Equilibrioception: A Method To Evaluate The Sense Of Balance

Matteo Cardaioli
GFT
Padova, Italy
matteo.cardaioli@gmail.com

Marina Scattolin
Department of General Psycology
Padova, Italy
marina.scattolin@gmail.com

Patrizia Bisiacchi
Department of General Psycology
Padova, Italy
patrizia.bisiacchi@unipd.it

Abstract

In this study, we present an algorithm for the assessment of one's own perception of balance (equilibrioception). Upright standing position is maintained by continuous updating and integration of vestibular, visual and proprioceptive information, so that a compensatory reaction can be implemented when perturbations occur. This ability to monitor and maintain balance can be considered as a physiological sense, so, as for the other senses, it is fair to assume that healthy people can perceive and evaluate differences between balance states. The aim of this study is to investigate how changes in stabilometric parametres are perceived by young, healthy adults. Participants were asked to stand still on a Wii Balance Board (WBB) with feet in a constrained position; 13 trials of 30 s each were performed by each subject, the order of Eyes Open (EO) and Eyes Closed (EC) trials being semi-randomized. At the end of each trial (except the first one), participants were asked to judge if their performance was better or worse than the one in the immediately preceding trial. SwayPath ratio data were used to calculate the Just Noticeable Difference (JND) between two consecutive trials, which was of 0.2 when participants improved their performance from one trial to the next, and of 0.4 when performance on a trial was worse than in the previous one. This "need" of a bigger difference for the worsening to be perceived seems to suggest a tendency towards overestimation of one's own balance. Interestingly, participants' judgement was more reliable when evaluating consecutive EC rather than EO trials, at least when performance was worsening.

CHItaly '17, September 18-20, 2017, Cagliari, Italy.

Keywords
equilibrioception; sense of balance ;Wii Balance Board; stabilometry.

Introduction
Falls are a major public health problem with 30% of older people falling at least once a year.
Falling is associated with increased mortality, injuries, loss of independence and adverse psychosocial consequences [10].
In everyday life, standing balance is a rather simple task regulated automatically by subcortical nervous structures and spinal motor neuron pools [6].
Multisensory feedback is involved in the regulation of posture control by continuously updating the internal model of the body's position [7]. To maintain a good postural control humans have to integrate multisensory information from vestibular, visual and proprioceptive inputs [1].
When posture is disturbed, evaluation of afferent multisensory information allows compensatory reactions to be implemented [4].
The use of objective measures for the assessment of standing balance has widely taken place over the last years [9,2]: several studies demonstrated how stabilometric parameters can well describe changes in balance due to different causes, such as age, posture and neurological diseases [11,3,5]. Maintenance of the standing position is the result of complex interactions of different body systems which work synergistically.
The ability to maintain balance can be effectively considered as a physiological sense, which can be referred to as "sense of balance" or "equilibrioception". As for the other senses, it is fair to assume that healthy people can also physically and cognitively discern different balance states and in some way evaluate differences between them. The aim of this study is to investigate the rate of agreement between objective measures of balance and participants' self-report on their own performance.

Material and Methods
Participants
78 healthy individuals participated to the study, 29 males and 49 females (mean age = 23.1, SD = ±2.5). Participants were all normal weight and did not report any history of neurological diseases, orthopedic pathologies, use of medication or temporary problems that may have influenced the results of standing balance tests. The study was approved by the Institution's Research Ethics Committee; all participants provided written informed consent.

Procedure
Each subject performed 13 trials of 30 seconds each in a constrained foot position. Half of the participants performed an EO first trial and the other half performed an EC first trial. 6 out of the 12 remaining trials were performed with participants keeping their eyes open (EO) and 6 with their eyes closed (EC); the sequence of EO-EC trials was semi-randomized, so that 4 possible conditions could be investigated: EO trial followed by another EO trial (EO-EO); EC trial followed by another EC trial (EC-EC), EO trial followed by an EC trial (EO-EC), EC trial followed by an EO trial (EC-EO).
For all conditions, subjects were asked to place their feet according to the lines designed on the surface of the platform: heels had to be kept together where lines touched while toes were to be placed on top of the lines, so to form a 30° angle. Once in the correct position, participants were asked to maintain a relaxed upright standing position with their arms along the body. For EO trials, a fixation cross was placed at 3m

distance and adjusted according to participants' height, so that each subject was looking straight ahead during trials. For EC trials, participants were instructed to look at the fixation cross before closing their eyes, so that head position was the same across trials.
At the end of each trial, except the first one, subjects were asked to judge if their performance on the present trial was better or worse than their performance on the immediately preceding one. Subjects were given approximately 1 minute to relax between one trial and the following. The examiner always waited for participants to announce their intention to resume the test, stop talking and eventually close their eyes before proceeding with data acquisition. Trials were performed in a non-noisy environment.
Data were recorded with the Nintendo Wii Balance Board (WBB) using Matlab [8] and acquired at a frequency of 50 Hz.
A total of 1010 trials was recorded without any malfunction or technical problem leading to the test being invalidated.

