Eurographics Conference on Visualization (EuroVis), Posters Track (2016)
T. Isenberg and F. Sadlo (Guest Editors)

Visual Data Exploration for Balance Quantification During Exergaming

V. Soancatl[1], J. J. van de Gronde[1], C. J. C. Lamoth[3], N. M. Maurits[2] and J. B. T. M. Roerdink[1]

[1]University of Groningen, Johann Bernoulli Institute for Mathematics and Computer Science, The Netherlands
[2]University of Groningen, University Medical Center Groningen, Department of Neurology, The Netherlands
[3]University of Groningen, University Medical Center Groningen, Center of Human Movement Sciences, The Netherlands

Abstract

Recently, digital games controlled by real-time body movements (exergames) have been proposed as an innovative method to improve balance among older adults. One of the main challenges for exergames is to automatically quantify balance during game-play to adapt the game difficulty according to the skills of the player. Here we perform a multidimensional exploratory data analysis, using visualization and force plate data, to establish suitable measures for quantifying balance in real-time. Our visualizations provide quick insight and directions for further data exploration. They suggest that speed, curvature, the root mean square of the mediolateral displacement of the center of pressure, and a turbulence measure are the most promising measures for balance quantification. The next step is to apply the present techniques to data of whole body movements as recorded by devices such as Kinect, that are available for gameplay at home.

Categories and Subject Descriptors (according to ACM CCS): I.5.4 [Computing Methodologies]: PATTERN RECOGNITION/Applications—Signal processing

1. Introduction

Falls due to loss of balance commonly cause serious injuries and loss of independence among the older population. Moreover, unintentional injuries are among the ten leading causes of death in older adults and falls cause 60% of these deaths [Rub06]. Given the great popularity of digital games around the world at all ages, exergames have been proposed as a way to improve balance among older adults [LSLL13]. Exergames are digital games controlled by real-time body movements recorded with tracking technology such as inertial measurement units, infrared cameras, and force plates [LSLL13, SL13]. Balance control or postural control is defined as the ability to maintain the center of body mass within limits of stability determined mostly by the base of support (the feet) during static or dynamic tasks [WSC96, PDRP00]. According to a state-of-the-art study [vDLS*13], the most common methods to study the effectiveness of exergames, based on balance improvement, rely on assessing balance before and after exergame training. However, balance control is typically not assessed *during* gameplay (in real-time). Real-time balance control assessment could improve effectiveness and adherence of exergames by increasing motivation and providing the player with the most appropriate adaptive feedback.

The main goal of this study is to conduct an exploratory multidimensional data analysis, using visualization techniques, to establish measures that can be used to quantify balance ability in real-time during exergaming.

2. Methods

Our data was collected in a study by van Diest et. al. [vDSW*15]. Fourty 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 ten times according to five different instructions. The balance exercise consisted of repeatedly swaying the center of mass in both lateral directions. Thus, during game-play $40 \times 10 = 400$ trajectories of the center of pressure (CoP) were derived from force plate recordings.

The following features were extracted from the CoP trajectories: three common measures of balance, standard deviation (*SD*), root mean square (*RMS*) and coefficient of variation (*CoV*) of the fluctuations from the mean using running windows [PMH*96, RSV05]; three variants $SD' = SD/d$, $RMS' = RMS/d$ and $CoV' = CoV/d$, where d is the distance traveled within the running windows; instantaneous speed, which is also a common measure of balance [PMH*96, DF10]; curvature (κ), the extent to which a curve is not a straight line [Pre01]; turbulence intensity (TI), defined as the *CoV* of speed within the running windows [Stu88, Car11]; and a variant of turbulence intensity, *SD* of speed divided by the mean square speed (TI').

In general it is known that younger adults (age less than 60 years) have better balance than older adults [PMH*96, LvH12]. Thus, here

© 2016 The Author(s)
Eurographics Proceedings © 2016 The Eurographics Association.

