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Original Research

Computerised dynamic posturography in women with knee osteoarthritis

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Abstract: The aim of this study was to compare the postural control of women with knee OA and healthy women peers and to determine the effect of knee OA on postural control. Thirty-two individuals, sixteen women with knee osteoarthritis (52.12±10.69) and sixteen healthy women (51.00±10.00) who were same age (± 3yr), were evaluated on postural control as measured by a NeuroCom EquiTest. Outcomes included equilibrium scores, sensory analysis ratios, sway energy score, and latencies from sensory organisation test, motor control test, and adaptation test and were examined using the independent t-test. Equilibrium scores (in condition 1: p=0.030, condition 3: p=0.019, condition 4: p=0.045, condition 5: p=0.010, condition 6: p=0.041, and Composite value: p=0.011), strategy score (Strategy 5: p = 0.015), sensory analysis ratios (vestibular ratio: p=0.013 and management ratio: p=0.023), and latencies (large forward: p=0.020 and comprehensive latency: p=0.016) were significantly better in the healthy women group. The presence of knee OA had an impact on the sensory system's effectiveness and its utilization in postural control. Lower values of equilibrium scores, strategy scores, sensory analysis ratios for women knee OA group were evidence of larger displacements of the center of gravity in the forward–backward direction suggesting that women knee OA group was unable to maintain balance compared to healthy knee controls. Also, women with knee OA displayed a longer neuromuscular response latency to balance perturbations, indicating a reduced ability to begin in recover balance quickly following an unexpected disturbance. This observation should be taken into account in the fall prevention, especially, individuals should place in dynamic situations with conflicted sensory environment, as these are found in daily life.

Keywords: Women with Knee Osteoarthritis; Computerized Dynamic Posturography; Motor Control Test; Latency; Adaptation test

1. Introduction

Osteoarthritis (OA) is the most prevalent arthritis and is a leading cause of disability and loss of function (Sharma, Kapoor, & Issa, 2006). Although OA can damage any joint in the body, the knee is the most commonly weight-bearing joint affected and knee OA is characterized by pain, loss of lower limb muscular strength, abnormal proprioception, and substantial decline of mechanoreceptors as compared to age-matched healthy peers (Roos, Herzog, Block, & Bennell, 2011; Tarigan et al., 2009; van der Pas et al., 2013; Wylde, Palmer, Learmonth, & Dieppe, 2012). These characteristics of individuals with knee OA reduce their capability of postural control.

As the senses required for the postural control deteriorate with disease

(Takacs, Carpenter, Garland, & Hunt, 2013), they provide reduced sensory information or insufficient input, which contributes to loss of postural control (Lord, 2007). As a result, people with knee OA have been shown to have less postural control, as demonstrated by higher static postural sway (Hinman, Bennell, Metcalf, & Crossley, 2002) and lower scores on clinical assessments such the single leg stance test, tandem stance test, and functional reach test (Hatfield, Hammond, & Hunt, 2015; Khalaj, Abu Osman, Mokhtar, Mehdikhani, & Wan Abas, Wan Abu Bakar, 2014). Static balance has traditionally been used in clinical tests of postural control, in which the participant is required to maintain their center of gravity over a stable base of support on a fixed support surface (Broglio, Sosnoff, Rosengren, & McShane, 2009). The degree of sway is subjectively judged and interpreted during the test based on the clinician's experience. This test technique has been developed and utilized in a variety of situations, and it has been shown to be effective in detecting decreased postural control associated with knee OA (Hinman et al., 2002). However, the external validity of static balance tasks is limited by the low physiologic or sensory demands, and the changing base of support, which makes it more difficult for the participant, is thought to represent the real scenario (Broglio et al., 2009). Traditionally, computerized dynamic posturography (CDP) has been used to complete this type of assessment and it provides objective quantification and differentiations among the various possible sensory, motor, and central adaptive abnormalities in dynamic environment.

