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Self-Mobilization Exercise Program Improved Postural Stability in the Anterior-Posterior Direction with Eyes Closed

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Abstract: Maintenance of equilibrium is influenced by postural symmetry and deviations such as a forward head. An exercise program involving an effect such as self-joint mobilization was developed to address spinal curvature; however, its effect on postural stability is still unclear. The purpose of this study was to address to what extent the self-mobilization exercise program would influence postural sway while standing still. The Exercise group (n = 16) performed the self-mobilization while lying supine on a cylinder-shaped tube (98 cm length, 15 cm diameter), consisting of three warm-up positionings followed by seven motions. The Control group (n = 16) laid supine on a flat surface with their legs flexed. Before and immediately after respective interventions, the plantar center of pressure was quantified while subjects were standing with eyes open and closed. The results show the exercise group reduced the postural sway in the antero-posterior direction only during the eyes-closed condition. Neither exercise nor control groups showed a significant change in postural sway during the eyes-open condition. Our findings indicate the self-mobilization exercise program improved the participant's stability when visual feedback was not reliable for postural control. The improved postural control in the antero-posterior direction may be accounted for by facilitated activation of planterflexors and dorsiflexors which are primary muscles in ankle strategy for postural control. Effects of this exercise program on postural stability appear to be direction dependent, which provide insight when healthcare professionals incorporate exercise programs for postural symmetry.

Keywords: postural control; balance; sensorimotor integration; exercise

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1. Introduction

Loss of stability can be caused by the asymmetrical distribution of body weight. Postural stability is controlled by constant and fine adjustment of the body's center of gravity to be inside the base of support [1]. This adjustment occurs both during dynamic activities and static positions such as seating and standing. Specifically, appropriate motor commands must be sent to muscles responsible for postural control while integrating multi-sensory feedback from the visual, proprioceptive, and vestibular systems [2–5]. Central processing of these sensory signals should be adapted to peripheral stimuli such as postural changes and is critical for stability control [6]. This processing of multi-sensory feedback is commonly compromised, which can lead to impaired postural stability control [7]. In addition to the central processing, multi-sensory feedback from visual [2], vestibular [8], and proprioceptive [6,9–12] systems provide critical information for stability control. Specifically, postural sway in standing increased due to a vibration applied directly over the ankle muscles [3,4,13,14]. Thus, one's ability of stability control is influenced by peripheral signals responsible for detecting position changes and central processing of these signals.

Posture, specifically the spinal alignment and relative positions of body parts, is a factor influencing stability [15–18]. Common postural deviations include sway back,

rounded shoulder, thoracic hyperkyphosis, lumbar hyperlordosis, and forward head. Such postural deviations can result in an increase in the activation of cervical and thoracic erector spinae muscles among healthy adults [19] as an indication of adjusted motor commands in response to postural changes. Additionally, the forward head and hyperkyphosis are associated with a greater postural sway [18,20,21]. These findings support the notion that posture can influence neuromuscular control of stability and resultant fluctuations of the center of gravity. Although the clinical impacts of postural deviations on stability control have been documented in the literature, it is still unclear how a change in posture induced by an exercise intervention would influence stability control.

An exercise program was developed to aim for an effect such as joint mobilization via self-initiated positionings and motions while lying supine. It is expected to cause a gravitational force on body segments, resulting in a glide on joints, which is similar to a joint play during joint mobilization. This self-mobilization exercise program can address spinal curvature [22,23], where postural deviations such as hyperlordosis, hyperkyphosis, and forward head are commonly seen. Additionally, after completion of the self-mobilization exercise program, postural sway in anterior-posterior (AP), but not medio-lateral (ML) direction, decreased when standing on an unstable, not stable platform [16]. This finding can be interpreted as an improvement in postural stability by the self-mobilization exercise program. However, there were limitations in the sway measurements particularly when subjects stood on the stable platform. A protocol built into the measuring equipment (i.e., software in Biodex Balance System) was used to measure the postural sway without a direct measurement of the plantar center of pressure (CoP). Although the postural stability was improved by this exercise program, the sway analysis in the previous study [16] did not reveal how postural stability was mechanically improved because of a lack of information on plantar CoP. Thus, it is necessary to describe how individuals gain postural stability by examining the movement of the plantar CoP data [24].