DOI: 10.2312/eurp.20161133

delivered by EUROGRAPHICS DIGITAL LIBRARY
www.eg.org diglib.eg.org

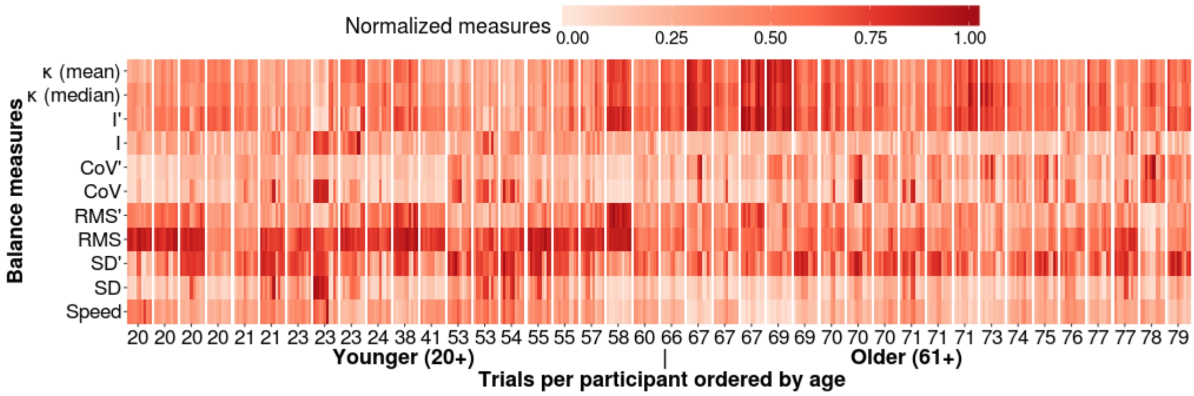

Figure 2: *Visualization of feature median values per trial and participant as a heatmap. The measures that show the clearest differences between older and younger participants are* κ*, I', RMS, and to a lesser degree speed;* κ *and I' values are clearly lower for younger than for older participants. In contrast, RMS values are higher for younger than for older participants. Speed values show slightly higher values for younger than for older participants but not as clearly as for the other measures.*

we consider measures to be suitable for quantifying balance if they show age-related differences.

3. Results

Results are visualized using violin plots [HN98], a heatmap [WF09] and a projection of the measures onto the two first principal components (PC) [Jol02]. Violin plots provide quick insight into the structure of the data because they show the distributions of raw data by participant (Fig. 1). The heatmap allows for the identification of measures that show differences between older and younger participants (Fig. 2). The projection allows us to visualize younger and older groups and the overlap between groups (Fig. 3).

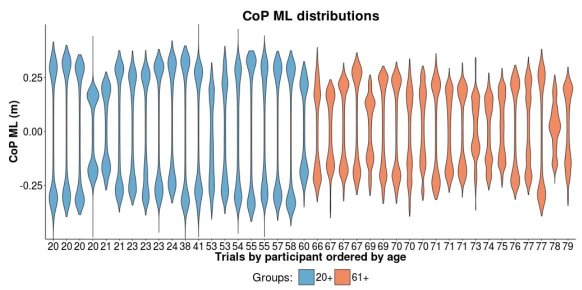

Figure 1: *Violin plots representing CoP lateral transitions between feet. Distances between bumps suggest that younger participants may have a larger base of support than older participants. The thickness of the distributions of valleys between bumps indicates faster CoP transitions among younger than older participants.*

In Fig. 3, the first two PCs account for more than 79% of the variance. Correlation values between the measures and the first two PCs indicate that κ, I', *RMS*, and speed strongly contribute to PC1, and *RMS* strongly contributes to PC2. This is consistent with the observations in Fig. 2. In addition, correlation values reveal that *SD* and CoV' also contribute significantly to PC1 and PC2 respectively.

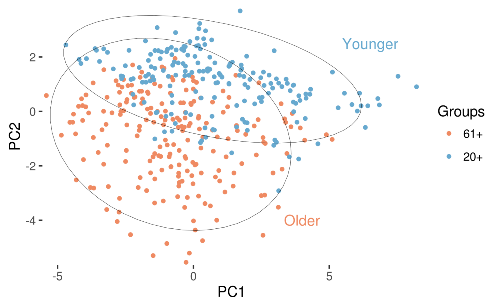

Figure 3: *Projection of the feature median values, using data from Fig. 2, on the first two principal components PC1 and PC2.*

4. Conclusions

Here we have shown an example of how visualization can be used as a way to explore multivariate data of balance quantification. The properties of the used visualizations can reveal clusters, patterns and relationships hidden in the data. Moreover, the creation of such visualizations are straightforward because they are commonly implemented in standard software for statistical analysis.

