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Arm Movement Effect On Balance

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Abstract— The background research shows a high incidence of falls and loss of balance related injuries, which cause serious consequences to individual health and quality of life, as well as substantial healthcare impact in services and costs. The literature review emphasizes that arm movements have a potentially significant effect on balance, and indentifies the use of balance boards as a relevant and meaningful tool for dynamic balance evaluation. The primary objective of this initial study was to develop a method to test and evaluate the effect of arm movements on the maintenance of postural stability. Further we investigated the impact of dominant and non-dominant arms, the reaction time of arms, and the amount of activity of arms related to dynamic balance control. The study applied an accelerometer-based balance board test to measure postural stability as related to arm movements. The evaluation consists of accelerometers placed on the two arms and the balance board. Data were acquired from four different subjects and processed accordingly. The finding verified that arms play an important role in the improvement of balance. Our findings suggest that the dominant arm is more active in balance control and that the movement of arms most often occurs just prior to and during loss of balance. The results also suggest that the amount of arm movement activity directly relates to balance control and the use of the dominant arm.

I. Introduction

Balance related accidents and injuries are a major problem, especially with an aging population and rank among the most serious clinical issues. Balance impairments are particularly high among elders who suffer from stroke, traumatic brain injury, Parkinson's disease, and diabetic peripheral neuropathy, and in general for people who suffer from various neurological disorders. The resulting accidents and injuries can be fatal, and also contribute to early nursing home placement[1]. The importance of balance and falls prevention in the elderly has arguably never been greater. Falls are very common and usually result in injuries leading to serious physical and social effects, which have an impact on the individual, their family and the community[2]. For general neurologists and other physicians or healthcare providers and even care givers postural balance represents one of the most challenging aspects in the elderly population which requires attention and exploration of effective ways to evaluate risk and develop training programs that prevent falls. A challenging aspect has been the development of reliable assessment tools and methods to investigate and study balance and identify loss of balance. We investigated arm movement effect on postural balance. The hypothesis of this study was that greater use of arms leads to better stability. Further it was also hypothesized that the dominant arm has a greater effect in balance control.

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Arm movements during falls or loss of balance

While falling or losing balance the arms may be used to provide protection, or to reach for support in a possible fall. The arms can also provide mechanical counterbalancing, to help stabilize the body, or to counteract angular momentum, especially when falling[3]. Arm movement produces forces in the body through momentum as well as through a change in the static joint positions. The equilibrium condition of different arm positions has often been used to evaluate the role of arm movements in posture[4,5]. The arm movements disturb the equilibrium position of the body either in anticipation of or in reaction to loss of balance. Even while walking, arm movements create torque with respect to the trunk[6,3,7].

The existing evidence supports the use of balance boards as a relevant and meaningful tool for dynamic balance evaluation while using arms. The balance board is a standard wobble board used in clinical settings for physiotherapy. Several studies show that they provide valuable information for postural balance diagnostics[8,9]. In addition, it has been shown that exercise programs on balance boards can improve patients' postural balance and muscle strength and overall functional capability[10,11].

Importance of study

The analysis of the related literature shows considerable number of studies that confirm the high incidence and severe consequences of loss of balance. Many studies suggest that falls lead to more accidents and injuries among the older population[8]. It has been documented that in the United States over 15,400 deaths occurred due to falls-related to loss of balance or poor postural control in 2001. The related medical expenses were over $20 billion per year, and it is projected that they will reach $32 billion per year by 2023[12]. Another review estimated the impact for those 60 years and older. They concluded an annual cost of over $23 billion in United States in 2008[13].

An analysis of the 2005 Canadian Community Health Survey (CCHS) which was based on a large national sample (N=132,221), also indicates that among Canadians, loss of balance leading to falls is a major contributor to injuries in adults aged 65 and older[8]. Also, slips, trips and stumbles as grounds for serious injury were also documented to have greater occurrence among the elderly. Hospitalization and emergency room visits were also much higher among this group which was associated not only with falls-related hip fractures but with other results of falls such as fear of falling and isolation from society, considering the fact that some 95% of hip fractures are caused by falls[8,2].

