Songklanakarin J. Sci. Technol.
42 (5), 984-990, Sep. - Oct. 2020

http://www.sjst.psu.ac.th

*Original Article*

# Concurrent validity of a developed accelerometry-based device for postural sway assessment

Plaiwan Suttanon[1], Benjarath Kuhaphensaeng[1], Tak Choawanachan[1], Thatchaya Prathum[1], Praewpun Saelee[1], and Sudarat Apibantaweesakul[2*]

[1] *Department of Physical Therapy, Faculty of Allied Health Sciences, Thammasat University, Rangsit Campus, Khlong Luang, Pathum Thani, 12121 Thailand*

[2] *Department of Sports Science and Sports Development, Faculty of Allied Health Sciences, Thammasat University, Rangsit Campus, Khlong Luang, Pathum Thani, 12121 Thailand*

Received: 24 August 2018; Revised: 13 January 2019; Accepted: 14 June 2019

## Abstract

Postural control is one factor related to falls. Many instruments are available to objectively evaluate postural control performance. However, feasibility and applicability is limited by setting and financial restraints. Therefore, the purpose of this study was to assess the concurrent validity between a developed accelerometry-based sway meter and 3D-motion analysis system. Twenty healthy volunteers participated in this study. Postural sway during quiet stance, and leaning (forward, backward, left and right) were collected using a 3D-motion analysis system and the developed accelerometry-based device simultaneously. Pearson's product correlation coefficient was used to determine the relationship between the two instruments. Significant correlations were found between center of mass sway angle measured by 3D-motion system and the developed sway meter. These findings and the affordable sway meter device may provide support for the use of the accelerometry sway meter in evaluating sway when standing both static and dynamic conditions.

**Keywords:** postural sway, sway meter, accelerometer, falls

## 1. Introduction

Falls are more common health problems and the leading cause of injury-related visits to primary care centers among children and the elderly (Cumming *et al.*, 2008; Lee *et al.*, 2017; Peden, 2008; World Health Organization [WHO], 2007). The elderly had falling rates 10 times higher than children for hospitalizing and 8 times the number of deaths (Runge, 1993). Related studies found that 30% of individuals over 65 years of age had falling rates at least once per annually (Dolinis, Harrison, & Andrews, 1997; O'Loughlin, Robi taille, Boivin, & Suissa, 1993; Reyes-Ortiz, Al Snih, Loera, Ray, & Markides, 2004). In Thailand, falling rates were reported from 12 to 43% related to types of falls, populations and evaluation (Assantachai, Praditsuwan, Chatthanawaree, Pisalsarakij, & Thamlikitkul, 2003; Hanjangsit, 1994; Runge, 1993; Treeyawuttiwat, 2001). Consequences of falls could range from mild to severe injuries including fractures and consequently hospitalization as well as institutionalization (Carey & Laffoy, 2005; Peel, Kassulke, & McClure, 2002, Morris *et al.*, 2004, Kenny *et al.*, 2008; Rowe & Fehrenbach, 2004). In 2008, regarding the situation of the elderly in Thailand, falling was one of the top reported injury causes accounting for 40% of the total (Damrikarnlerd *et al.*, 2008). Therefore, falls among the elderly are common problems in health systems concerning preparing for the aging society (Alekna, Stukas, Tamulaityte-Morozoviene, Surkiene, & Tamulaitiene, 2015; Damrikarnlerd, Kaewket, & Thananchai, 2008; WHO, 2011).

The ability to maintain postural sway and stability of balance during standing, walking or other activities re-

