Bencsik, L. and Nagy, D. J. and Zelei, A. and Insperger, T.: The mechanical background of devices for balancing skill development. In Theoretical Approaches in Non-Linear Dynamical Systems, Ed: Awrejcewicz, J. and Kazimierczak, M. and Mrozowski, J., pp 65-72. Dec 2-5, 2019, Lodz, POLAND. ISBN 978-83-66287-29-7

The mechanical background of devices for balancing skill development

László Bencsik, Dalma J. Nagy, Ambrus Zelei, Tamás Insperger

Abstract: In the studies dealing with the analyses of balancing, the falling in elderly age is mentioned as the main motivation. It can be considered as a generation problem in our aging society. Besides, the motion therapy is another important field, where the understanding of the mechanism of balancing can help. In our society the number of premature babies is increasing, many of them requires intensive motion therapy. The natural learning of different motions and upright standing is a really long process during infancy and childhood. In case of children with dyspraxia or other disabilities the learning process has to be assisted and accelerated.

Most of the balancing improvement trainings are based on simple devices like the balance board, the Bosu ball or the Huple which is a Hungarian development especially for children. By means of the destabilization effect, these devices make the upright standing harder, which is not simple anyway. One can feel that standing on one of these devices is much more unstable and requires high concentration.

The aim of this is work is to analyse the mechanical background of this problem and verify the usability of these devices with motion capturing. By using engineering approaches, quantitative performance measures are introduced, which assist the mainly visual observation based existing scoring systems. The proposed process utilizes the mechanical model of the human and the balancing device.

1. Introduction

Due to the expected increase in median age of the human population, significance of human balancing has been increeased considerably. Accidental injuries and esepcially fall overs are a major cause of fatal injury leading to the death. Death caused by fall over has a similar number as heart cerebrovascular disease, cancer and respiratory system disease among all the causes and it is the first among the non-disease causes [3].

The occurrence of fall overs is related to physiological condition, disease, environment, psychological status, and so on. Among the physiological factors, the increasing reaction delay and the reducing muscle capacity of the elderly are important causes of falls. More falls occur during standing and weight transferring than during walking.

The balancing skill development of premature birth children is also a key motivation in the human balancing research, besides the fall overs in elderly age [7].

In the prevention of fall overs, and in the balancing skill development of children, a key step is the understanding of the human balancing process and to discover the effect of the above mentioned physiological factors. Although, there has been considerable amount of research related to feedback process which is implemented by central nervous system, there are still open questions related to the working principle of the process. Our main research focus is on the modelling of the neural process during postural balancing with a special focus on the developement of the balancing skills.

The Huple [1] is a well-tried skill development tool for children in early age. The structure is basically a hemisphere in which the children can stand or sit, meanwhile they solve some interesting task.

In the present proof of concept study, the goal is to demonstrate the applicability of quantitative parameters for the analysis of the balancing abilities.

2. Undearctuation as the stimulation of the human balancing system

From the mechanical point of view, postural balancing (e.g. standing still on the ground or balancing in the Huple) is the stabilisation of an unstable equilibrium point. The sensory organs collect the relevant information from the environment, subsequently all these information is processed in the brain and finally the muscles receive the activation signals. In this whole process the strategy of decision on the muscle activation is unknown, and there are several cancidate models for it [4].

The rolling balance tools such as the Huple increase the degrees of freedom of the system, while the variety of control inputs does not change. Fig 1 demonstrates, how the Hupple involves the issue of underactuation [6]. When standing on the ground, both the hip and the ankle joint are acuated, consequently the system is fully-actuated. In constrans, when standing on a rolling object, the joint that is formed by the rolling contact with the ground is passive. Therefore the system is underactuated.

The underactuation makes the balancing task harder, so the subject of the training are forced to the border of their balancing abilities. Such that, we hypothesize that the balancing skills develop.