Therefore, this study addressed the question of to what extent would the self-mobilization exercise program influence multiple sway parameters while standing still on a stable surface. To address this question, this study assessed the postural control represented by the plantar CoP relative to the base of support in standing. The self-mobilization exercise program can address spinal curvature deviation including hyperkyphosis, hyperlordosis, and forward head and decreased sway in AP direction [16,22,23]. Based on these previous findings, we hypothesized that postural sway parameters derived from the plantar CoP data after the intervention of the exercise program would decrease in AP, but not ML direction. Additionally, the secondary purpose of this study was to examine the effects of exercise programs on sway parameters with eyes open and eyes closed. Our previous study [16] found that the exercise program decreased postural sway regardless of the availability of visual feedback (i.e., eyes closed or eyes open). Thus, our hypothesis was that changes in sway parameters after the exercise program would be similar between with eyes closed and eyes open.

2. Materials and Methods

2.1. Subjects

Thirty-two young healthy subjects were recruited. Individuals were excluded from the study if one of the following applied: history of major orthopedic injuries, psychiatric conditions, excess curvature on the spine, and pregnancy. The screening was performed through an interview, and the eligibility was based on self-reported health conditions. Subjects were randomly assigned into one of two groups: exercise on a cylinder-shaped tube (98 cm length, 15 cm diameter, durometer hardness: 24°, StretchPole, LPN Corporation, Nagoya, Japan, Exercise group), and a control group that laid supine on a flat surface (Table 1). Subjects gave their written informed consent, and the protocols were approved by the Office of the Institutional Review Board at the University of New Mexico (#683081).

Table 1. Demographic and anthropometric characteristics of subjects by group.

	Exercise (*n* = 16)	**Control (*n* = 16)**
Age (years)	22.44 ± 5.39	22.81 ± 6.15
Sex (male/female)	9/7	9/7
Height (cm)	170.33 ± 10.32	168.63 ± 11.62
Weight (kg)	71.32 ± 17.85	73.72 ± 21.34
Body mass index (kg/m^2)	24.34 ± 4.18	25.50 ± 5.08

The Exercise group = performed the exercise program on a cylinder-shaped tube; the Control group = laid supine on a flat surface. Data are given as mean ± standard deviations except for sex.

2.2. Interventions

Subjects in the Exercise group performed the exercise program that has been previously described elsewhere [16,22,25,26] and in Supplementary Material. Briefly, the exercise program was composed of the three preparatory positionings followed by seven motions with small magnitude while lying on a Styrofoam cylinder-shaped tube (Figure S1). The duration of the exercise program was approximately 15 min. A single experimenter instructed each subject on how to perform the positionings and motions. Subjects in the Control group were asked to lay supine on a flat surface for 15 min with their legs flexed. All subjects were also required to refrain from any intensive exercises for one week before the study.

2.3. Procedures and Measurements

Before and immediately after respective interventions, the subject's standing postural stability was assessed by capturing the plantar pressure with the MatScan system (Tekscan, Inc., Boston, MA, USA). The MatScan consists of a 5.7 mm thick floor mat (432 × 368 mm), comprising 2288 resistive sensors (resolution: 1.4 sensors/cm^2), and sampling data at a frequency of 10 Hz. The sensors capture the distribution of pressure under both soles and plantar center of pressure (CoP) was recorded while subjects stood on the pressure mat. The sway parameters are determined by using the Sway Analysis Module (Tekscan, Inc., Boston, MA, USA.). Trajectories of CoP movement were used to compute sway parameters including area, distance, antero-posterior (AP) excursion, medio-lateral (ML) excursion, root mean square (RMS) AP displacement, and RMS ML displacement.

All subjects performed the postural stability assessment while standing still with natural foot width, and arms on the side. During the assessment, subjects were asked to look at a specific visual target located on a wall at a height of 1.335 m, separated from a subject of at least 5.57 m. The postural stability assessment was performed with their eyes open and closed (EO and EC, respectively). The comparison between EO and EC conditions allowed us to examine changes in the contributions of the visual system to postural stability after interventions. The duration of each trial was 10 s and repeated 3 times with at least 5 s rest between the trials. The sway parameters over 10 s of each trial were recorded and averaged across the 3 trials for analysis. The order of EO and EC conditions was counterbalanced across subjects.

