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Enhancement of force patterns classification based on Gaussian distributions

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ABSTRACT

Description of the patterns of ground reaction force is a standard method in areas such as medicine, biomechanics and robotics. The fundamental parameter is the time course of the force, which is classified visually in particular in the field of clinical diagnostics. Here, the knowledge and experience of the diagnostician is relevant for its assessment. For an objective and valid discrimination of the ground reaction force pattern, a generic method, especially in the medical field, is absolutely necessary to describe the qualities of the time-course. The aim of the presented method was to combine the approaches of two existing procedures from the fields of machine learning and the Gauss approximation in order to take advantages of both methods for the classification of ground reaction force patterns. The current limitations of both methods could be eliminated by an overarching method.

Twenty-nine male athletes from different sports were examined. Each participant was given the task of performing a one-legged stopping maneuver on a force plate from the maximum possible starting speed. The individual time course of the ground reaction force of each subject was registered and approximated on the basis of eight Gaussian distributions. The descriptive coefficients were then classified using Bayesian regulated neural networks. The different sports served as the distinguishing feature.

Although the athletes were all given the same task, all sports referred to a different quality in the time course of ground reaction force. Meanwhile within each sport, the athletes were homogeneous. With an overall prediction (R = 0.938) all subjects/sports were classified correctly with 94.29% accuracy. The combination of the two methods: the mathematical description of the time course of ground reaction forces on the basis of Gaussian distributions and their classification by means of Bayesian regulated neural networks, seems an adequate and promising method to discriminate the ground reaction forces without any loss of information.

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1. Introduction

Description of ground reaction force patterns is a standard method in fields such as medicine, biomechanics, and robotics. Different fields of science use this parameter to analyze, interpret or optimize movement behaviors and abnormalities. The ground reaction force characterizes the real loading, which affects humans through the interaction between the ground and the foot. In combination with kinematic parameters, the external force can be transferred to internal loads by inverse-dynamic calculations. While using specific model assumptions, joint moments and muscular forces can be estimated or determined with high precision. In medical settings, loadings of the musculoskeletal apparatus as well as neuronal behaviors in the activation of the musculature are usually interpreted by means of the visual observation of the ground reaction force. For example, the degree of motor recovery after stroke (Chen et al., 2007) or the influence of surgery on the hip joint (Alexander and Goldberg, 2005) can be determined using the vertical component of the ground reaction force. Numerous features and characteristics have been shown in different studies (Fredericson and Misra, 2007; Kluitenberg et al., 2016; Lopes et al., 2012; Messier et al., 2008; Nigg et al., 2015; Salzman, 2010; Saragiotto et al., 2014; van Mechelen, 1992). Therefore, the analysis of the ground reaction force is not only a description of physiological loadings, but serves as an essential parameter in the choice of a medical measure and as an indicator of the success of a therapy. In addition to musculoskeletal or neurological diseases and injury-related influencing factors, other elementary

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influencing factors could be determined on the course of the ground reaction force pattern. This includes, for instance, the gait (Alexander and Jayes, 1980; Marey, 1874; Nilsson and Thorstensson, 1989), techniques (forefoot or heel strike) (Nilsson and Thorstensson, 1989), individual training status and conditions (Clark and Weyand, 2014), gender (Keller et al., 1996), age and physical features (Bus, 2003), influences of surface and terrain (Arampatzis et al., 2001; Ferris and Farley, 1997; Ferris et al., 1998; Gottschall and Kram, 2005) as well as influences of the footwear (Frederick, 1986; Sacco et al., 2010; Thompson et al., 2016).

Standardized characteristics for comparisons are rare and to date there is no mathematically-correct description of the ground reaction force pattern that allows an objective classification. This means that, due to the large number of influencing factors, the interpretation of the ground reaction force pattern on a visual basis depends to a great extent on the experience of the diagnostician. Consequently, diagnosticians can reach different conclusions from analysis of the same pattern, depending on their respective experience. The consequences are different interventions and therapeutic settings for the same conditions.

