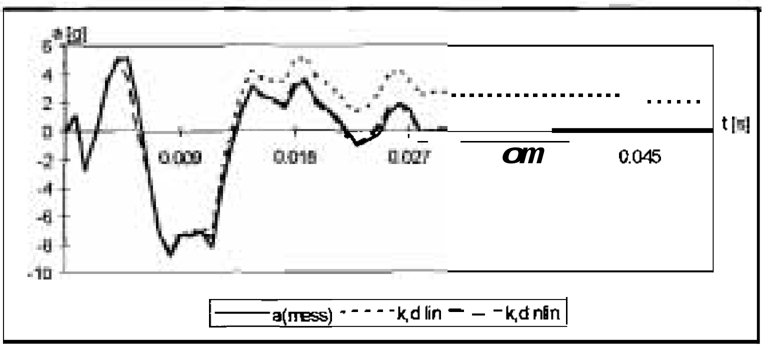

Figure 4 — Comparison of measured acceleration and calculated acceleration using different damped springs

The figure shows a better correspondence between measured and simulated acceleration when non-linear spring and damping functions were used ($r^2 = .99$, $p < .001$ vs. $r^2 = .91$, $p < .001$).

CONCLUSIONS: The study shows that it is possible to determine the characteristics of an area-elastic surface with the help of acceleration measurements and an easy 1 mass - 1 spring - 1 damper -model. The different shapes of the force curves in Figure 2 emphasize the necessity to calculate the influence of the force platform on the obtained results by modeling the system 'force platform + area-elastic surface'. This model should be 3-dimensional with more masses and damped spring-connection between the masses in the horizontal plane. Nevertheless, the platform PF 2 seems to be a suitable force measuring system on area-elastic surfaces due to the low mass and the small area of contact with the floor. In a next step the landing movement will be simulated with a 4 mass - 4 spring - 4 damper -model of an athlete. This model already calculated VGRFs during landing on a hard and point-elastic floor, which agree well with the measured curves. So the combination of the model of the athlete and the model of the area-elastic surface should give information of the external load produced by an area-elastic surface in a gymnasium. These simulations combined with the low mass platform may produce important results for both the constructor of the surface in the gymnasium and the athlete who may get information to prevent overload injuries. So during his activities the athlete can perform his landing movement in dependence of the surface's attributes.

REFERENCES:
Chesney, D. A. & Axelson, P. W. (1996). Preliminary test method for the determination of surface firmness. IEEE Transactions on Rehabilitation Engineering, 4(3), 182-187.
De Vita, P. & Skelly, W. A.(1992). Effect of loading stiffness on joint kinetics. Medicine and Science in Sports and Exercise, 24(1), 108-115.
Hennig, E. M. (1998). Measurement and evaluation of loads on the human body during sports activities. Book of Abstracts XVIth International Symposium on Biomechanics in Sports I, 399-402.
Huo, M., Nitsche, St. & Nicol, K. (1999). Messung der dynamischen Interaktion auf dem Sprungbrett. Book of Abstracts Vth Symposium der dvs-Sektion Biomechanik, in press.
Müller, R. (1987). Schaut doch mal auf den Boden! Bulletin der ETH Zurich.
Nigg, B. M. (1988). The assessment of loads acting on the locomotor system in running and other sport activities. Seminars in Orthopaedics, 3(4), 197-206.
Nigg, B. M. (1990). The validity and relevance of tests used for the assessment of sports surfaces. Medicine and Science in Sports and Exercise, 22(1), 131-139.
Nigg, B. M. & Yeadon, M. R. (1987). Biomechanical aspects of playing surfaces. Journal of Sports Science, 5, 117-145.
Peikenkamp, K., van Husen, M. & Nicol, K. (1998). Vertical surface reaction forces during landing on hard and elastic gymnasium surfaces. Book of Abstracts XVIth International Symposium on Biomechanics in Sports 1, 552-555.
Rutkowska-Kucharska, A. (1998). Take-off structure and touch down loads during landing in selected rhythmic sport gymnastic jumps. Book of Abstracts XVIth International Symposium on Biomechanics in Sports II, 238-241.
Stacoff, A., Kaelin, X. & Stuessi, E. (1987). Belastungen im Volleyball bei der Landung nach einem Block. Deutsche Zeitschrift fur Sportmedizin, 38(11), 458-464.
Vailiant, G.A., Cooper, L.B. & McGuire, J. (1986). Measurements of the rotational friction of court shoes on an oak hardwood playing surface. Book of Abstracts North American Congress on Biomechanics, 295-296.
Yeadon, M. R. & Nigg, B. M. (1988). A method for the assessment of area-elastic surfaces. Medicine and Science in Sports and Exercise, 20(4), 403-407.