In addition, from the perspectives of clinical trials and biomechanics research, most research in which balance is an outcome assumed that the differences between genders are negligible and that the genders were treated as one. If characteristics are dissimilar between male and female knee OA groups, these may increase between subject variability and reduce the ability to identify an intervention's influence on the postural control or a statistically meaningful result. Interestingly, knee OA affects and burdens women more than men (Blagojevic, Jinks, Jeffery, & Jordan, 2010). Previous research has found that osteoarthritis appears differently in women than in men and affects certain parts of the knee disproportionally (Hame & Alexander, 2013). This is evidenced by the fact that women are more likely than men to have isolated patellofemoral arthritis in the patellofemoral joint (Felson et al., 1995). Furthermore, women typically present in more advanced stages compared with men, have different gait patterns (Debi et al., 2009). Therefore, a comprehensive postural control evaluation with measures of computerized dynamic posturography among each gender with knee OA is required. However, no studies have been undertaken to date employing computerized dynamic posturography to examine the postural control of women with knee OA, and new research is needed. Therefore, the purpose of this study was to compare the postural control of women with knee OA and age and gender matched-healthy peers.

2. Materials and Methods

Ethical approval and informed consent - The research related to human use has complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by Ethics Committee. And informed consent has been obtained from all individuals included in this study.

Sample - The study involved sixteen women with knee OA who met the inclusion criteria. A specific control subject was chosen to match a female knee OA participant of the same age (±three years). All participants were free of the following: (1) coexisting health conditions that could damage the postural control, such as neurological or major musculoskeletal disorder, inner ear disease, or injury in lower body; (2) incapability of independent gait. Exclusion criteria in this study consist of the following: asymptomatic OA of one or both knees, rheumatoid arthritis, psoriatic arthritis, and ankylosing spondylitis, history of lower-limb joint surgery, any disease that severely restricts gait, and mental illness or incapacity to understand and follow instructions. Women with knee OA were matched with asymptomatic control participants based on gender and age. Control participants with any other type of arthritis, a history of the lower extremity injury, or long-term knee pain, and knee surgery were excluded. And control participants having persistent or prolonged knee pain in the previous month were excluded, even if pain-free on the day of testing. Table 1 shows the characteristics of the participants.

Instrumentation - Computerized dynamic posturography was controlled by the NeuroCom EquiTest® (NeuroCom International, Clackamas, OR) to attain the center of pressure records needed to evaluate the postural control. This machine made up of two 9″ x 18″ force plate attached by a pin joint which is a rod that serves as the medial-lateral rotating axis and can quantify vertical forces applied by a participant's feet. The vertical force of the participant's anterior-posterior sway is measured with two strain gauges installed below each of the two force plates. The shear force is measured by a fifth strain gauge, which is positioned perpendicular to the other four beneath the pin joint's center. The test area is enclosed on the front and sides by a moving visual surrounding wall, preventing the participant from seeing anything else in the environment. The wall and force plates' fore-aft tilt is controlled by software (Version 8.5 NeuroCom, A Division of Natus, Clackmas, Oregon, USA). At a sampling rate of 100 Hz (ADC = 12 bit), the electrical signals from the force plates were collected.

Table 1. Participant Demographics

Participant Characteristics	Knee OA Mean (S.D.)	Healthy Women Mean (S.D.)	*P* value
Age (yr)	52.12(±10.69)	51.00(±10.00)	0.761
Height (cm)	160.75(±7.42)	163.19(±8.65)	0.399
Mass (kg)	75.96(±12.28)	73.84(±12.97)	0.638
BMI (kg/m^2)	29.45(±4.92)	27.71(±4.38)	0.299