II. Method

A. Subjects

This study included four participants who volunteered from a group of 10 healthy individuals with a mean age of 56. The participants had no background of neurological or other underlying disease, no history or fear of falls, and no vestibular, somatosensory, cognitive or musculoskeletal impairments that might have restricted them in participating.

B. Data Acquisition

The test consisted of maintaining balance for 60 seconds, on a balance board that had been instrumented with a triaxial accelerometer to monitor balancing performance. A commercially available, round balance board (PT Balance Board, PT fitness) was used that was 5.5 cm high with a diameter of 36 cm and 18˚ of inclination freedom.

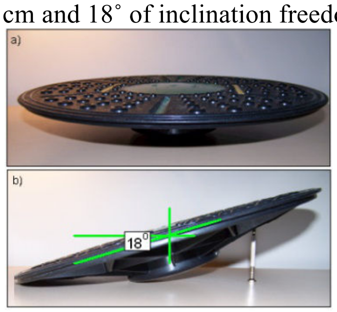

Figure 1. The Balance Board (adapted from [8])

The participants were equipped with accelerometers on both arms (Figure 2). The experimental measurements were taken using MEMS differential capacitance accelerometers (Kionix Inc., USA, model KXM52-1050 and Analog Devices Inc., modelMMA7260Q, 3-axial accelerometer with a range of ±2.0g). All of the measurements were recorded for post-processing. The testing on the balance board was performed twice. In the first trial, the test was performed with the arms positioned against the body (limited arms), while in the second trial, it was performed with the arms being used freely (free arms). The test was first demonstrated to the participants so that the participants could familiarize themselves with the apparatus and the testing procedure for a total of approximately 15 minutes before data were collected. The familiarization period was implemented in order to provide experience with the testing protocol to all participants before the data collection.

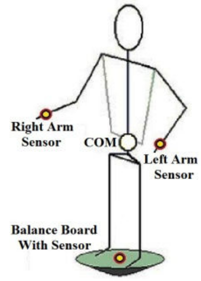

Figure 2. Accelerometer placement on both arms and the balance board (adapted from [8]), COM = centre of mass

Signals were acquired using a 12-bit data acquisition system (NI-USB 6008, National Instruments). The sampling frequencies of the accelerometers on the balance board and the arms were respectively 10 Hz and 1000 Hz. The entire accelerometer signal readings were pre-filtered by hardware using a low-pass filter (f_c = 0.16 Hz) and were further processed on a PC. Real-time acquisition and processing were performed using a LabVIEW 8.0 (National Instruments) custom-built application. The post-processing and filtering were performed using Matlab 2011b (MathWorks Inc.).

C. Signal Processing

The signals were processed and analyzed according to the manufacturer's calibration specifications (Kionix Inc.). The evaluation of accelerometer vector magnitudes, which characterize a measurement of the magnitude of the accelerations (Kionix Inc.), represent a physiologically meaningful representation of arm movements. These measurements and comparisons of magnitudes and variations over time provide interpretable results about arm movement dynamics[14,15]. Since human motion is typically in the 0.3 to 3.5 Hz range[15], the signals were filtered by a band-pass filter to eliminate unnecessary frequencies above 10Hz. Further in order to reduce computational complexity and remove noise from the signal, a 10-point moving average filter was applied to the accelerometer data, according to the equation below[16]:

$$y(n) = \frac{1}{10}\sum_{k=0}^{9} x[n-k] \quad (1)$$

Accelerometer outputs were measured in three spatial dimensions (X, Y, Z) and combined to represent movements according to the equation below[15]:

$$VMU = \sqrt{(x^2 + y^2 + z^2)} \quad (2)$$

The balance region detection algorithm is based on analyzing signal slope, amplitude and width components[16]. It is adapted from the Pan and Tompkins algorithm for ECG signal analysis[17]. The block diagram in 3 shows our implementation.