However, in order to identify and compare the individual characteristics of a force pattern analytically and objectively, different classification methods have been developed over the past few years, which have been applied depending on the scientific area and the complexity of the ground reaction force. Thus, by the end of the last century Alexander had already been able to classify different gaits and movement speeds by means of Fourier analysis (Alexander and Jayes, 1980). Individual characteristics, however, remained undiscovered due to the restriction to a few coefficients. Ertelt and Blickhan could use Gauss approximations to show that even complex sequences of a certain setting could be classified with good precision (Ertelt and Blickhan, 2009). On the basis of neuronal networks or "machine learning" algorithms, Alaqtash et al. classified different diseases using individual parameters of the ground reaction force pattern (Alaqtash et al., 2011). Despite these approaches with regard to the objectification of force patterns by means of classification methods, a comprehensive application as well as the necessary implementation remains complicated. The cause can be seen, in particular, in the two last-mentioned methods. While the Alaqtash et al. method is based on neural networks and on simple force parameters, the Ertelt et al. method relies on a variety of approximation coefficients. Due to the complexity of force patterns from different areas, both methods are reaching their limits in their current version. While the recourse to simple force parameters does not reproduce specific characteristics of the force pattern (Alaqtash et al., 2011), the method of Ertelt and Blickhan (Ertelt and Blickhan, 2009) seems to describe the course precisely, but classification by means of discriminant and cluster analytical procedures with consideration of numerous force types also has limits. Therefore, both methods have been used only in very specific settings. A generalized method, which is mandatory especially in the medical field, is currently not available. The aim of the presented method was therefore to combine the approaches of both methods in order to improve the possibilities for the classification of ground reaction force patterns.

2. Materials and methods

To evaluate the classification method under real conditions, abrupt one-legged stopping maneuvers were carried out as a highly-specific movement situation with a complex force pattern which occurs in many sports. In addition, single-legged jumps are increasingly used for diagnostics due to the more specific application in sports-specific tasks (Ertelt and Gronwald, 2017; Meylan et al., 2010; Taboga et al., 2013). In order to obtain the most diverse and complex patterns of ground reaction forces as possible, 29 male athletes (aged 24.1 ± 2.8 years, weight 78.2 ± 8.8 kg) were selected from 10 different specialized sports (throwing, jumping, combined events, badminton, soccer, handball, triathlon, endurance run, swimming, volleyball) in the experiments. The participants also had at least 5 years of training experience in their sport and practiced the sport at a high national level. Each participant had the task of carrying out a one-legged successful stopping maneuver from the maximum possible starting speed (3.5 m/s ± 0.61 m/s). The trial was successful when the force plate was completely hit and no further compensation step was necessary. Each participant had to achieve at least three successful attempts at this speed. A total of 105 experiments were included in the analysis. The forces were registered on a 3D force plate with a frequency of 1000 Hz (Kistler Type 9287 – Bioware 4, Winterthur, Switzerland). The force plate was let into the ground. A two-beam light barrier system with passive reflection unit (Voss, Leipzig, Germany) was used to measure the speed.

In order to focus on the mathematical description of the time course of the ground reaction force, the methods introduced by Ertelt and Blickhan were used (Ertelt and Blickhan, 2009). The registered force patterns were normalized in the subsequent analysis to maximum force and limited to a time window of 300 ms after touch down. Since the expected force patterns were complex time sequences, the number of Gaussian distributions for the approximation of the force pattern was increased to eight distributions. Each of the distributions provide the three coefficients amplitude, width and position. Furthermore, the conditions of the Gaussian approximation were that no negative amplitudes are permitted and the maximum positive amplitudes can assume a maximum

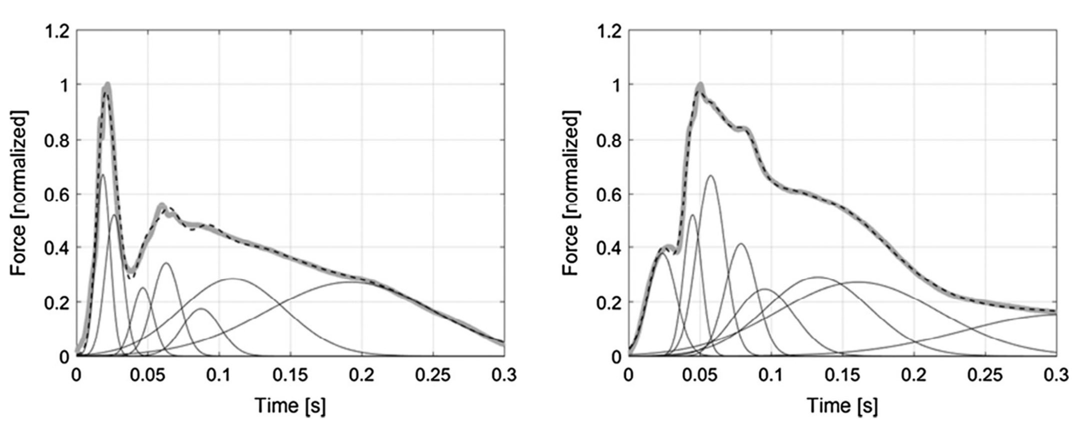

Fig. 1. Examples of two individual Gauss-Fitted force patterns during one-legged stopping maneuvers. Left: Jumper, Right: Triathlete. Grey line: measured ground reaction force at a start-up speed of approx. 3.5 m/s. Dotted line indicates the resultant Gauss-Fit, based on the eight single distributions (black line).

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