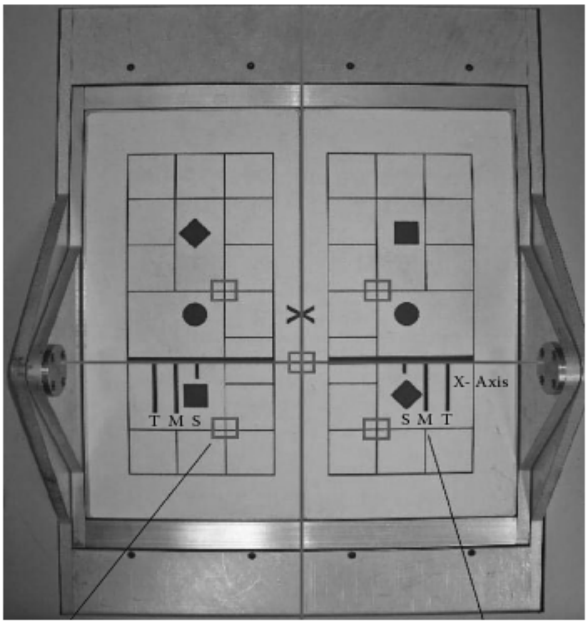

Figure 1. Dual force plate

Experimental procedures - When a potential participant came at the testing facility, she was given written and verbal information about the testing procedures and asked to sign a consent form in accordance with Institutional Review Board protocol. The potential participant completed the WOMAC questionnaire, which is a self-administered health status survey for individuals with knee OA, as well as a medical history and a health status assessment. The answers were reviewed by the primary investigator to ensure that the participant met the inclusionary and exclusionary criteria. If the participants met the criteria, testing was continued. The participant put on a safety harness with two straps extending down from an overhead bar. Then, the participant stands on the NeuroCom force plate and the safety harness was fastened to the straps. Next, the investigator placed the participant's feet on the force plate according to Neurocom instructions. Each participant's medial malleolus was centered directly over a thick line on a dual force plate positioned perpendicular to them. The participant's height was used to determine where the lateral heel should be placed. Lines 'S', 'M', and 'T' are marked on the force plate (Figure 1), where

S = Short 76-140 cm (30-55 inches)

M = Medium 141-165 cm (56-65 inches)

T = Tall 166-203 cm (66-80 inches)

Then, the participant completed Sensory organisation test, Motor control test and Adaptation test protocols.

Trial conditions –

Sensory organisation test - The Sensory organisation test (SOT) assesses the participant's ability to effectively employ visual, vestibular and somatosensory information while suppressing inappropriate sensory information. During the tests, proprioceptive and visual environments were changed systematically by 'sway referencing' the surrounding wall and the force plates, and the participant's responses were measured. Sway referencing is when the force plate and/or the surrounding wall move in proportion to the participant's anteroposterior sway, modifying their visual and proprioceptive feedback. The information obtained from the ankle joints (sway-referenced support) or vision (sway-referenced vision) is rendered unreliable for balance control by this process (Table 2).

(Condition 1) eyes open with fixed support; (Condition 2) eyes closed with fixed support; (Condition 3) eyes open with sway-referenced surrounding; (Condition 4) eyes open with sway-referenced support; (Condition 5) eyes closed with sway-referenced support; and (Condition 6) eyes open with sway-referenced support surface and surroundings (Figure 2). The participants' feet were positioned according to the manufacturer's specifications for the postural control tests, and their arms stayed at their sides while gazing straight ahead into the visual surrounding wall.

Motor control test (MCT) - During the MCT, participants' automatic responses to support surface translations were assessed. Each participant maintained their eyes open, and the environment remained immobile. The MCT included six translations, three of which were graded backward and three of which were graded forward (Figure 3). The translations were scaled to the participant's height, but the durations were not changed. Small, medium, and large translations produced translations of 1.25cm, 3.14cm, and 5.7cm, respectively, for 250ms, 300ms, and 400ms. Each translation was given at a consistent velocity, delivering constant forward or backward angular momentum to the participant.