3. Methods

3.1. Experimental protocol

In this study, the measurements were accomplished for the proof of concept. We tested different benchmark balancing tasks: 1) standing in the Huple with aiming for minimum

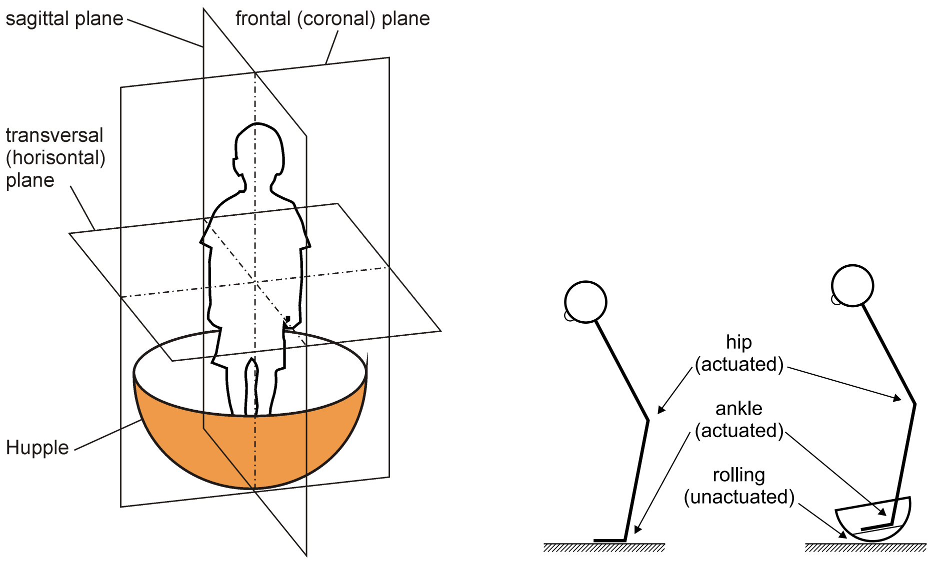

Figure 1. Left panel: Hupple skill development tool together with the anatomical planes. Right Panel: illustrative figure for the demonstraion of the underactuation during balancing on the balance board or in the Hupple.

sway motion (see Fig. 1 left); 2) sitting in the Huple with aiming for minimum sway motion; 3) sitting in the Huple and recover the vertical still position from a intentionally tilted Huple position. Each measurement was 30 seconds long.

The motion of the children was recorded by OptiTrack® [2] motion tracking system. The reflective markers were placed on the head, the shoulders, on the hip and on the Huple device. The spatial position of the markers were recorded with 120 Hz sampling frequency. The maximum position error was 0.2 mm (reported by the Motive software [2] after our on-site calibration).

Ten children were involved in the measurements; however only six was technically successful. Four children couldn't really follow the instructions, therefore a couple of markers couldn't be tracked during the whole task. The data processing and the results of the six successful measurements are explained in the followings.

3.2. Experimental data processing

In this proof of concept study, the motion is decomposed into frontal and sagittal plane as it is depicted in Fig. 2. Based on the symmetrically placed markers (e.g. shoulders, hip), the frontal plane and then the sagittal plane were identified. The angle of the subject

Figure 2. Experimetal setup: the Huple and the motion tracking system.

was considered according to the single inverted pendulum model [5]. The head and marker positions were averaged, and the contant point of the Huple with the ground was also located. The body angle was determined from these two point.

Besides of the body angle, the angle of the Huple device was also processed. Here the frontal plane and the sagittal plane was distinguished too, respectively to the planes of the human body.

4. Results

Among the above presented tasks, the results of the first task (standing in the Huple with aiming for minimum sway motion) are the best for characterization of the balancing ability. Figures 3-7 summarize the results of the measurements. The subjects are listed in the horizontal axis, with the age and the gender shown.

In Fig. 3, the angular oscillation in the frontal plane of the body is depicted. The upper panel shows the maximal oscillation while the lower panel show the Root-mean-square (RMS) value of the oscillation angle. Except the third subject, the maximum angle and the RMS are in correlation: higher RMS goes with higher maximum amplitude. Fig. 4 shows the angular oscillation in the sagittal plane of the body is depicted in the same structure. It is not possible to show statistically significant correlation between the sagittal and the frontal plane oscillation amplitudes and RMS values.