Data Analysis
In order to assess participants' sense of balance, responses given by subjects to their own SwayPath parameter (SP) were compared. Since participants were asked to evaluate their own performance in subsequent trials, the ratio between parameters recorded in subsequent trials was considered according to the following formula:
$RSP=\log_2(SP_i/SP_{i-1})$,where i=2,3…,13 is the considered trial.
Smaller values for SP indicate a better balance performance, while higher values indicate a worsened balance performance. Hence, when evaluating subsequent trials, we can say that if the RSP value is smaller than 0, performance in the latter trial is better than the one preceding it, while if RSP shows values bigger than 0, performance in the last trial was worse than performance in the immediately preceding one.
In order to evaluate a just noticeable difference (JND) for the sense of balance we first identified RSP intervals where participants did not perceive differences, that is to say participants gave 50% of correct answers to RSP values falling within this interval (centered in 0).
The range amplitude has been calculated iteratively, so that the percentage of correct answers of at least one of the two adjacent intervals to the one centered in 0 was statistically different from the chance level observed for the 0 interval. Following this procedure, we determined a range amplitude of 0,2 for RSP.

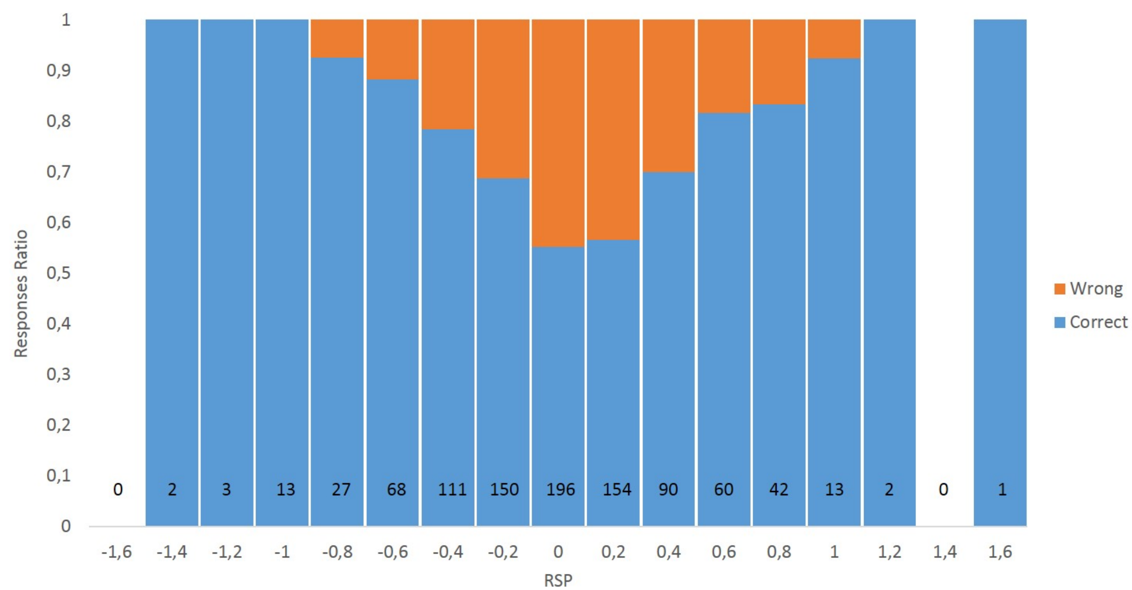
Results and Discussion

Paired t-tests were performed for SP in order to assess possible fatigue or practice effects (from the first to the thirteenth trial): no significant difference was found. In Table 1 are reported mean and standard deviation (SD) values for SP parameter in each tested condition (EO and EC) grouped by sequence order.

	EO		**EC**	
Trials	Mean	SD	Mean	SD
1	36,53	8,15	54,70	18,40
2	35,79	8,13	52,79	16,98
3	36,40	9,39	52,08	16,87
4	36,73	9,15	51,28	15,40
5	36,73	9,03	50,74	16,05
6	36,56	9,88	50,89	17,09
7	37,60	9,30	49,65	20,94

Table 1: SP mean and standard deviation values (in cm) in each tested condition EO and EC.

