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Soanatl Aguilar, Venustiano; van de Gronde, Jasper J.; Maurits, N.M.; Lamothe, Claude; Roerdink, Johannes

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# Curvature and Speed for Balance Quantification during Exergaming

Venustiano Soancatl<sup>1,\*</sup>, Jasper J. van de Gronde<sup>1</sup>, Natasha M. Maurits<sup>2</sup>,  
Claudine C.J.C. Lamoth<sup>3</sup>, Jos B.T.M. Roerdink<sup>1</sup>

<sup>1</sup>University of Groningen, Johann Bernoulli Institute for Mathematics and Computer Science,

<sup>2</sup>University of Groningen, University Medical Center Groningen, Department of Neurology,

<sup>3</sup>University of Groningen, University Medical Center Groningen, Center of Human Movement Sciences

**Keywords:** Balance quantification, speed, curvature, two-level linear mixed models

**Concepts:** ●Mathematics of computing → Time series analysis;  
Exploratory data analysis;

## 1 Introduction

The assessment of the quality of body movements in real-time is of utmost importance in exergames, that is digital games controlled by body movements, that are designed for the elderly population. In consideration of the fact that among elderly people the number of injuries and fatalities (caused by fall incidences) is increasing, the ultimate goal of exergames is not only to provide fun, entertainment and exercise but also to improve postural control and balance. It is known that improving balance can reduce the number of falls among the elderly population. Real-time assessment of body movements during exergaming could be used to adapt the difficulty of the game as a function of the quality of the movements of the player, as well as to provide immediate feedback. This in turn could increase motivation to play and therefore increase the effectiveness of exergames as tools to improve balance. In a previous study we identified curvature and speed of motion trajectories as promising metrics for balance quantification using bi-dimensional force plate data [Soancatl et al. 2016]. The main aims of this study are (1) to investigate whether curvature and speed could be used to quantify balance using three-dimensional trajectories derived from whole body movements as recorded by Kinect, and (2) to identify which body parts provide the most insight into balance. We consider measures to be suitable for balance quantification if they can differentiate between two groups (older and younger participants). This categorization can provide insight into balance control, as in general it is known that younger adults (here: younger than 60 years) have better postural control than older adults.

## 2 Methods

Our data was collected in a previous study where forty healthy participants, twenty older (mean age 71.9 years, SD 4.0 years) and twenty younger adults (mean age 37.0 years, SD 16.6 years), played a custom-made ice-skating exergame by repeatedly swaying the center of mass in both lateral directions [van Diest et al. 2015]. Each participant played the game 10 times. Each trial lasted approximately 1 minute. During gameplay Kinect tracked 15 body parts at 30Hz and force plate recordings were used to derive the center of pressure (CoP) at 170Hz. The power law relation between

\*e-mail: v.soancatl.aguilar@rug.nl

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curvature  $\kappa$  and speed [Gribble and Ostry 1996], suggest that a two-level linear mixed model can be used to analyze the data:

$$\log(s_{ij}) = (\gamma_{00} + U_{0j}) + (\gamma_{10} + U_{1j}) \cdot \log(\kappa_{ij}) + R_{ij}$$

where  $s_{ij}$  and  $\kappa_{ij}$  are the  $i$ th values of speed and curvature from body part  $j$ ,  $\gamma_{00}$  is the mean intercept,  $U_{0j}$  are the random intercepts by body part,  $\gamma_{10}$  is the mean slope,  $U_{1j}$  are the random slopes by body part, and  $R_{ij}$  are the residuals. Intercepts represent speed values at zero curvature, and slopes represent the rate of change as curvature increases.

## 3 Results

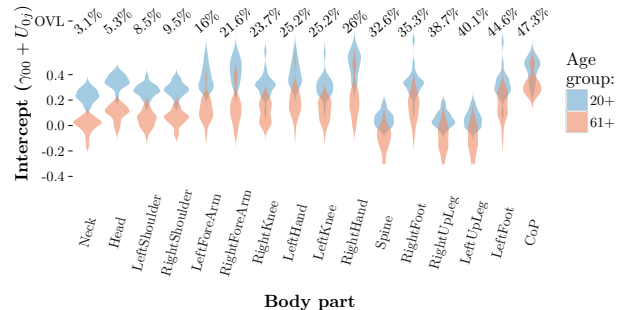


Figure 1: Violin plots showing the differences between groups.

Figure 1 shows the distribution of intercepts by age category and body part. Percentages above violin plots represent the amount of overlap between distributions. The upper body parts (Head, Neck and Shoulders) clearly differentiate older and younger participants. The rest of the body parts differentiate the groups to some degree. Interestingly, the CoP is commonly used for balance quantification but here shows the least difference between groups.

In conclusion, the combination of curvature and speed provides promising measures for balance quantification. The next step is to apply this method in real-time to provide immediate feedback and to adapt the difficulty of the game according to the performance of the player.

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