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MULTIDIMENSIONAL DIFFERENCES IN HUMAN GAIT DUE TO DIFFERENT FOOTWEAR

[1]Hendrik Enders, [1]Vinzenz von Tscharner, [1]Christian Maurer and [1]Benno M. Nigg
[1]Human Performance Laboratory, Faculty of Kinesiology, University of Calgary

SUMMARY

Vector-based approaches have become a popular tool in biomechanics as they are well suited to understand the complex, and often multidimensional differences in human movement patterns. This multidimensionality can be addressed by an iterative support vector machine (SVM) approach. This study decomposed the kinematic data from two shoe conditions into a classifying SVM subspace and its orthogonal complement. The SVM subspace described all movement patterns that changed due to the footwear intervention while the orthogonal complement described all movements that were robust to the footwear intervention. For future applications, this approach can be used to a) understand weather two experimental conditions are different, b) to identify all complex movement patterns that are characteristic for the intervention and c) evaluate if a new trial/subject could be correctly classified based on the identified movement patterns.

INTRODUCTION

Recently, vector-based approaches have become popular tools in biomechanics as they allow for the analysis of the entire data set [1]. Specifically, these vector-based approaches have recently been used to determine differences in kinematic movement patterns due to different footwear interventions [2]. The conceptual framework of a vector-based approach is based on the fact that any time series of length *N* can be represented as a vector in an *N*-dimensional vector space. As an example kinematic data consists of time series indicating the time-dependent positions of markers attached to the body. Thus, we can define a vector space that is spanned by the kinematic data collected in different footwear conditions. The use of a support vector machine (SVM) can then obtain a discriminant vector that describes the difference between data collected from two different footwear conditions [3]. However, this approach identifies the differences between conditions in a single dimension. As human movement is complex and multidimensional, using a single SVM approach may not fully identify the differences between footwear conditions.

We addressed this problem by applying an SVM in an iterative manner to obtain multiple vectors, each capturing specific differences in a movement between two footwear conditions. Ultimately, all movement features showing a difference are combined to create a complex movement pattern by combining all vectors to a multidimensional subspace. The advantage of such an iterative approach is that it captures multidimensional aspects of the running movement. This means that movement changes due to different footwear conditions can be identified as a combination of movements at multiple joints and in multiple directions. This approach gives a much more comprehensive description of the effect of footwear interventions on human movement.

Therefore, the purpose of this study was to apply this iterative SVM approach in order to determine the multidimensional differences in running kinematics due to different footwear conditions.

METHODS

Eleven male recreational runners with a weekly mileage of at least 30 km participated in this study (23.81 ± 5.51 years, 176.38 ± 4.93 cm, 72.25 ±6.18 kg, mean ± SD). Two shoes (identical model) with an elastic or viscoelastic heel midsole material were tested. Kinematic data were collected using 13 reflective markers that were attached to the pelvis and the right leg. Eight infrared cameras (Motion Analysis, CA) were used to collect kinematic data with a sampling frequency of 240 Hz. For each subject 20 running trials were collected in both shoe conditions in a randomized order. The location of each marker in space was normalized to the stance phase and appended end-to-end to create one 3939 component vector for each running trial (13 markers x 100 points x 3 coordinate directions). Vectors were organized into columns of a matrix *M*. A whitening process was applied to obtain a matrix with zero mean and unit variance [4].

An SVM was applied to the input matrix to calculate a discriminant vector. The discriminant indicates the direction of the largest difference in the vector space between the two shoes. Based on the discriminant the classification rate was calculated using a leave-one-out method [1, 2]. A binominal distribution with probability set to 0.5 was used to determine the probability for a significant classification. The significance level was set to 0.05. If the classification rate of the first SVM discriminant was significant, the SVM was reiterated. This process ended when no discriminant was found that allowed for significant classification between the two shoes. All discriminants that allowed for a significant classification formed an orthogonal base of the classifying SVM subspace. The orthogonal complement to this subspace then captures the kinematic information that cannot separate between the two shoes [1].