*Corresponding author
Email address: sudarat.thamm@gmail.com

present essential indicators of fall risks among the elderly (Gill, Taylor, & Pengelly, 2005; Russell, Hill, Blackberry, Day, & Dharmage, 2006). Through the years, postural sway and balance have been investigated in several studies using various methods and tools (Paillard & Noé, 2015) such as functional balance tests (Kejonen & Kauranen, 2002; O'Sul livan, Blake, Cunningham, Boyle, & Finucane, 2009), fall alarm detector (Kangas, Korpelainen, Vikman, Nyberg, & Jamsa, 2015), Lord's sway meter (Nalawade & Ganvir, 2015; Ramachandran & Yegnaswamy, 2011; Sturnieks, Arnold, & Lord, 2011) force platform (Cumming *et al.*, 2008; Pickerill & Harter, 2011; Sturnieks *et al.*, 2011), head-mounted wearable device (Salisbury, Keshav, Sossong, & Sahin, 2017) and motion analysis (Kejonen & Kauranen, 2002; Wang, Skubic, Abbott, & Keller, 2010). The tools used may be simple or sophisticated. Technological developments may lead to improved postural sway assessment. Therefore, many different balance measurements have been developed to provide accurate body sway information with the aims of reducing cost of production and increasing clinical use such as fall alarm detector, webcam, smartphone assessment and accelerometer (Kangas *et al.*, 2015; McGrath *et al.*, 2012; O'Sullivan *et al.*, 2009; Patterson, Amick, Thummar, & Rogers, 2014; Wang *et al.*, 2010). The three main technologies developed for sway detection include stain-gauge, kinematics and accelerometer (O'Sullivan *et al.*, 2009; Paillard & Noé, 2015; Wang *et al.*, 2010). In related studies, the automatic fall detector and accelerometer were used to assess balance and fall risk among the elderly (Doheny *et al.*, 2012; Zigel, Litvak, & Gannot, 2009). The accelerometry-based technologies for postural sway have been developed continuously using the center of mass (COM) displacement assessment concept in each axis (Doheny *et al.*, 2012; Yang & Hsu, 2010). Moderate to high validity of accelerometry-based measures were reported among healthy individuals with postural instability and gait disability compared by force platform device (Mancini *et al.*, 2012; Rumore, 2014) and clinical balance tests (O'Sullivan *et al.*, 2009). In addition, Christina *et al.* in 2012 found similarities of balance assessment between force pate and acceleration data (Seimetz, Tan, Katayama, & Lockhart, 2012). However, correlation of balance assessment between accelerometer and laboratory standards remains unclear. The motion analysis system measured together with force platform is a common standardized tool to evaluate postural sway by calculating COM position. The purpose of this study was to determine the correlation of postural sway assessment between the developed accelerometry-based device and 3D-motion analysis system to improve the accelerometer regarding inexpensive, accurate and practical balance or fall risk assessment among the elderly and individuals with balance problems.

## 2. Materials and Methods

### 2.1 Subjects

Twenty healthy adults, aged 19 to 79 years (11 males, 9 females; mean age 42.65 ± 22.61 years, mean height 161.35±10.17 cm and mean weight 61.95±8.23 kg), volunteered for the study. Before the study, informed consent protecting the legal rights of the participants was obtained. All participants completed the screening questionnaire. The participants were included if they were able to walk independently and live in the community. This study considered exclusion criteria comprised major musculoskeletal impairments, neurological problems and history of balance problems.

### 2.2 Protocol

The study was approved by the Ethics Committee on Research Involving Human Subjects, Thammasat University. Postural sway was measured in bipedal standing with feet shoulder-width apart, comfortable arms and eyes open, while looking ahead on a firm surface concerning five conditions: quiet stance (comfortable position), leaning forward, leaning backward, leaning left sway and leaning right sway. Postural sway in each condition was demonstrated first. Participants were required to practice two to three times. Then each participant was instructed to sway for three trials and holding five seconds each trial. All conditions were randomized with three trials except quiet stance that was performed as the first condition. Postural sway was defined as an angular movement of the body around the axis at the ankle joint (Nayak, 1987). Participants rested two minutes in between conditions. Mean value of postural sway for each condition was calculated from three trials. Recordings from the postural sway meter and 3D-motion analysis were recorded simultaneously throughout each trial.

### 2.3 Postural sway meter: a new developed accelerometry-based device

The postural sway meter in this study was designed and developed using a small size and light weight accelerometry- and clinometry-based device (4.5x4.5x1.175 $cm^3$) (0.05 kg) (Figure 1) that recorded COM sway angle in the two planes (sagittal, and frontal planes) at waist level. The device consisted of three main parts: 1) digital three axial acceleration sensor to detect COM in X and Y planes (Sagittal, and frontal planes, respectively). The Z axis in this device was unable to measure COM sway. The sensor measured the alteration of sway angles of COM compared with the reference line (center of gravity line in starting position when static standing). A WIFI chip controlled data transferred to the personal computer and displayed sway angle data (Figure 2). The sagittal plane (anteroposterior (AP) and frontal plane mediolateral (ML) sway angles were calculated and transferred. These two planes were used to assess balance as in the related study.