Furthermore a series of χ2 tests were performed in order to determine the JND. This has been calculated iteratively, for all trials changing the range interval until the percentage of correct answers of at least one of the two adjacent intervals to the one centered in 0 was significant. Following this procedure, we determined a JND of 0.2 for RSP ($\chi2 = 6.57$ $p<0.01$) when participants improved their performance and a JND of 0.4 when participants' performance worsened ($\chi2 = 5.69$ $p<0.05$). In Figure 1 the overall distribution of balance self evaluation is reported.
Considering the responses given by participants in the same subsequent condition (EO-EO,EC-EC and EO-EC together) we found that : EO - EO $\chi2 = 7.56$ $p<0.01$; EC - EC $\chi2 = 2.42$ ns; EO - EC $\chi2 = 6.38$ $p<0.05$.



The use of WBB and the algorithm used in this study permit to merge objective stabilometric data with self evaluation judgements, giving a measure of equilibrioception. A unimodal function has been obtained by RSP self evaluation distribution, demonstrating that RSP describes participants' ability to perceive changings in their balance performance. This ability is not completely symmetric: JND is smaller for balance improvement and bigger for worsening. This "need" of a bigger difference for the worsening to be perceived seems to suggest a tendency towards overestimation of one's own balance. Interestingly, participants' judgement was more reliable when evaluating consecutive EC rather than EO trials, at least when performance was worsening.

Figure 1: Overall distribution of balance self evaluation for RSP

References

1. Thomas Brandt 2013. Vertigo: Its Multisensory Syndromes, 2nd ed. Springer, London, pp.503.
2. Bridget Burmester , Janet Leathem,P aul Merrick (2016) Subjective Cognitive Complaints and Objective Cognitive Function in Aging: A Systematic Review and Meta-Analysis of Recent Cross-Sectional Findings. Neuropsychology Review , 26 (4), pp 376–393 DOI: 10.1007/s11065-016-9332-2
3. Naiara Demnitz, Patrick Esser. Helen Dawes, Vyra Valkanova Heidi Johansen-Berg, Klaus P .Ebmeier 2016 A systematic review and meta-analysis of cross-sectional studies examining the relationship between mobility and cognition in healthy older adults. Gait & posture, 2016, 50: 164-174 https://doi.org/10.1016/j.gaitpost.2016.08.028
4. Hans Christoph Diener, Johannes Dichgans, B. Guschlbauer, M. Bacher, 1986. Role of visual and static vestibular influences on dynamic posture control. Hum. Neurobiol. 5 (2),105–113.
5. Elisa Gervasoni, Davide Cattaneo, Paolo Messina, E Casati, Angelo Montesan, Elisa Bianchi & Ettore Beghi 2015 Clinical and stabilometric measures predicting falls in Parkinson disease/parkinsonisms. Acta Neurologica Scandinavica, 132(4), 235-241 DOI: 10.1111/ane.12388
6. Jean Massion, 1994. Postural control system. Curr. Opin. Neurobiol. 4 (6), 877–887.
7. Thomas Mergner, Thomas Rosemeier, 1998. Interaction of vestibular, somatosensory and visual recordings for postural control and motion perception under terrestrial and microgravity conditions-a conceptual model. Brain Res. Rev. 28 (1–2), 118–135.
8. Piero Pavan, Matteo Cardaioli, Ilaria Ferri, Erica Gobbi, & Attlio Carraro, 2015. A contribution to the validation of the Wii Balance Board for the assessment of standing balance. European journal of sport science, 15(7), 600-605 http://dx.doi.org/10.1080/17461391.2014.956801.
9. EA Solovykh, LN Maksimovskaya, OG, Bugrovetskaya, EA Bugrovetskaya 2011 Comparative analysis of methods for evaluation of stabilometry parameters. Bull Exp Biol Med. 2011 Dec;152(2):266-72 https://doi.org/10.1007/s10517-011-1504-8
10. Mary E. Tinetti 2003 Clinical practice. Preventing falls in elderly persons The New England Journal of Medicine, vol. 348 (1), 42–49, DOI: 10.1056/NEJMcp020719
11. Maria Stella Valle, Antonino Casabona , Agata Fiumara2, Dora Castiglione2, Giovanni Sorge2 & Matteo Cioni (2016) Quantitative analysis of upright standing in adults with late-onset Pompe disease, Scientific Reports | 6:37040 | DOI: 10.1038/srep37040