RESULTS AND DISCUSSION

Twenty-seven base vectors showed a significant difference between the two shoes. The combination of these vectors formed the multidimensional SVM subspace that distinguished between the two shoes. The orthogonal complement showed no differences between the two shoes (Figure 1). The SVM subspace explained 2.73% of the variance of the whole movement.

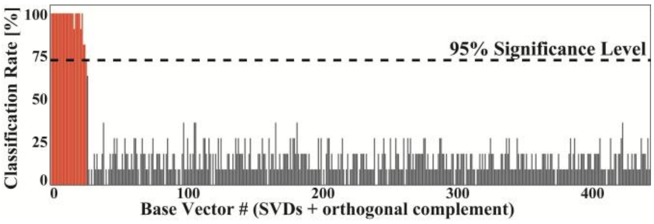

Figure 1: Classification rate for all base vectors. The first 27 vectors spanned the classifying SVM subspace. All base vectors of the orthogonal complement did not allow for significant classification between the two shoes. The dashed line shows the threshold for a significant classification.

The largest movement differences between the two shoes occurred at the ankle joint. Static images of the marker positions were visualized during mid-stance in the sagittal and frontal plane for both subspaces (Figure 2). The static images as well as the marker movement demonstrated that the SVM subspace described all the differences in the movement pattern between the two shoes (Figure 2a-c). The orthogonal complement captures the movement features that were identical for the two shoes (Figure 2d-f).

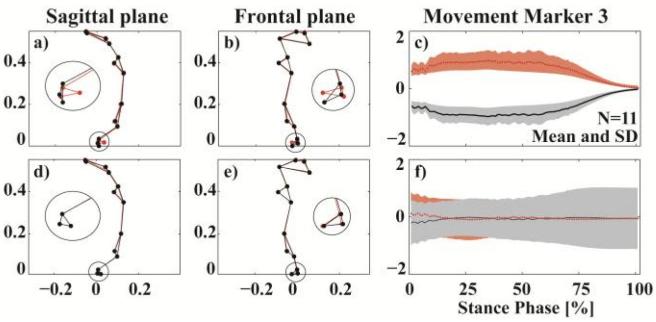

Figure 2: (a-c) Stick figures and marker movement of the SVM subspace showed a clear separation between the viscoelastic (black) and elastic heel (red). (d-f) The orthogonal complement showed no separation between the two shoes. The circles show magnifications of the movement differences.

CONCLUSIONS

For the first time, the complex differences between human movement patterns could be identified using a multidimensional subspace decomposition method. Using a vector-based approach in combination with an iterative SVM, an entire data set could be decomposed into two functionally different subspaces. Each subspace provides fundamental insight into the biomechanical effects of different footwear conditions. The SVM subspace captured all multidimensional (27 vectors) aspects of the running movement that changed due to the footwear intervention. The orthogonal complement contained all movement aspects that did not change with the shoes. Splitting a movement into two functionally different subspaces is an important step in order to understand and interpret biomechanical differences in human locomotion. This method was sensitive enough to detect small kinematic changes (~ 3%) for the entire running movement. In the present case, the largest kinematic differences were primarily identified at the foot which seems to be in agreement with previous studies investigating the effects of footwear on ankle mechanics during running [5]. This indicates that movements at the ankle joint may be most sensitive to the footwear intervention in this study. In summary, we conclude that footwear interventions may primarily have local effects on the most proximal joint while the main running movement is minimally affected.

While this methodological approach was used to identify kinematic changes due to different footwear interventions in the current study, such an approach may easily be used for a variety of biomechanical research questions. For example, the current approach can significantly improve gait analysis for rehabilitation purposes by identifying which movement patterns change due to an injury or a pathological condition. Once the sensitive movements have been identified, this information can be used to specify the variables of interest for future diagnosis or to monitor the rehabilitation process of patients.

This approach is valuable as it copes with the complex nature of human movement and the multifaceted differences that may occur due to an intervention or an injury. While being complex from a theoretical and scientific point of view, the result is a visualization of movements allowing medical professionals, coaches and patients to understand the differences in human movement between groups or due to an injury, disease, or external intervention.

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