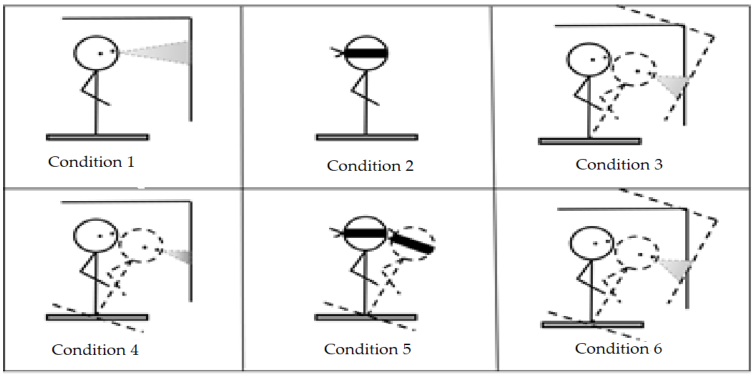

Figure 2. Conditions of SOT

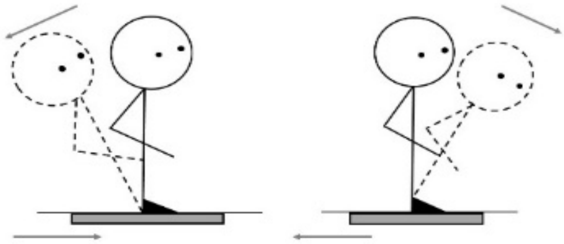

Figure 3. Forward/Backward Translations

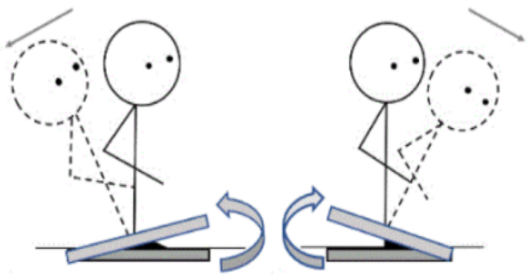

Figure 4. Toes-up and Toes-down Rotations

Table 2. Descriptions of Sensory analysis ratios

Ratios	Formula	Significance
SOM	$\frac{Condition\ 2}{Condition\ 1}$	Question: Does sway increse in the absence of visual information? Low scores: Insufficient reliance on somatosensory references
VIS	$\frac{Condition\ 4}{Condition\ 1}$	Question: Does sway increase in the absence of somatosensory information? Low scores: Inefficient use of visual references
VEST	$\frac{Condition\ 5}{Condition\ 1}$	Question: Does sway increase in the absence of visual information and when somatosensory information is inaccurate? Low scores: Ineffective use of vestibular information or the absence of vestibular information.
PMAN	$\frac{Condition\ 4+5+6}{Condition\ 1+2+3}$	Question: Does incorrect somatosensory information cause more sway than correct somatosensory information? Low scores: Insufficient compensation for disruptions in specific sensory inputs.

secondary responses were reinforced to reduce overall sway.

Statistical analysis - This study's demographic characteristics comprised (a) age, (b) height, (c) mass, and (d) body mass index (BMI). These data, as well as the equilibrium score, sensory analysis ratio, strategy analysis, and latency findings, were examined using the independent t-test to identify differences in the balance between the knee OA and healthy control group.

For the normality test, a Shapiro-Wilk analysis of the data was completed to determine if the assumption of normality had been met. Also, The Levene's test for equality of variances was utilized to assess homogeneity. In the instance of homogeneity violation of variance, the corrected *t* value was used. Mann-Whitney U test was used if the data violated normality test assumptions.

The significance coefficient (*p*) indicated the findings of the examination of the significance of the differences. The degree of statistical significance was denoted by the symbol "*" – $p<0.05$.

3. Results

Independent t-tests were conducted to compare the women with knee OA and healthy knee controls. An analysis of sensory organisation test (Fig 5.) showed significant differences in condition 1 (p=0.030), condition 3 (p=0.019), condition 4 (p=0.045), condition 5 (p=0.010), condition 6 (p=0.041), and Composite values (p=0.011) between groups. This parameter was higher for healthy knee women group.

Figure 6 shows the Sensory analysis ratio results of both groups. There was statistically significance of VEST (p = 0.013) and PMAN (p = 0.023) between groups. This parameter was higher for healthy knee women group.

Figure 7 shows the Strategy analysis results for both groups. There was statistically significance in Strategy 5 (p = 0.015) between groups. This parameter was higher for healthy knee women group.

Figure 8 shows the Latency results for both groups. There were statistically significant in Large_Forward (p=0.020) and Comp_latency (p=0.016) between groups. This parameter was faster for healthy knee women group.

Figure 9 shows Sway Energy Score of Adaptation test results for both groups. There were statistically significant in ADW 2(plantarflexion) (p=0.017) between groups. This parameter was smaller for healthy knee women group.

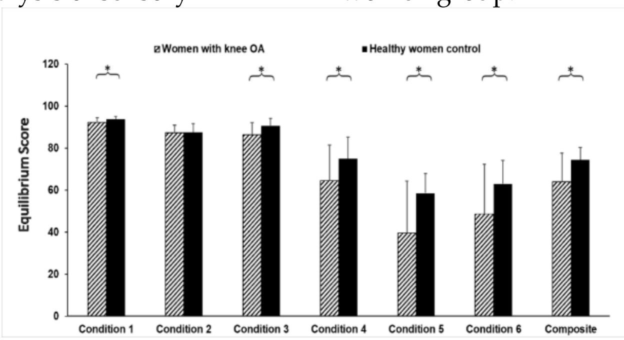

Figure 5. Equilibrium scores in the sensory organisation test.
* Statistically significant mean difference ($p < 0.05$)

