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Short communication

Describing force-patterns: A method for an analytic classification using the example of sledge jumps

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ABSTRACT

To recognise and classify movement patterns correctly can be a difficult task. Nevertheless, movement analysts are working on it on a daily basis. Therefore, we have developed and evaluated a method to do the classification by using contact forces during hopping in a sledge system. Here, experiments showed that reaction-forces of different subjects on a sliding sledge could be divided into four major types. These types are symmetric single-modal (type I), positive mono-modal (type II), negative mono-modal (type III), and multi-modal associated with plateau formation (type IV).

Up until now, an exact determination of these types was not possible. However, the new method helps to approximate those four types with well established mathematical functions. With this approach, the measured reaction-force will be reproduced by particular coefficients. Subsequently, the coefficients are subjected to a discriminant-analysis. The result is a three-dimensional function-coefficient, which allows the classification of the actual force-pattern on the one of the four types.

1. Introduction

The time-course of reaction-forces, especially those of the ground-reaction-force resulting in acceleration of the system's centre of gravity, entails essential information about system dynamics. Correspondingly, description and classification of such forces are essential in clinical everyday life and in motion science. For simplicity, we revert mostly to standard parameters such as the maximum force, the contact-time or the duty factor. This approach neglects details in the time-course which may be used by experts to classify the force-pattern as a pathological one. A mathematical parameterisation of the complex time structure would facilitate objectivation. Alexander and Jayes (1980) introduced a method to discriminate between the time-courses of ground-reaction-forces generated during walking and running. His procedure, a four parameter Fourier-transformation, represented a further development and refinement of the Jacobs-method (Jacobs et al., 1972). Schamhardt and Merkens (1987) used indices to describe the magnitude, timing and symmetry of the ground-reaction-forces of horses which allowed to "rate founding" and injured horses, respectively. Both approaches do not offer sufficient detail to characterise detailed differences in the time-course which are observed in gait analysis or for example in experiments on sledge jumping which in turn may be caused by injuries or individual motor strategies. In the present study, we introduce a quantification based on fitted Gauss-functions, which facilitates parametric description and classification of the time-course of force-patterns.

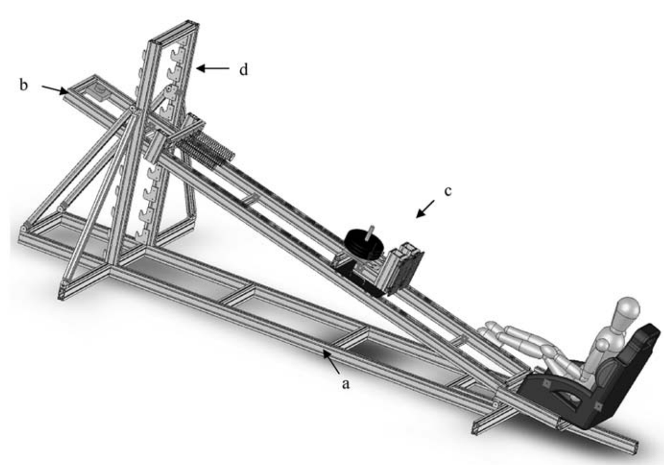

Fig. 1. Construction of the sledge system (Science of Motion, Jena): (a) basic frame, (b) inclinable plane, (c) sledge system, and (d) vertical adjustment. The construction is represented without cable discharge and anti-oscillation support. The sledge contains two independent force plates and each plate includes five force transducers.

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2. Materials and methods

To develop the method, experimental data were collected. In order to produce a large variability, the experiments were accomplished in the so-called sledge system (Fig. 1). Here, the load and the movement speed can be controlled. The present method is explained by the example of force-patterns while pushing a sledge. However, this represents no restriction, since the method can be generally used for classifying other patterns.

2.1. Subjects

Nine people, all males, participated in the study. Mean age 25.2 years (SD = 4.3), mean height 180 cm (SD = 5.5), and mean body mass 77 kg (SD = 8.4).

2.2. Procedures

Each subject had to push the sledge at three different frequencies, controlled by a metronome (2, 1, and 0.6 Hz). Each frequency varied with three different loads (blank-net weight of the sledge: 28 kg, body weight, double body weight). The subjects were instructed to do the exercise in a dynamic way, which meant that retaining phases during contact should be avoided. Each test had to be repeated. Two independent force plates (FSU-Jena Germany and Tetra Ilmenau Germany) mounted on the sledge registered the forces and recorded them via A/D-converter (500 Hz, IMC musycs) on a personal computer for further analysis. The sledge was situated on an inclined plane under 20° to the horizontal. A sitting proband had to push the sledge with both legs upwards at the determined frequency (Fig. 1). The hopping trials were processed with MatLab (2006a). The resultant forces were calculated by adding the force-data of the two plates. By means of force detection the entire hopping task was divided into individual cycles, which included contact and flight phases. Force pushes were eliminated when contact-time exceeded more than double the standard deviation. The computation considered 2110 cycles (Table 1). SPSS was used for statistical analysis.