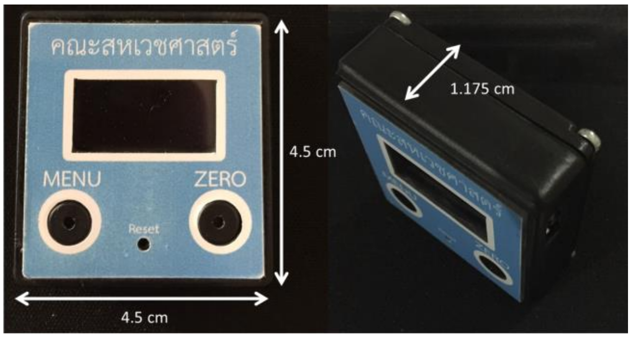


Figure 1. Configuration of postural sway meter.

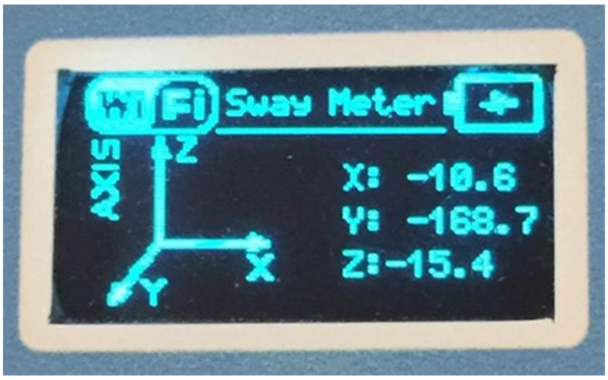


Figure 2. Display of postural sway meter.

The angle in each axis was calculated using these equations below.

1) Equations 1-3: Z axis was perpendicular to the earth's field

$$X° = \arctan2(accY, accZ) \times 57.29577951 \quad (1)$$

$$Y° = \arctan((-accX)/\sqrt{(accY\text{^}2+accZ\text{^}2)}) \times 57.29577951 \quad (2)$$

$$Z° = \arctan(\sqrt{(accX\text{^}2+accY\text{^}2)}/accZ) \times 57.29577951 \quad (3)$$

2) Equations 4-6: X axis was perpendicular to the earth's field

$$X° = \arctan2(accY, accX) \times 57.29577951 \quad (4)$$

$$Y° = \arctan((-accZ)/\sqrt{(accY\text{^}2+accX\text{^}2)}) \times 57.29577951 \quad (5)$$

$$Z° = \arctan(\sqrt{(accZ\text{^}2+accY\text{^}2)}/accX) \times 57.29577951 \quad (6)$$

3) Equations 7-9: Y axis was perpendicular to the earth's field

$$X° = \arctan2(accZ, accY) \times 57.29577951 \quad (7)$$

$$Y° = \arctan((-accX)/\sqrt{(accZ\text{^}2+accY\text{^}2)}) \times 57.29577951 \quad (8)$$

$$Z° = \arctan(\sqrt{(accX\text{^}2+accZ\text{^}2)}/accY) \times 57.29577951 \quad (9)$$

X°: x angle
Y°: y angle
Z°: z angle
*57.29577951: by converting radians to degrees

In addition, Kalman's filter theory was applied to reduce angular error (Brown, & Hwang, 1992).

## 2.4 Three-dimensional motion analysis

An 8-camera Vicon motion analysis system (Vicon MX 512 M, OMG, Oxford, UK) with a sampling rate of 250 Hz that allowed for accurate measurement of movement was used to record the motion of the 36 individual markers throughout each postural sway trial. The data from the 3D-motion analysis system was used to validate calculations. Calibration procedures and marker placement were performed according to manufacturer guidelines. A similar computed concept, as described in the previous section, was applied to extract the coordination of COM in anteroposterior and lateral sway directions and calculate the COM sway angle in each condition of the study.