2.4. Statistical Analysis

The sway parameters over 10 s were averaged across the 3 trials for statistical analysis. One-way analysis of variance (ANOVA) was used to determine differences in subjects' demographic and anthropometric characteristics between the two groups. Two-way mixed ANOVA with Intervention (Exercise vs. Control) as a between-subject factor and Time (Pre-test vs. Post-test) as a within-subject factor was used to examine changes in the sway parameters and group difference for each condition (i.e., EO and EC conditions). When appropriate, post hoc tests were run using pairwise comparisons with Bonferroni corrections for the interactions between Intervention and Time. Sphericity assumptions were tested for all analyses (Mauchly's sphericity test). When the sphericity assumptions were violated, we used Greenhouse–Geisser analysis ($p < 0.01$). Box's test was used to

test the homogeneity of covariance ($p > 0.05$). All tests were performed at the $p \leq 0.05$ significance level. Values in the text are reported as means ± standard error of the mean.

3. Results

3.1. Subjects

The demographic and anthropometric characteristics of the subjects are summarized in Table 1. A one-way ANOVA demonstrated no significant difference in age, height, weight, or body mass index between the two groups ($p > 0.05$).

3.2. Sway Parameters in Eyes-Open Condition

During the eyes-open condition (Figure 1, left), the analysis of the two-way mixed ANOVA showed that no interaction between Time and Intervention (Area, $F_{[1,30]} = 0.817$, $p = 0.37$; Distance, $F_{[1,30]} = 3.899$, $p = 0.06$; AP excursion, $F_{[1,30]} = 2.692$, $p = 0.11$; ML: excursion, $F_{[1,30]} = 0.055$, $p = 0.82$; RMS AP displacement, $F_{[1,30]} = 0.003$, $p = 0.96$; RMS ML displacement, $F_{[1,30]} = 0.001$, $p = 0.98$). In addition, there were also no main effects of Time on all sway parameters (Area, $F_{[1,30]} = 0.336$, $p = 0.57$; Distance, $F_{[1,30]} = 1.156$, $p = 0.29$; AP excursion, $F_{[1,30]} = 1.418$, $p = 0.24$; ML: excursion, $F_{[1,30]} = 0.06$, $p = 0.80$; RMS AP displacement, $F_{[1,30]} = 0.664$, $p = 0.42$; RMS ML displacement, $F_{[1,30]} = 0.241$, $p = 0.62$) or *Intervention* (Area, $F_{[1,30]} = 0.001$, $p = 0.98$; Distance, $F_{[1,30]} = 0.000$, $p = 0.99$; AP excursion, $F_{[1,30]} = 0.297$, $p = 0.59$; ML: excursion, $F_{[1,30]} = 1.365$, $p = 0.25$; RMS AP displacement, $F_{[1,30]} = 0.423$, $p = 0.52$; RMS ML displacement, $F_{[1,30]} = 1.148$, $p = 0.29$). No interaction or main effects on all sway parameters indicate no effect of the exercise program on the postural stability when subjects stood still with their eyes open.