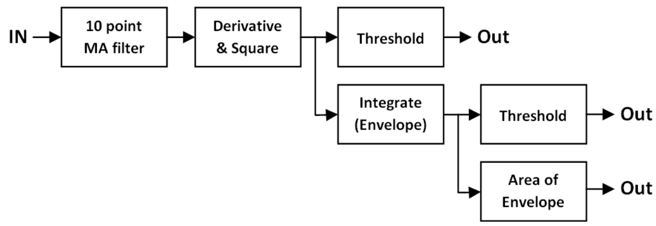

Figure 3. Block diagram implementation of the algorithm

The derivative operation performed highlights the high slopes of the signal attributed to fast movements, which are indicative of loss of balance, and at the same time suppresses the low-frequency components. The derivative filter used in equation 3 below is ideal for processing signals up to 30Hz [16]. The squaring operation further emphasizes the lower values, which are due to the loss of balance, and takes the absolute value of the signal.

$$y(n) = \frac{1}{8}[2x(n) + x(n-1) - x(n-3) + 2x(n-4)] \quad (3)$$

The moving-window integration filter performs an enveloping operation, which helps to easily recognize the multiple regions of balance loss during the recording. A window size of N = 80 in equation 4 below was found to be ideal for this type of signal independent of their frequency of occurrence, duration and magnitude.

$$y(n) = \frac{1}{N}\left[\begin{matrix} x(n-(N-1)) + x(n-(N-2)) \\ + \cdots + x(n) \end{matrix}\right] \quad (4)$$

The thresholding procedure is used to define the regions of balance loss, based on user defined and experimentally determined, threshold values. This allows the user to define the sensitivity of selection to reflect the individual subject's differences and their abilities to maintain balance on the balance board. Finally the area of the obtained envelope by the integration gives us the amount of activity performed by the arms or the balance board during loss of balance.

III. Results

Based on the performance on the balance board, the results indicate improved maintenance and recovery of postural balance with free arm movements. It is clear from 4c that while the subject used his arms he experienced a lot less instability and loss of balance. This is particularly easy to see from 4d (after derivative threshold) where we have a lot less loss of balance occurrences when arms are used to help maintain balance. In total for all four of the subjects, we observed 66.3% more instances of loss of balance when the subjects did not use their arms as compared to when they did use their arms to help them in controlling their balance. It is also evident in all of the four subjects as is shown in 4e and 4f (after integral threshold) that when subjects did not use their arms, their loss of balance was more frequent, longer and severe.

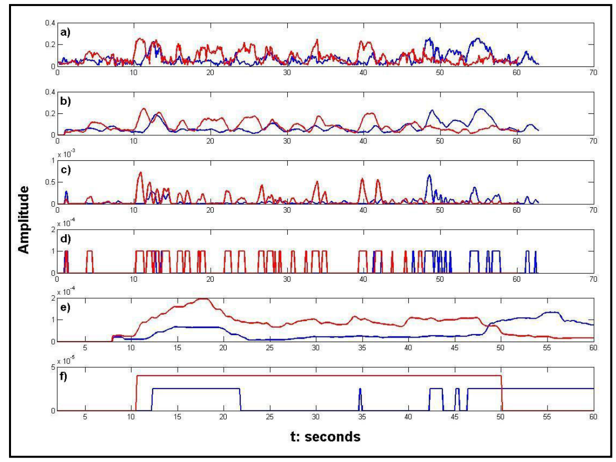

Figure 4. Balance board data from subject 2, Blue line = free arm movement, Red line = no arm movement, a): Raw data, b) 10 point MA filter, c): Derivative & Squared, d): Derivative threshold, e): Integral (envelope), f): Integral threshold.

While analyzing the arm movements of the subjects we found that during loss of balance the arms were generally used prior and/or during the loss of balance as is apparent in 5 below.

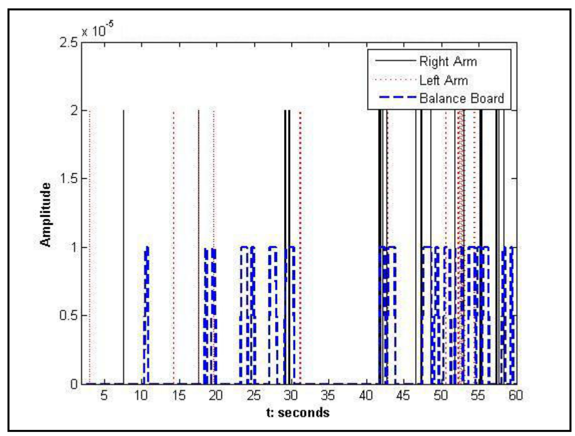

Figure 5. Derivative thresholding of arms and balance board with free arm movement from subject 3.