## 2.5 Statistical analysis

For the recorded parameters, the mean values and standard deviations were computed. All recorded parameters derived from both postural sway meter and 3D-motion analysis were normal distribution. Therefore, Pearson's correlation coefficients were determined between the sway angle measured by the postural sway meter and COM sway angle from the 3D-motion analysis system in X (anteroposterior sway) and Y axes (Mediolateral sway). All correlations were verified at the significance level of 0.05.

# 3. Results and Discussion

Twenty healthy subjects participated in this study. The characteristics of the participants are presented in Table 1.

Sway angle parameters from computed 3D-motion analysis and postural sway meter are described using statistical data (mean and standard deviation) in Table 2. The results showed a very high correlation ($r=0.982$, $p<0.01$) between the sway angle computed from 3D-motion analysis and postural sway meter in anteroposterior direction during quiet stance. The anteroposterior and posteroanterior sway between the sway angle computed from 3D-motion analysis and postural sway meter presented high correlations ($r=0.879$, $p<0.01$ and $r=0.733$, $p<0.01$, respectively). In addition, the results in left and right sway (mediolateral direction) between the sway angle computed from 3D-motion analysis and postural sway meter presented high correlations ($r=0.835$, $p<0.01$ and $r=0.835$, $p<0.01$, respectively). All results for correlations are presented in Table 2.

The scatterplots of the sway angle computed from 3D-motion analysis and postural sway meter in each condition were also evaluated (Figure 3).

Evaluation of postural sway is an important tool that can be applies in general assessment and can be developed for fall alarm devices. Therefore, this study aimed to evaluate the validity of the postural sway meter developed based on accelerometry and clinometry theories with affordable and

Table 1. Characteristics of subjects (n = 20).

| Participant's characteristics | Mean (Standard deviation) | Minimum-Maximum |
|---|---|---|
| Age (yrs) | 42.65 (22.61) | 19.00-79.00 |
| Mini–mental state Examination (MMSE) | 28.25 (2.31) | 24.00-30.00 |
| Height (cm) | 161.35 (10.17) | 144.00-183.00 |
| Weight (kg) | 61.95 (8.23) | 51.00-82.00 |
| Body mass index ($kg/m^2$) | 24.06 (4.47) | 18.81-34.48 |

Table 2. Sway angle parameters and correlation coefficient (r) between those computed from 3D-motion analysis and postural sway meter during 5 conditions.

| Situation/Direction | 3D-motion analysis Mean±SD (Degree) | Postural sway meter Mean±SD (Degree) | Correlation coefficient[a] (r) |
|---|---|---|---|
| Comfortable stance/ with A/P sway measurement | 0.280±0.677 | 0.167±0.510 | 0.982** |
| Antero-posterior sway | 5.713±1.734 | 7.089±1.658 | 0.879** |
| Postero-anterior sway | 2.140±1.057 | 3.431±1.370 | 0.733** |
| Left sway | 5.064±1.622 | 3.339±1.245 | 0.835** |
| Right sway | 5.173±1.396 | 3.382±1.199 | 0.835** |