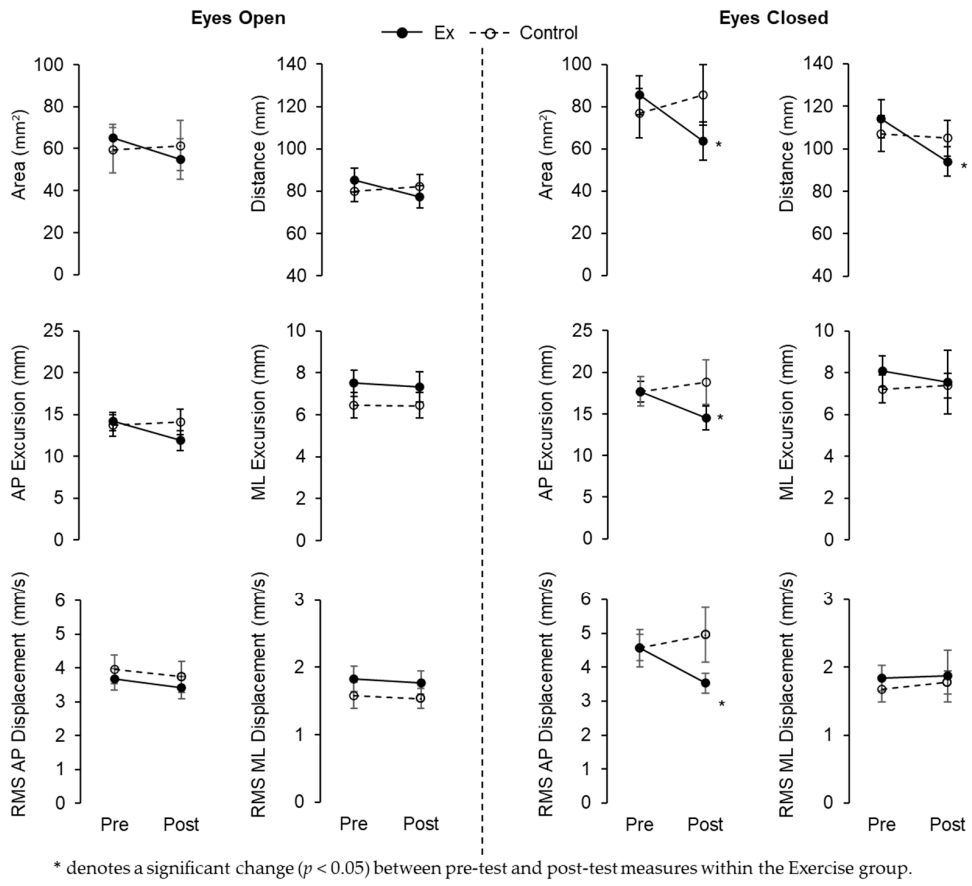

Figure 1. Center of Pressure (CoP) sway parameters for the eyes-open (**left**) eyes closed (**right**) conditions. Parameters averaged across all subjects before and after the exercise program (pre-test and post-test, respectively) are shown for the groups (Ex: Exercise and Control: black and white circles, respectively). Vertical lines denote the standard error of the mean.

3.3. Sway Parameters in Eyes-Closed Condition

During the eyes-closed condition (Figure 1, right), the analysis of the two-way mixed ANOVA revealed a significant interaction between Time and Intervention for Area, ($F_{[1,30]} = 9.063$, $p = 0.005$, $\eta^2 = 0.232$), Distance ($F_{[1,30]} = 7.689$, $p = 0.009$, $\eta^2 = 0.204$), AP excursion ($F_{[1,30]} = 4.213$, $p = 0.04$, $\eta^2 = 0.123$), and RMS AP displacement ($F_{[1,30]} = 4.226$, $p = 0.04$, $\eta^2 = 0.123$), but not ML excursion ($F_{[1,30]} = 0.420$, $p = 0.52$), or RMS ML displacement ($F_{[1,30]} = 0.063$, $p = 0.80$). The post-hoc tests revealed that Area, Distance, AP excursion, and RMS AP displacement significantly decreased in the Exercise group only (Figure 1. $p < 0.05$).

4. Discussion

This study examined the effects of a self-mobilization exercise program that was designed to realign the spinal curvature on multiple CoP sway parameters while standing on a stable surface. The main findings of this study are that (a) no significant difference in the CoP sway parameters between the pre- and post-test measures for both groups with eyes open, and (b) a significant decrease in the area, distance, excursion, and RMS displacement of the CoP sway in the AP direction in the Exercise group with eyes closed. Changes in excursion or RMS displacement in the ML direction were not significant for both groups with eyes open or closed. These findings indicate not only less overall movement of CoP as shown by decreased CoP area, distance, and AP excursion but also less fluctuation of CoP as shown by decreased RMS CoP displacement. Therefore, a comprehensive analysis of postural stability with multiple CoP parameters allowed us to interpret that participants became more stable in standing with their eyes closed after the self-mobilization exercise program [24,27].