It is also clear from this that the dominant arm was used more frequently. The study provides strong indication that both dominant and non-dominant arms and their coordinated activity play an important role for balance maintenance. Even though the results show that the use of the dominant arm is more frequent it is particularly important to use both arms in a coordinated manner during both recovery and stable balance.

Based on the results of the integral threshold of arms and the balance board as the example shown in 6, the duration and amount of loss of balance is a lot less when arms are used in controlling the balance. It is also evident that at times of balance loss the arms were used more actively. The reason why there are arm movements appearing in the lower part of 6 when there is supposed to be no movement of arms is because of the detection of loss of balance by the sensors on the arms. Another reason might be due to unintentional small reflexes to correct postural balance.

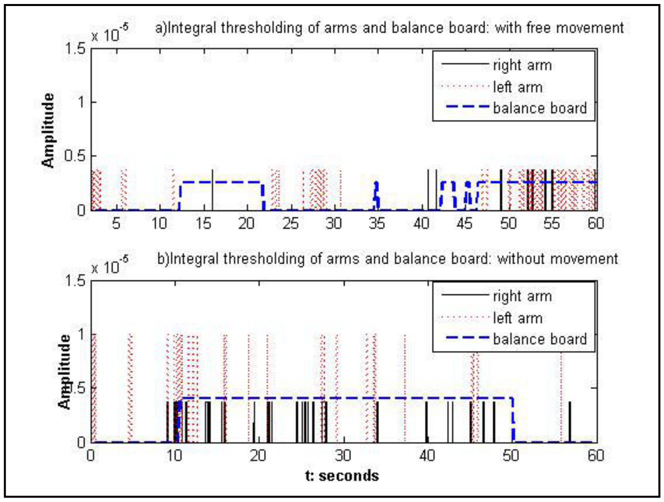

Figure 6. Integral threshold of arms and balance board with free arm movement and without arm movements from subject 2

When evaluating and observing the entire obtained results from the calculation of the areas under the integral threshold one can only conclude that there is strong indication that arms provide an improved counterbalancing mechanism during dynamic balance maintenance. The results of all subjects combined have been tabulated below.

TABLE I. CALCULATED RESULTS OF AREAS UNDER THE INTEGRAL THRESHOLD

	Area	Mean	Median
Balance board (with arm movement)	0.0162	0.004	0.004
Balance board (no arm movement)	1.2973	0.3243	0.2939
Right arm (movement)	0.0057	0.0014	0.0014
Right arm (no movement)	0.0053	0.0013	0.0014
Left arm (movement)	0.0045	0.0011	0.0012
Left arm (no movement)	0.0044	0.0011	0.0012

As we can see from the table above, there is a very big difference in the area of instability when arms were used versus when the arms were limited to no movement. This difference was calculated to be 97.5%. The difference in the area of the right arm movement (dominance) versus left arm movement while correcting balance was calculated to be 11.7%. Therefore both of these results provide further prove on the importance of arm movement in loss of balance as well as the greater use of the dominant arm in this process.

IV. CONCLUSION

While the literature review emphasized that arm movements to have a potentially significant effect on balance, this paper showed that the proposed accelerometer-based balance board test provides useful diagnostic information for postural balance and arm movements evaluation as they are related to each other. The study confirmed the important impact of arm movement on postural stability and provides an insight into dynamics of the arm movements and balance maintenance. Furthermore the greater use of the dominant arm was demonstrated. All of the results were also verified by the calculations of amount of activity of arms related to dynamic balance control. This was an initial study and for future work more measurements should be performed with a larger sample size.

V. ACKNOWLEDGMENTS

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REFERENCES

[1] Laurence Z. Rubenstein. “Falls in older people: epidemiology, risk factors and strategies for prevention”, Age and Ageing, Vol. 35, Issue 2, pp. ii37-ii41, 2006.