[a] = Pearson Correlation; **= Significant at $p < 0.01$

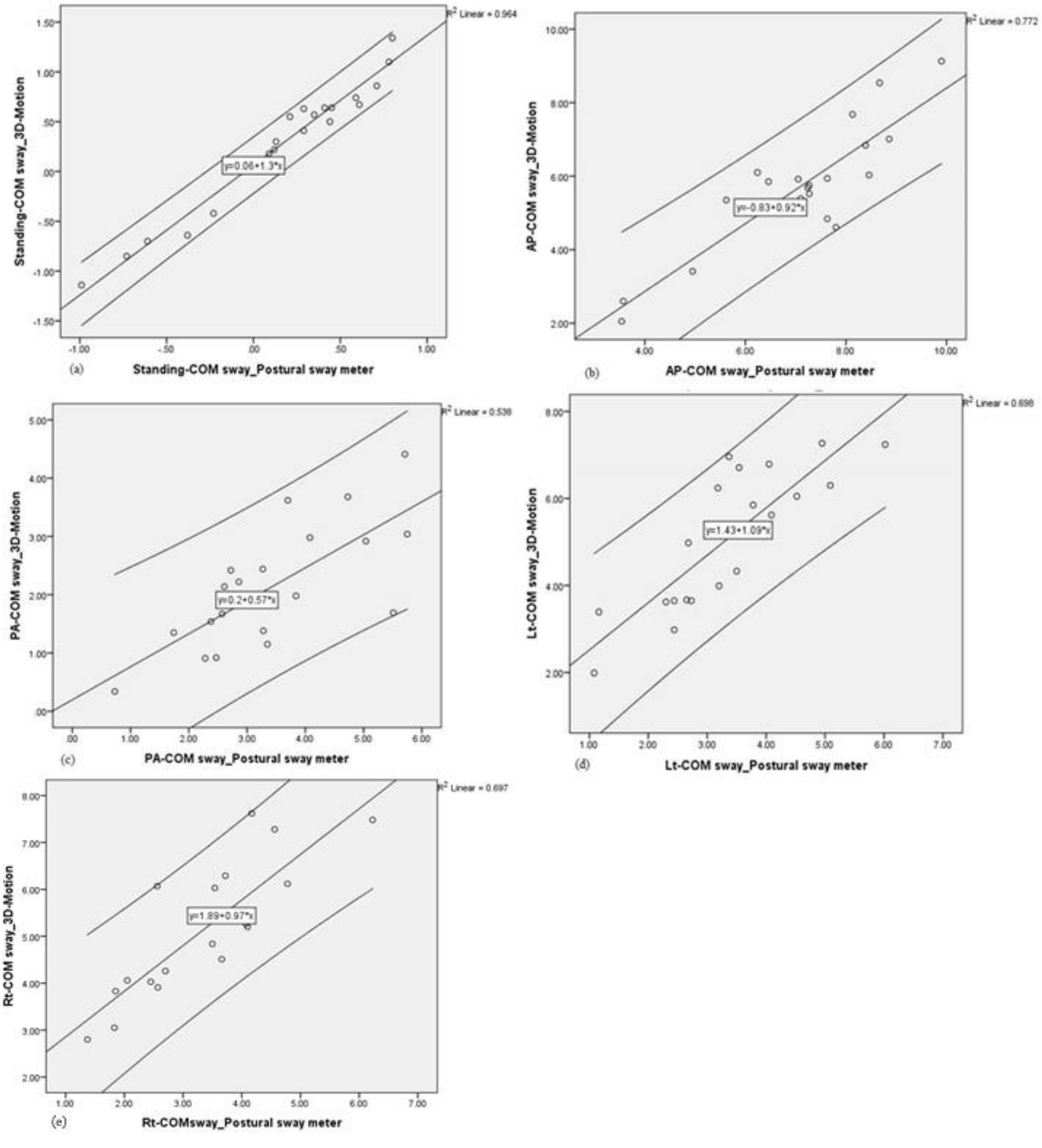


Figure 3. Scatterplot of COM sway angle computed by 3D-motion analysis and postural sway meter: (a) Quiet stance (b) Antero-posterior direction (c) Postero-anterior direction (d) Left mediolateral direction (e) Right mediolateral direction.

convenient features. The validity study sample consisted of 20 healthy participants, and the validity of the sway meter was assessed by comparing the results using a standardized 3D-motion analysis system (Brink *et al.*, 2013; Godwin, Agnew, & Stevenson, 2009; Kejonen & Kauranen, 2002; Wang *et al.*, 2010), which were synchronized with an LED light.