We found decreased CoP shift in the AP, but not ML direction, which is consistent with the previous study [16], even with multiple CoP sway parameters. The decreased CoP sway in the AP direction can be explained by the positioning of participants during the exercise program. Throughout the exercise program, subjects were asked to lie supine on the pole and 3 body areas (i.e., sacrum, thoracic spinal processes, and back of the head) only were supported on the pole. This position causes a gravitational pull on the body parts that are not supported on the tube (e.g., hip, shoulder joints) toward the posterior. The posterior gravitational pull is thought to be a primary factor of changes in spinal alignment [16,23] as well as postural stability in the AP direction without any side-to-side effects. Thus, the effects of the exercise program on postural stability appear to be direction dependent. Postural sway in the AP direction is controlled by the activation of planterflexors and dorsiflexors while postural sway in the ML direction is predominantly controlled by the hip abductors and adductors [28,29]. Accurate somatosensory information from the muscle receptors is required in the ankle strategy for postural stability. Specifically, disturbed proprioceptive feedback by vibration applied over the triceps surae muscle tendons induced an increase in movement of the center of mass as well as CoP during quiet standing [30]. Thus, the exercise program used in the present study might facilitate the activation of ankle muscles for postural control in the AP direction, but not the hip muscles, resulting in no changes in the sway in the ML direction during static standing.

The present study found decreases in CoP parameters during the eyes-closed condition only. This finding indicates that the postural sway was reduced by this exercise program when visual feedback did not contribute to stability control. In our experiment, it is speculated that the improvement of postural stability is dominated by other sensory systems (i.e., vestibular, proprioception), rather than the visual system. This is consistent with the previous study that showed a greater reduction in postural sway during challenging balance tasks, e.g., standing on a foam surface with eyes closed [5]. When the eyes are closed, the visual system cannot provide accurate information regarding the spatial orientation in the environment [2]. With little or no contribution by the visual system, postural control becomes a more challenging task. During challenging conditions, the source of sensory information would be shifted to more reliable sources for stability control.

Specifically, the nervous system would rely on more vestibular and proprioceptive signals when the accuracy of visual feedback decreases such as the eye-closed condition [31,32].

However, mechanisms of the shift in sensory integration behind the reduced postural sway are still unclear. Further investigations are needed to examine dominant sensory systems for stability control in response to challenging conditions. Additionally, since the present study assessed the postural stability while standing still, a contribution of the postural change on the postural stability in a dynamic task such as gait needs to be investigated. Similarly, because only healthy young adults participated in the present study, investigations on whether our findings can be applied to patient and elderly populations are required.

Despite the limitations, our findings indicated that the self-mobilization exercise program can be implemented for improving postural stability in the AP direction. Additionally, it is important to note that changes in postural stability were found as a result of the exercise program without the presence of any pathology. Participants in this present study were healthy young adults with no known orthopedic injuries, psychiatric conditions, or excess spinal curvature associated with postural asymmetry. Thus, the exercise program can be clinically beneficial for those who may need to improve postural stability as well as to understand the general response of spinal realignment on postural stability in the AP direction.

5. Conclusions

After the completion of the self-mobilization exercise program, it is expected to reduce the postural sway in the AP direction during static standing with the eyes closed. The posterior gravitational pull on the hip and shoulder joints during the exercise program would be a primary factor contributing to the reduced postural sway in the AP direction. Activation of planterflexors and dorsiflexors which are primary muscles in ankle strategy for postural control in the AP direction might be facilitated after the exercise program. When visual feedback is not reliable during the eyes-closed condition, postural stability was maintained by shifting the reliable sensory information more toward the vestibular and proprioceptive systems. The reduced static postural sway with the eyes closed due to the exercise program should be clinically meaningful because it indicated a successful distribution of the center of mass in the sagittal plane. The effects of the exercise program on postural stability appear to be direction dependent. Improved postural sway by the rearranged distribution of the center of mass can be an applicable concept to other directions such as trunk lateral mobilization for lumbar region symmetry. This information will benefit various healthcare professionals including, but not limited to physical therapists, athletic trainers, and conditioning coaches when they consider a therapeutic intervention for rearranging the spinal segment and improving postural symmetry.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/sym15071321/s1, Figure S1: Self-mobilization exercise program for the Exercise group.