2.3. Analysis

In the following analysis, a general method for the quantification of force-patterns will be exemplified by "pushing a sledge". The approach to the quantification of force-sequences can be divided into four steps:

1. Classification of appearing patterns.
2. Approximation by means of Gauss-functions.
3. Transfer of the located Gauss-coefficients to the appearing patterns.
4. Computation of the group affiliation of the individual pattern.

The first three steps are the basics for building up a data set for the discriminant-analysis (training-set). The fourth step implies the computation and classification possibilities.

The force-data show that for the given task (pushing a sledge) the different sequences exhibit certain characteristics. These characteristics can be assigned by a visual classification into four specific classes or types which simplified can be partitioned to symmetric single-modal (type I), positive mono-modal (type II), negative mono-modal (type III), and multi-modal associated with plateau formation (type IV) (Fig. 2). Time- and amplitude-dominant influences were normalised to one (100%).

Table 1
Descriptive statistics of the considered hopping cycles. Hopping cycles (N) grouped according to the hopping frequency and the load.

Cf [1/s]	Load	N
Descriptive statistics		
2 Hz	Blank	425
	Weight	390
	Double weight	369
1 Hz	Blank	209
	Weight	190
	Double Weight	190
0.6 Hz	Blank	107
	Weight	116
	Double Weight	114
Total		2110/

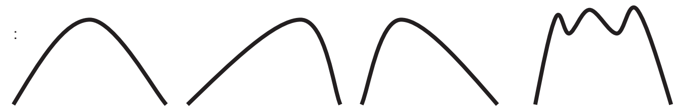

Fig. 2. The four characteristic force-patterns during pushing a sledge. From left to right: symmetric single-modal (type I), positive mono-modal (type II), negative mono-modal (type III), and multi-modal associated with plateau formation (type IV).

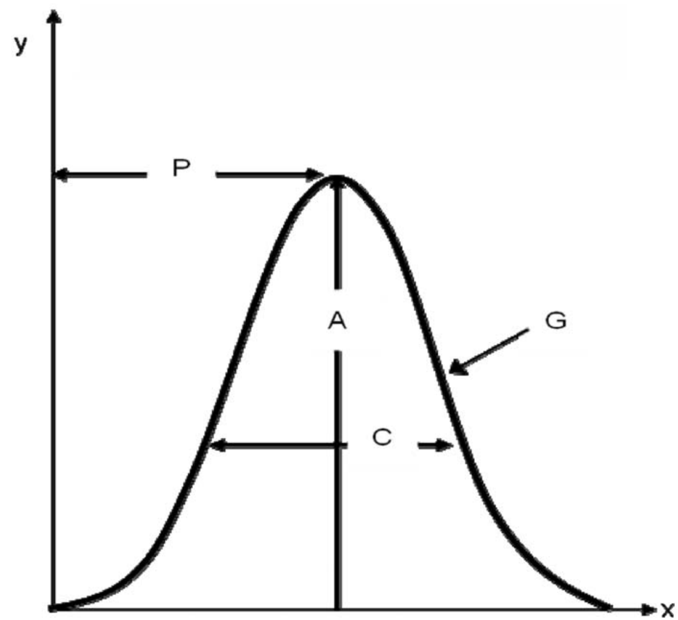

Fig. 3. Gauss-function with its parameters. G: Gauss-function, A: amplitude, P: position, C: width (double of standard deviation). For the computation see Eq. (2).

The visual evaluation and classification of the force-data (step 1) is followed by the approximation via superposition of Gauss-functions (step 2). Research into the number of Gauss-processes, necessary for an adequate analysis of the reaction-force spectrum during pushing the sledge, shows that a good result can be expected concerning an approximation with five distributions. Each set of Gauss distribution (Eqs. (1)–(3)) results in a matrix with its three characteristic parameters (Fig. 3) (Bronéstejn et al., 1997). A superposition of five Gauss-processes for each approximation of the force-function leads to a 3×5 matrix. In the following (step 3), the observed pattern-classes have to be assigned to these matrix parameters. That leads to the so-called training-set for the discriminating process. For higher accuracy and for the presentability in a three-dimensional system, the discriminant-analysis is based on three functions (Eqs. (4)–(6)). These new discriminant-functions are denoted as force quantification-coefficients FQC (FQC1–3).

Gauss-function with the parameters A (amplitude), P (location), and C (standard deviation) under the approximation condition: only "positive" amplitudes:

$$G = \sum_{i=1}^{n} G_i \quad (1)$$

$$G_i = A_i e^{[-(x-P_i)\backslash C_i]^2} \quad (2)$$

with $0 < A_i < \infty$.

Superposition of the five Gauss-functions:

$$G = A_1 e^{[-(x-P_1)/C_1]^2} + A_2 e^{[-(x-P_2)/C_2]^2} + \cdots + A_4 e^{[-(x-P_4)/C_4]^2} + A_5 e^{[-(x-P_5)/C_5]^2} \quad (3)$$

Coefficients, resulting from the discriminant-analysis (Table 3):

$$FQC1 = -1,959 + A_1(0,202) - P_1(0,308) + C_1(1,633) + \cdots - P_5(0,660) - C_5(3,588) \quad (4)$$