[2] John Davison, Sarah Marrinan, ”Falls”, Reviews in Clinical Gerontology, Vol. 17, Issue 2, United Kingdom. pp. 93-107, Apr. 2008.

[3] Mirjam Pijnappels, Idsart Kingma, Daphne Wezenberg, Guus Reurink, Jaap H. van Dieën, “Armed against falls: the contribution of arm movements to balance recovery after tripping”, Experimental Brain Research, Vol. 201,Issue 4, pp. 689-699, Dec 2009.

[4] Thierry Pozzo, Paul J. Stapley, Charalambos Papaxanthis, “Coordination between equilibrium and hand trajectories during whole body pointing movements”, Experimental Brain Research, Vol. 144, Issue 3, pp. 343-350, Apr. 2002.

[5] Myriam Ferry, Luc Martin, Nicolas Termoz, Julie Côté, Francois Prince, “Balance control during an arm raising movement in bipedal stance: which biomechanical factor is controlled?”, Experimental Brain Research, Vol. 91, Issue 2, pp. 104-114, Aug. 2004.

[6] Matija Milosevic, Kristiina M. Valter McConville, Kei Masani, “Arm movement improves performance in clinical balance and mobility tests”, Gait and Posture, Vol. 33, Issue 3, pp 507-509, Mar. 2011.

[7] Sjoerd M. Bruijn, Onno G. Meijer, Peter J. Beek and Jaap H. van Dieën, “The effects of arm swing on human gait stability”, The Journal of Experimental Biology, Vol. 213, Issue 23, pp.3945-3952, Sep. 2010.

[8] Matija Milosevic, “Arm Movements and Dynamic Postural Stability: Accelerometer-based Balance Tests”, Thesis, Ryerson University, 2009.

[9] Richard W. Mechling, “Objective assessment of postural balance through use of the variable resistance balance board”, Physical Therapy, Vol. 66, Issue 5, pp. 685-688, May 1986.

[10] Wiliam R. Ferrell, Nicola Tennant, Roger D. Sturrock, Linda Ashton, Gisela Creed, Gillian Brydson, and Daniel Rafferty, “Amelioration of symptoms by enhancement of proprioception in patients with joint hypermobility syndrome”, Arthritis and Rheumatism, Vol. 50, Issue 10, pp. 3323-3328, Oct. 2004.

[11] Demirhan Diracoglu, Resa Aydin, Akin Baskent, Ajda Celik, “Effects of kinesthesia and balance exercises in knee osteoarthritis”, Journal of Clinical Rheumatology, Vol. 11, Issue 6, pp. 303-310, Dec. 2005.

[12] Bastiaan R. Bloem, Janneke A.G. Steijns, Bouwien C. Smits-Engelsman. “An update on falls”, Current Opinion in Neurology, Vol. 16, Issue 1. pp. 15-26, 2003.

[13] J. C. Davis, M. C. Robertson, M. C. Ashe, T. Liu-Ambrose, K. M. Khan & C. A. Marra, “International comparison of cost of falls in older adults living in the community: a systematic review”, Osteoporosis International, Vol.21, Issue 8, pp. 1295-1306, Feb 2010.

[14] Diane M. Jackson, John J. Reilly, Louiuse A. Kelly, Colette Montgomery, Stan Grant, and James Y. Paton, “Objectively measured physical activity in a representative sample of 3- to 4-year-old children”, Obesity Research, Vol. 11, Issue 3, pp. 420-425. Mar 2003.

[15] Bonnie G. Steele, Lyn Holt, BasiaBelza, Scot Ferris, S. Lakshminaryan, and David M. Buchner, “Quantitating physical activity in COPD using a triaxial accelerometer”, Chest, Vol. 117, Issue 5, pp. 1359-1367, May 2000.

[16] Rangaraj M. Rangayyan, “Biomedical Signal Analysis a case-study approach”, Edition 1, Johyn Wiley & Sons - IEEE Press, Calgary, Canada, 2001.

[17] Jiapu Pan, Willis J. Tompkins, “A real-time QRS detection algorithm”, IEEE Transactions on Biomedical Engineering, Vol. 32, Issue 3, pp. 230-236, Mar 1985.