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References

1. Enoka, R.M. Neural Control of Movement. In *Neuromechanics of Human Movement*, 5th ed.; Human Kinetics: Champaign, IL, USA, 2015.
2. Wade, M.G.; Jones, G. The Role of Vision and Spatial Orientation in the Maintenance of Posture. *Phys. Ther.* **1997**, *619*, 619–628. [CrossRef] [PubMed]
3. Kavounoudias, A.; Roll, R.; Roll, J.P. Foot Sole and Ankle Muscle Inputs Contribute Jointly to Human Erect Posture Regulation. *J. Physiol.* **2001**, *532*, 869–878. [CrossRef] [PubMed]
4. Teasdale, N.; Furmanek, M.P.; Germain Robitaille, M.; de Oliveira, F.C.L.; Simoneau, M. Sensory Integration during Vibration of Postural Muscle Tendons When Pointing to a Memorized Target. *Front. Hum. Neurosci.* **2017**, *10*, 682. [CrossRef]
5. Qiu, F.; Cole, M.H.; Davids, K.W.; Hennig, E.M.; Silburn, P.A.; Netscher, H.; Kerr, G.K. Enhanced Somatosensory Information Decreases Postural Sway in Older People. *Gait Posture* **2012**, *35*, 630–635. [CrossRef]
6. Goble, D.J.; Coxon, J.P.; Van Impe, A.; Geurts, M.; Doumas, M.; Wenderoth, N.; Swinnen, S.P. Brain Activity during Ankle Proprioceptive Stimulation Predicts Balance Performance in Young and Older Adults. *J. Neurosci.* **2011**, *31*, 16344–16352. [CrossRef] [PubMed]
7. Guskiewicz, K.M. Balance Assessment in the Management of Sport-Related Concussion. *Clin. Sport. Med.* **2011**, *30*, 89–102, ix. [CrossRef]
8. Allum, J.H.J.; Adkin, A.L.; Carpenter, M.G.; Held-Ziolkowska, M.; Honegger, F.; Pierchala, K. Trunk Sway Measures of Postural Stability during Clinical Balance Tests: Effects of a Unilateral Vestibular Deficit. *Gait Posture* **2001**, *14*, 227–237. [CrossRef]
9. Morton, S.M.; Bastian, A.J. Cerebellar Control of Balance and Locomotion. *Neuroscientist* **2004**, *10*, 247–259. [CrossRef]
10. Goodwin, G.M.; Mccloskey, D.I.; Matthews, P.B.C. Proprioceptive Illusions Induced by Muscle Vibration: Contribution by Muscle Spindles to Perception? *Science* **1972**, *175*, 1382–1384. [CrossRef]
11. Edin, B.B.; Johansson, N. Skin Strain Patterns Provide Kinaesthetic Information to the Human Central Nervous System. *J. Physiol.* **1995**, *487*, 243–251. [CrossRef] [PubMed]
12. Burgess, P.R.; Wei, J.Y.; Clark, F.J.; Simon, J. Signaling of Kinesthetic Information by Peripheral Sensory Receptors. *Annu. Rev. Neurosci.* **1982**, *5*, 171–187. [CrossRef]
13. Adamcova, N.; Hlavacka, F. Modification of Human Postural Responses to Soleus Muscle Vibration by Rotation of Visual Scene. *Gait Posture* **2007**, *25*, 99–105. [CrossRef]
14. Ceyte, H.; Cian, C.; Zory, R.; Barreaud, P.-A.; Roux, A.; Guerraz, M. Effects of Bilateral Achilles Tendon Vibration on Postural Orientation. *Neurosci. Lett.* **2007**, *416*, 71–75. [CrossRef] [PubMed]
15. Imagama, S.; Ito, Z.; Wakao, N.; Seki, T.; Hirano, K.; Muramoto, A.; Sakai, Y.; Matsuyama, Y.; Hamajima, N.; Ishiguro, N.; et al. Influence of Spinal Sagittal Alignment, Body Balance, Muscle Strength, and Physical Ability on Falling of Middle-Aged and Elderly Males. *Eur. Spine J.* **2013**, *22*, 1346–1353. [CrossRef] [PubMed]
16. Shibata, D. Gait & Posture Improvement of Dynamic Postural Stability by an Exercise Program. *Gait Posture* **2020**, *80*, 178–184. [CrossRef] [PubMed]