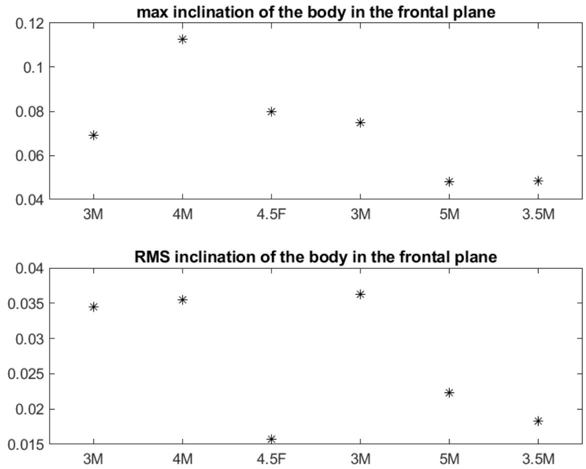

Figure 3. Angular oscillations in the frontal plane (maximal value on the upper panel, RMS value on the lower panel).

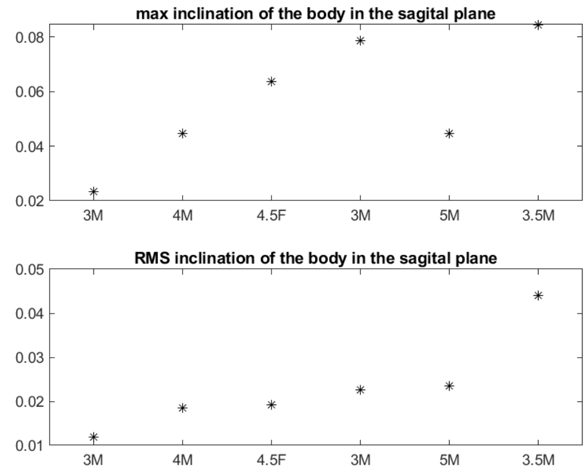

Figure 4. Angular oscillations in the sagital plane (maximal value on the upper panel, RMS value on the lower panel).

Figures 5, 6 show the angular values of the Huple. The results are in good correspondence with body the angles.

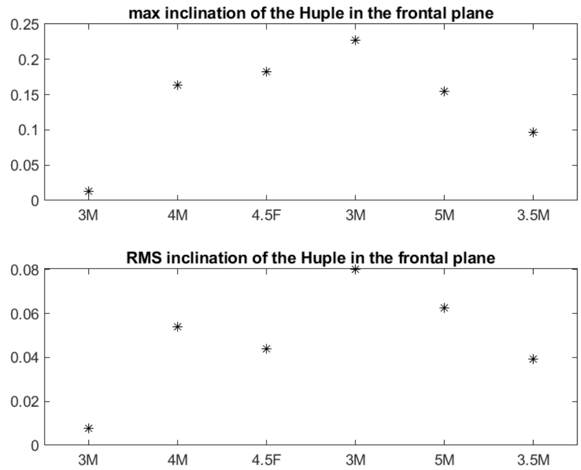

Figure 5. Tilt angle of the Hupple in the frontal plane (maximal value on the upper panel, RMS value on the lower panel).

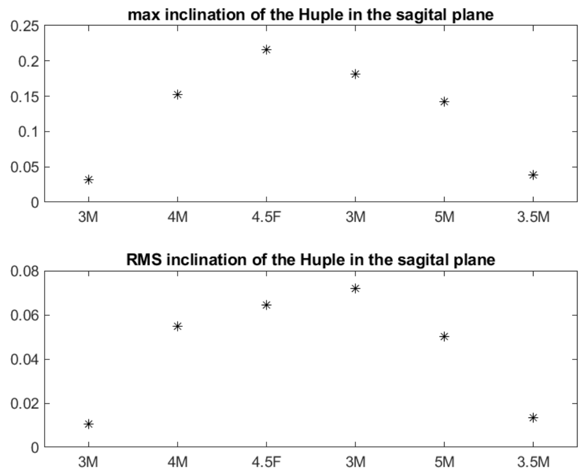

Figure 6. Tilt angle of the Hupple in the sagital plane (maximal value on the upper panel, RMS value on the lower panel).

Figure 7 shows the correlation of frequency spectrum of the Huple and the body angles in the sagittal plane. By the comparison of the angular sway and correlation, it can be concluded that in case of higher correlation the angular sway is smaller for both the body and the Huple. Physically it means that the subjects, who "feel" the dynamics of the Huple are better in balancing during standing.