High to very high correlations (r = 0.733–0.982) between the postural sway meter and standardized 3D-motion analysis during quiet stance and leaning in four directions in frontal and sagittal planes implied good validity of the developed postural sway meter. The results indicated that different COM sway during dynamic sway in each direction significantly influenced results between using the 3D-motion analysis system and developed accelerometry-based device to assess postural sway. In this study, the postural sway meter was attached to the fifth lumbar spinous process to represent COM movement. The basic definition in related studies reported COM is a point of the total body mass that is regulated by the balance control system including the angle sway between the COG projection, the vertical projection of COM onto the ground, and sway positions (Hamideh, 2017; Winter, 1995). In this study, the correlation level in comfortable standing in A/P directions was very high (r = 0.982). The analysis of this study concerned the previous finding that in quiet standing an ankle strategy was mainly used in the A/P direction (Winter, 1995). On the other hand, the correlations were high when leaning in four directions (r = 0.733 leaning backward, r = 0.879 leaning forward and r = 0.835 leaning to the left and right directions). During dynamic sway test, COM position may have moved using the postural control strategy among individual participants which may have influenced the different results between COM from 3D-motion analysis and COM sway angle especially when using a hip strategy (Shumway-Cook & Woollacott, 2007) although the participants were asked to perform the dynamic sway with using ankle strategy. In higher perturbations the ankle strategy could not act upon the alternative strategies such as hip strategy, combined strategy and stepping to respond in these situations (Winter, 1995). The values of the sway angle using 3D-motion analysis and the accelerometer in this study in all directions were in normal range (8 degrees, 4 degrees and 8 degrees for forward, backward and lateral directions, respectively) (Shumway-Cook & Woollacott, 2007). In addition, all parameters of sway angle in quiet stance and dynamic sway were also relevant to a related study (Hamideh, 2017). These findings and the affordable sway meter device may provide support for using the accelerometry sway meter to evaluate sway while standing in both static and dynamic conditions. These correlations corresponded to results in related studies that compared using clinical balance tests (O'Sullivan *et al.*, 2009) and a force plate device (Mancini *et al.*, 2012; Sturnieks *et al.*, 2011).

Further research on the accelerometer in other conditions is required. Related studies (Hamideh, 2017; Winter, 1995) reported the results of investigating sway patterns in each condition including quiet standing, perturbed standing, walking in each phase and wearing shoes. These conditions could help to further develop an accelerometry-based device to assess postural sway for older people and individuals with balance problems.

## 4. Conclusions

Regarding falls related to the postural sway, the accuracy of assessment is crucial as well as the affordability of the assessment. This study contributes in developing an accelerometry-based device to assess postural sway when quiet standing and internal perturbed standing in four directions in group of healthy individuals. Correlations were found between the developed accelerometry-based device and standardized 3D-motion analysis system. The developed accelerometer in this study provided assessed potential postural sway among healthy individuals and could be used as guidelines to develop the postural sway devices to evaluate and prevent injury among individuals with balance problems.

## Acknowledgements

The author gratefully acknowledges the financial support provided by Thammasat University under the TU Research Scholarship. We would like to express our sincere appreciation to the subjects for participating in the study.

## References

Alekna, V., Stukas, R., Tamulaityte-Morozoviene, I., Surkiene, G., & Tamulaitiene, M. (2015). Self-reported consequences and healthcare costs of falls among elderly women. *Medicina, 51*(1), 57-62. doi:10.1016/j.medici.2015.01.008

Assantachai, P., Praditsuwan, R., Chatthanawaree, W., Pisalsarakij, D., & Thamlikitkul, V. (2003). Risk factors for falls in the Thai elderly in an urban community. *Journal of the Medical Association of Thailand, 86*(2), 124-130.

Brink, Y., Louw, Q., Grimmer, K., Schreve, K., van der Westhuizen, G., & Jordaan, E. (2013). Development of a cost effective three-dimensional posture analysis tool: validity and reliability. *BMC Musculoskelet Disord, 14*, 335-335. doi:10.1186/1471-2474-14-335

Carey, D., & Laffoy, M. (2005). Hospitalisations due to falls in older persons. *Irish Medical Journal, 98*(6), 179-181.

Cumming, R. G., Sherrington, C., Lord, S. R., Simpson, J. M., Vogler, C., Cameron, I. D., & Naganathan, V. (2008). Cluster randomised trial of a targeted multifactorial intervention to prevent falls among older people in hospital. *BMJ, 336*(7647), 758-760. doi:10.1136/bmj.39499.546030.BE

Damrikarnlerd, L., Kaewket, W., & Thananchai, C. (2008). *Situation of the Thai Elderly 2008*. Retrieved from http://thaitgri.org/?p=36180#

Doheny, E. P., McGrath, D., Greene, B. R., Walsh, L., McKeown, D., Cunningham, C., . . . Caulfield, B. (2012). Displacement of centre of mass during quiet standing assessed using accelerometry in older fallers and non-fallers. *Conference Proceeding IEEE Engineering in Medicine and Biology Society, 2012*, 3300-3303. doi:10.1109/embc.2012.6346670

Dolinis, J., Harrison, J. E., & Andrews, G. R. (1997). Factors associated with falling in older Adelaide residents *Australian and New Zealand Journal of Public Health, 21*(5), 462-468.