The most promising measures are *RMS*, I', κ and speed, as they show the largest differences between groups and provide additional information on the quality of the movements. One of the main drawbacks of this study is that force plates are not common devices used at home. Therefore, the next step in our research is to apply the techniques presented here to data recorded from devices more commonly used at home such as Kinect.

5. Acknowledgements

The exergaming project has been performed on behalf of research center SPRINT of the UMCG and was supported by INCAS3. The project was financially supported by the Northern Netherland Provinces Alliance, Course for the North. V. Soancatl was supported by the Mexican National Council of Science and Technology (CONACYT) under scholarship number 313791.

© 2016 The Author(s)
Eurographics Proceedings © 2016 The Eurographics Association.

References

[Car11] CARPMAN N.: Turbulence intensity in complex environments and its influence on small wind turbines. *Examensarbete vid Institutionen för geovetenskaper*, 219 (2011). 1

[DF10] DUARTE M., FREITAS S. M. S. F.: Revision of posturography based on force plate for balance evaluation. *Revista brasileira de fisioterapia (São Carlos (São Paulo, Brazil)) 14*, 3 (2010), 183–192. 1

[HN98] HINTZE J. L., NELSON R. D.: Violin plots: A box plot-density trace synergism. *American Statistician 52*, 2 (1998), 181–184. 2

[Jol02] JOLLIFFE I. T.: Principal component analysis, second edition. *Springer Series in Statistics 98* (2002), 487. 2

[LSLL13] LARSEN L. H., SCHOU L., LUND H. H., LANGBERG H.: The physical effect of exergames in healthy elderly -a systematic review. *Games for Health Journal 2*, 4 (2013), 205–212. 1

[LvH12] LAMOTH C. J., VAN HEUVELEN M. J.: Sports activities are reflected in the local stability and regularity of body sway: Older ice-skaters have better postural control than inactive elderly. *Gait & Posture 35*, 3 (2012), 489–493. 1

[PDRP00] POLLOCK A. S., DURWARD B. R., ROWE P. J., PAUL J. P.: What is balance? *Clinical Rehabilitation 14*, August 1999 (2000), 402–406. 1

[PMH*96] PRIETO T. E., MYKLEBUST J. B., HOFFMANN R. G., LOVETT E. G., MYKLEBUST B. M.: Measures of postural steadiness differences between healthy young and elderly adults. *Transactions of Biomedical Engineering 43*, 9 (1996), 965–966. 1

[Pre01] PRESSLEY A.: *Elementary Differential Geometry*. Springer, 2001. 1

[RSV05] RAYMAKERS J. A., SAMSON M. M., VERHAAR H. J. J.: The assessment of body sway and the choice of the stability parameter(s). *Gait & posture 21*, 1 (jan 2005), 48–58. 1

[Rub06] RUBENSTEIN L. Z.: Falls in older people: epidemiology, risk factors and strategies for prevention. *Age and Ageing 35*, 2 (2006), 37–41. 1

[SL13] SUN T. L., LEE C. H.: An Impact Study of the Design of Exergaming Parameters on Body Intensity from Objective and Gameplay-Based Player Experience Perspectives, Based on Balance Training Exergame. *PLoS ONE 8*, 7 (2013). 1

[Stu88] STULL R. B.: *An Introduction to Boundary Layer Meteorology*, first ed. Academic Publishers, 1988. 1

[vDLS*13] VAN DIEST M., LAMOTH C. J. C., STEGENGA J., VERKERKE G. J., POSTEMA K., DIEST M. V.: Exergaming for balance training of elderly: state of the art and future developments. *Journal of neuroengineering and rehabilitation 10*, 1 (2013), 101. 1

[vDSW*15] VAN DIEST M., STEGENGA J., WÖRTCHE H. J., ROERDINK J. B. T. M., VERKERKE G. J., LAMOTH C. J. C.: Quantifying postural control during exergaming using multivariate whole-body movement data: A Self-Organizing Maps approach. *Plos One 10*, 7 (2015), e0134350. 1

[WF09] WILKINSON L., FRIENDLY M.: The History of the Cluster Heat Map. *The American Statistician 63*, 2 (2009), 179–184. 2

[WSC96] WOOLLACOTT M. H., SHUMWAY-COOK A.: Concepts and methods for assessing postural instability. *Journal of Aging and Physical Activity 4*, 3 (1996), 214–233. 1

© 2016 The Author(s)
Eurographics Proceedings © 2016 The Eurographics Association.