17. Hee Lee, J. Effects of Forward Head Posture on Static and Dynamic Balance Control. *J. Phys. Ther. Sci.* **2016**, *28*, 274–277. [CrossRef]
18. Kang, J.-H.; Park, R.-Y.; Lee, S.-J.; Kim, J.-Y.; Yoon, S.-R.; Jung, K.-I. The Effect of the Forward Head Posture on Postural Balance in Long Time Computer Based Worker. *Ann. Rehabil. Med.* **2012**, *36*, 98–104. [CrossRef]
19. O'Neil, D.; Olafsdottir, K.; Caneiro, J.P.; Barach, A.; Tveit, O.; Burnett, A.; O'Sullivan, P. The Influence of Different Sitting Postures on Head/Neck Posture and Muscle Activity. *Man. Ther.* **2009**, *15*, 54–60. [CrossRef]
20. Nurwulan, N.R.; Jiang, B.C.; Iridiastadi, H. Posture and Texting: Effect on Balance in Young Adults. *PLoS ONE* **2015**, *10*, e0134230. [CrossRef]
21. Vuillerme, N.; Rougier, P. Effects of Head Extension on Undisturbed Upright Stance Control in Humans. *Gait Posture* **2005**, *21*, 318–325. [CrossRef]
22. Yokoyama, S.; Gamada, K.; Sugino, S.; Sasano, R. The Effect of "the Core Conditioning Exercises" Using the Stretch Pole on Thoracic Expansion Difference in Healthy Middle-Aged and Elderly Persons. *J. Bodyw. Mov. Ther.* **2012**, *16*, 326–329. [CrossRef]
23. Sadakiyo, M.; Sugino, S.; Gamada, K.; Yamamoto, D.; Yokoyama, S. Effectiveness of Core-Conditioning Exercises Using a Stretch-Pole on the Spinal Realingmnet and Flexibility: A Single-Blinded Randomized Control Trial. In Proceedings of the 15th International Congress of the World Confederation for Physical Therapy, Vancouver, BC, Canada, 2–7 June 2007.
24. Palmieri, R.M.; Ingersoll, C.D.; Stone, M.B.; Krause, B.A. Center-of-Pressure Parameters Used in the Assessment of Postural Control. *J. Sport Rehabil.* **2002**, *11*, 51–66. [CrossRef]
25. Boruah, K. Effectiveness of Thoracic Core Conditioning Using Stretch Pole for Community Elderly with Moderate COPD-A Single Blind Study. *Int. J. Physiother. Res.* **2014**, *2*, 394–402.
26. Kim, C.-B.; Yang, J.-M.; Choi, J.-D. The Effects of Chest Expansion Resistance Exercise on Chest Expansion and Maximal Respiratory Pressure in Elderly with Inspiratory Muscle Weakness. *J. Phys. Ther. Sci.* **2015**, *27*, 1121–1124. [CrossRef] [PubMed]
27. Niam, S.; Cheung, W.; Sullivan, P.E.; Kent, S.; Gu, X. Balance and Physical Impairments after Stroke. *Arch. Phys. Med. Rehabil.* **1999**, *80*, 1227–1233. [CrossRef] [PubMed]
28. Winter, D.A. Human Balance and Posture Control during Standing and Walking. *Gait Posture* **1995**, *3*, 193–214. [CrossRef]
29. Lee, S.P.; Souza, R.B.; Powers, C.M. The Influence of Hip Abductor Muscle Performance on Dynamic Postural Stability in Females with Patellofemoral Pain. *Gait Posture* **2012**, *36*, 425–429. [CrossRef] [PubMed]

30. Thompson, C.; Bélanger, M.; Fung, J. Effects of Plantar Cutaneo-Muscular and Tendon Vibration on Posture and Balance during Quiet and Perturbed Stance. *Hum. Mov. Sci.* **2011**, *30*, 153–171. [CrossRef]
31. Peterka, R.J. Sensorimotor Integration in Human Postural Control. *J. Neurophysiol.* **2002**, *88*, 1097–1118. [CrossRef] [PubMed]
32. Oie, K.S.; Kiemel, T.; Jeka, J.J. Multisensory Fusion: Simultaneous Re-Weighting of Vision and Touch for the Control of Human Posture. *Cogn. Brain Res.* **2002**, *14*, 164–176. [CrossRef]