Gill, T., Taylor, A. W., & Pengelly, A. (2005). A population-based survey of factors relating to the prevalence of falls in older people. *Gerontology, 51*(5), 340-345. doi:10.1159/000086372

Godwin, A., Agnew, M., & Stevenson, J. (2009). Accuracy of inertial motion sensors in static, quasistatic, and complex dynamic motion. *Journal of Biomechanical Engineering, 131*(11), 114501. doi:10.1115/1.4000109

Hamideh, R. (2017). A comparison between static and dynamic stability in postural sway and fall risk. *Journal of Ergonomics, 7*, 1-7.

Hanjangsit, H. (1994). *Incident and factors related to home accident of the elderly in yasothorn province.* (Master's thesis, Mahidol University, Bangkok, Thailand).

Kangas, M., Korpelainen, R., Vikman, I., Nyberg, L., & Jamsa, T. (2015). Sensitivity and false alarm rate of a fall sensor in long-term fall detection in the elderly. *Gerontology, 61*(1), 61-68. doi:10.1159/000362720

Kejonen, P., & Kauranen, K. (2002). Reliability and validity of standing balance measurements with a motion analysis system. *Physiotherapy, 88*(1), 25-32.

Kenny, A. M., Bellantonio, S., Fortinsky, R. H., Dauser, D., Kleppinger, A., Robison, J., . . . Walsh, S. J. (2008). Factors associated with skilled nursing facility transfers in dementia-specific assisted living. *Alzheimer Disease and Associated Disorders Journal, 22*(3), 255-260. doi:10.1097/WAD.0b013e31816c92d5

Lee, K., Lee, J. S., Kim, K. H., Park, J., Shin, D. W., Kim, H., . . . Jeon, W. (2017). Characteristics and risk factors of fall-down injuries in preschool aged children. *Journal of the Korean Society of Emergency Medicine, 28*(4), 354-361.

Mancini, M., Salarian, A., Carlson-Kuhta, P., Zampieri, C., King, L., Chiari, L., & Horak, F. B. (2012). ISway: A sensitive, valid and reliable measure of postural control. *Journal of Neuro Engineering and Rehabilitation, 9*, 59-59. doi:10.1186/1743-0003-9-59

McGrath, D., Doheny, E. P., Walsh, L., McKeown, D., Cunningham, C., Crosby, L., . . . Greene, B. R. (2012). Taking balance measurement out of the laboratory and into the home: Discriminatory capability of novel centre of pressure measurement in fallers and non-fallers. *Conference Proceeding IEEE Engineering in Medicine and Biology Society, 2012*, 3296-3299. doi:10.1109/embc.2012.6346669

Morris, M., Osborne, D., Hill, K., Kendig, H., Lundgren-Lindquist, B., Browning, C., & Reid, J. (2004). Predisposing factors for occasional and multiple falls in older Australians who live at home. *Australian Journal of Physiotherapy, 50*(3), 153-159.

Nalawade, T. C., & Ganvir, S. D. (2015). Normative data of postural sway by using sway meter among young healthy adults. *International Archives of Integrated Medicine, 2*, 197-204.

Nayak, U. S. (1987). Comparison of the wright ataxiameter and the Kistler force platform in the measurement of sway. *Journal of Biomedical Engineering, 9*(4), 302-304.

O'Loughlin, J. L., Robitaille, Y., Boivin, J. F., & Suissa, S. (1993). Incidence of and risk factors for falls and injurious falls among the community-dwelling elderly. *American Journal of Epidemiology, 137*(3), 342-354.

O'Sullivan, M., Blake, C., Cunningham, C., Boyle, G., & Finucane, C. (2009). Correlation of accelerometry with clinical balance tests in older fallers and non-fallers. *Age Ageing, 38*(3), 308-313. doi:10.1093/ageing/afp009

Paillard, T., & Noé, F. (2015). Techniques and methods for testing the postural function in healthy and pathological subjects. *BioMed Research International*. doi:10.1155/2015/891390

Patterson, J. A., Amick, R. Z., Thummar, T., & Rogers, M. E. (2014). Validation of measures from the smartphone sway balance application: A pilot study. *International Journal of Sports Physical Therapy, 9*(2), 135-139.