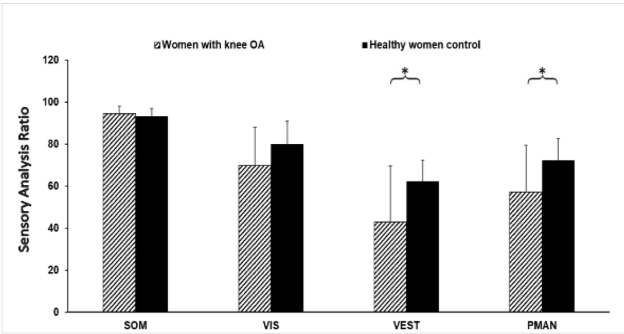

Figure 6. Sensory Analysis in the sensory organisation test.

* Statistically significant mean difference ($p < 0.05$)

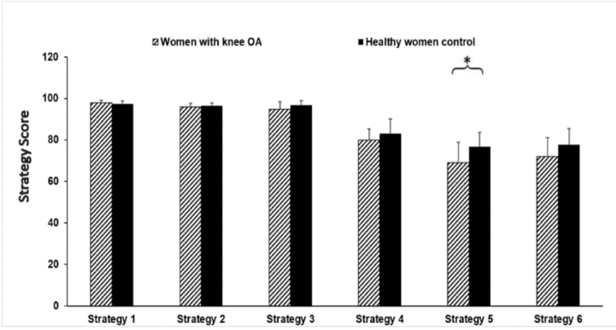

Figure 7. Strategy Analysis in the sensory organisation test.
* Statistically significant mean difference ($p < 0.05$). Strategy 1-6: strategy scores from sensory organization test trials

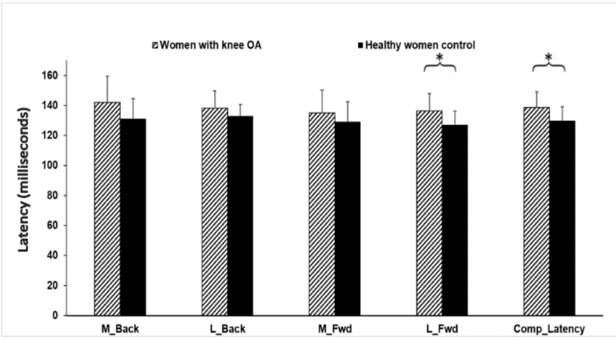

Figure 8. Results of Latencies.
* Statistically significant mean difference ($p < 0.05$). M_back: Medium backward translation; L_back; Large backward translation; M_Fwd: Medium forward translation; L_ Fwd; Large forward translation; Comp_Latency: Comprehensive latency

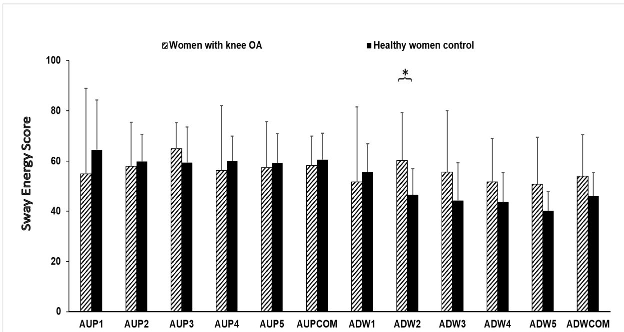

Figure 9. Results of Sway Energy Score.
* Statistically significant mean difference ($p < 0.05$). AUP1-5: AUP1-5: first to fifth upward rotations; AUPCOM: Mean of AUP1-5; ADW1-5: ADW1-5: first to fifth downward rotations; ADWCOM: Mean of ADW1-5

4. Discussion

The purpose of the current study was to compare the postural control of women with knee OA and age and gender-matched-healthy peers. The findings of the postural control comparing knee OA women and the healthy knee women showed that conditions 1, 3, 4, 5, 6, Composite of equilibrium score, VEST, PMAN of Sensory analysis, Strategy 5 of Strategy analysis, and Large_Forward, Comp_latency of latency were significantly better for healthy knee women than knee OA women. Higher Equilibrium values in the control group indicated smaller forward–backward displacements of the center of pressure. The Composite score indicated both groups' overall postural control, and a higher score in the control group indicates that the healthy knee women were better for the postural control and a stable position during the SOT test procedure compared to knee OA women. According to Hirsch and colleagues (Hirsch, Toole, Maitland, & Rider, 2003), conditions 4, 5, and 6 scores are essential and highly correlated. Those scores indicate postural control under the most challenging test setting, such as when the support surface is sway-referenced and visual information is confusing or absent, and have been proved to be a suitable measure of postural control function (Hirsch et al., 2003; Toole, Hirsch, Forkink, Lehman, & Maitland, 2000).