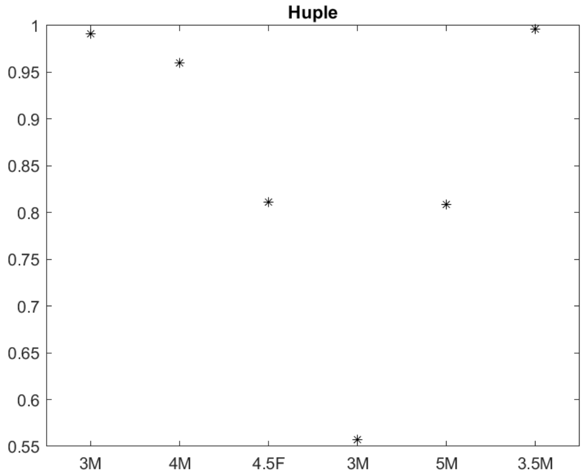

Figure 7. Correlation of the frequency spectrum of the Huple and the body angles.

5. Conclusions

Regarding the issue of quantitative analysis of the balancing capabilities, we showed that using an optical motion tracking system, it is possible to create quantitative paraeters for the balancing skills: the maximum tilt angle amplitude, the RMS value of the tilt angle and the correltaion of the frequency spectrum of the body angle and the angle of the Huple. It is presented that the correlation in the frequency spectrum of the Huple and the body angle in the sagittal plane is a good measure of the balancing ability.

We emphasized that introducing underactuation in the balancing scenario makes harder to perform the balancing task and therefore underactutaion stimulate the development of balancing skills.

As a future plan, the newly introduced quantitative parameters will be applied for the analysis of the development of the balancing abilities.

Acknowledgments

This work was supported by the The Higher Education Excellence Program of the Ministry of Human Capacities in the frame of Biotechnology research area of Budapest University of Technology and Economics (BME FIKP-BIO), by the Hungarian National Research, Development and Innovation Office (Project id.: NKFI-FK18 128636), by the National Research, Development and Innovation Fund (TUDFO/51757/2019-ITM, Thematic Excellence Program) and by the Hungarian-Chinese Bilateral Scientific and Technological cooperation Fund under Grant No. 2018-2.1.14-TET-CN-2018-00008.

References

[1] Huple. http://www.huple.hu/main.php. Accessed: 2019-10-10.

[2] Optitrack. https://optitrack.com. Accessed: 2019-10-10.

[3] The top 10 causes of death. https://www.who.int/news-room/fact-sheets/detail/falls. Accessed: 2019-10-10.

[4] HIDENORI, K., and Jiang, Y. A pid model of human balance keeping. *IEEE Control Systems Magazine 26*, 6 (2006), 18–23.

[5] Milton, J., Insperger, T., and Stepan, G. *Human Balance Control: Dead Zones, Intermittency, and Micro-chaos.* 02 2015, pp. 1–28.

[6] Spong, M. W. Underactuated mechanical systems. In *Control Problems in Robotics and Automation* (Berlin, Heidelberg, 1998), B. Siciliano and K. P. Valavanis, Eds., Springer Berlin Heidelberg, pp. 135–150.

[7] Sukal-Moulton, T., Krosschell, K. J., Gaebler-Spira, D. J., and Dewald, J. P. A. Motor impairment factors related to brain injury timing in early hemiparesis, part i: Expression of upper-extremity weakness. *Neurorehabilitation and Neural Repair 28*, 1 (2014), 13–23.

László Bencsik, Ph.D.: MTA-BME Research Group on Dynamics of Machines and Vehicles, Muegyetem rkp. 3. Budapest, H-1111, Hungary (*bencsik@mm.bme.hu*).

Dalma J. Nagy, MSc: Budapest University of Technology and Economics, Muegyetem rkp. 3. Budapest, H-1111, Hungary (*dalma.nagy@mm.bme.hu*).

Ambrus Zelei, Ph.D.: MTA-BME Research Group on Dynamics of Machines and Vehicles, Muegyetem rkp. 3. Budapest, H-1111, Hungary (*zelei@mm.bme.hu*). The author gave a presentation of this paper during one of the conference sessions.

Tams Isnperger, Professor: MTA-BME Lendület Human Balancing Research Group, Muegyetem rkp. 3. Budapest, H-1111, Hungary (*insperger@mm.bme.hu*).