Peden, M. (2008). *World report on child injury prevention*. Retrieved from https://www.unicef.org/eapro/World_report.pdf

Peel, N., Kassulke, D., & McClure, R. (2002). Population based study of hospitalised fall related injuries in older people. *Injury Prevention, 8*(4), 280-283. doi:10.1136/ip.8.4.280

Pickerill, M. L., & Harter, R. A. (2011). Validity and reliability of limits-of-stability testing: a comparison of 2 postural stability evaluation devices. *Journal of Athletic Training, 46*(6), 600-606.

Ramachandran, S., & Yegnaswamy, R. (2011). Measurement of postural sway with a sway meter-an analysis. *Journal of Physiotherapy, 2*, 46-53.

Reyes-Ortiz, C. A., Al Snih, S., Loera, J., Ray, L. A., & Markides, K. (2004). Risk factors for falling in older Mexican Americans. *Ethnicity and disease, 14*(3), 417-422.

Rowe, M. A., & Fehrenbach, N. (2004). Injuries sustained by community-dwelling individuals with dementia. *Clinical Nursing Research, 13*(2), 98-110. doi:10.1177/1054773803262520

Rumore, A. J. (2014). *Smart phone assessment of postural sway in chronic neck pain sufferers.* (Doctoral dissertation, University of Canberra, Canberra, Australia).

Runge, J. W. (1993). The cost of injury. *Emergency Medicine Clinics of North America, 11*(1), 241-253.

Russell, M. A., Hill, K. D., Blackberry, I., Day, L. L., & Dharmage, S. C. (2006). Falls risk and functional decline in older fallers discharged directly from emergency departments. *Journals of Gerontology Series A Biological Sciences and Medical Sciences, 61*(10), 1090-1095.

Salisbury, J. P., Keshav, N. U., Sossong, A. D., & Sahin, N. T. (2017). Standing balance assessment using a head-mounted wearable device. *bioRxiv*. doi:10.1101/149831

Seimetz, C., Tan, D., Katayama, R., & Lockhart, T. (2012). A comparison between methods of measuring postrual stability: force plates versus accelerometers. *Biomed Sci Instrum, 48,* 386-392.

Shumway-Cook, A., & Woollacott, M. H. (2007). *Motor control: translating research into clinical practice*. Philadelphia: Lippincott Williams and Wilkins.

Sturnieks, D. L., Arnold, R., & Lord, S. R. (2011). Validity and reliability of the swaymeter device for measuring postural sway. *BMC Geriatr, 11*, 63-63. doi: 10.1186/1471-2318-11-63

Treeyawuttiwat, S. (2001). *Factors related to home accidents of the elderly in Nakhonprathom province.* (M.S. Thesis), Mahidol University, Bangkok, Thailand,

Wang, F., Skubic, M., Abbott, C., & Keller, J. M. (2010). Body sway measurement for fall risk assessment using inexpensive webcams. *Conference Proceeding of IEEE Engineering in Medicine and Biology Society, 2010,* 2225-2229. doi:10.1109/iembs.2010.5626100

WHO. (2007). *WHO global report on falls prevention in older age* (pp. 1-7). Retrieved from http://www.who.int/ageing/publications/Falls_prevention7March.pdf

Winter, D. A. (1995). Human balance and posture control during standing and walking. *Gait Posture, 3*(4), 193-214.

World Health Organization. (2011). *Global health and aging*. (pp. 1-32). Retrieved from http://www.who.int/ageing/publications/global_health.pdf

Yang, C.-C., & Hsu, Y.-L. (2010). A Review of Accelerometry-Based Wearable Motion Detectors for Physical Activity Monitoring. *Sensors, 10*(8), 7772-7788. doi:10.3390/s100807772

Zigel, Y., Litvak, D., & Gannot, I. (2009). A method for automatic fall detection of elderly people using floor vibrations and sound--proof of concept on human mimicking doll falls. *IEEE Trans Biomed Eng, 56*(12), 2858-2867. doi:10.1109/tbme.2009.2030171