In condition 4, 5 and 6, the differences between groups were significantly higher than others. In other words, there were small differences in conditions (1, 2, 3) that did not stress balance. These results show that the balance differences appeared when the difficulty of the tests increased, especially in situations of conflicted sensory inputs. Therefore, lower scores of knee OA women could indicate deficit of total postural control and it is related to an off-balance center of pressure, hip or ankle strategy or abnormal sensory analysis ratios. As a result, significantly lower Strategy 5 values was observed in knee OA women. It may mean that when the support surface is unstable and visual information is unavailable, knee OA women had more hip muscular activity and lesser ankle muscular activity than healthy women group, although this cross-sectional study does not allow which specific muscles to be confirmed. However, both groups scored highly on the strategy scores for conditions 1 and 2, indicating that women with knee OA and healthy women controls were able to control the posture by mainly using an ankle strategy. Even with incorrect visual information (condition 3), or with incorrect somatosensory information (condition 4), knee OA women and healthy women could depend on the ankle strategy. When somatosensory and visual information were incorrect or absent in condition, 5 and 6, Strategy scores were lower than condition 1 through 4, showing that knee OA women and healthy control women used a combination of ankle and hip strategies to sustain balance. This result indicates that individuals who use a mainly hip or stepping strategy when visual and somatosensory information are incorrect or unavailable, have a higher risk of falls. In general, the anticipatory method is crucial for successfully performing dynamic postural control that involves the ankle rather than the hip joint (Horak & Nashner, 1986).

The previous studies have shown that the triggering of postural control depends on hip and trunk proprioceptive information and knee information provides a supplemental activation signal, allowing the onset of the very early phase of the triceps surae responses (Bloem, Allum, Carpenter, Verschuuren, & Honegger, 2002; Gauchard, Vançon, Meyer, Mainard, & Perrin, 2010). The current study shows that existing OA in the knee joint constrains the onset of a proper strategy, resulting in using hip joints more for postural control than the healthy women.

In addition, three participants in knee OA group fell, and scores decreased in condition 5, where individuals were expected to compensate for both visual loss and incorrect somatosensory information by increasing their dependence on vestibular information. According to Sensory analysis data, knee OA women exhibited lower VEST and PMAN ratios. These data show a less use of vestibular and somatosensory afferents when compared to healthy knee women. The VEST indicated the effectiveness of a vestibular system signal in maintaining balance, which has typically been used to determine the quality of the vestibular afferent (Qiu et al., 2012). All participants in condition 5 had to compensate for the visual removal and incorrect somatosensory information by increasing their use of vestibular dependence and correcting their posture by selecting a more proper strategy including re-organisation of the different mechanisms of the postural control (Vouriot et al., 2004). Poor postural control was related to a reduced dependence on vestibular afferents in strategy construction (Cohen, Heaton, Congdon, & Jenkins, 1996). A previous study showed that people with vestibular deficiencies rely substantially on visual information, and they lose balance when the visual information is eliminated by closing their eyes (Paulus, Straube, & Brandt, 1987). Similar results were observed in this study when visual information was eliminated and somatosensory inputs were manipulated, a considerably reduced Equilibrium scores followed. Furthermore, a study (Amor-Dorado et al., 2014) on vestibular and postural control in persons with psoriatic arthritis found that psoriatic arthritis can induce vestibular damage, which could impair people's capacity of postural control, and that persons with psoriatic arthritis had impaired postural control of vestibular origin. Also, an electronystagmography investigation found an association of rheumatoid arthritis with vestibular system dysfunction as well as auditory impairment (Yilmaz, Erbek, Erbek, Ozgirgin, & Yucel, 2007). (Hülse et al., 2019) reported that women were more normally affected by vestibular disorder such as dizziness and vertigo, regardless of the specific cause, in the largest epidemiological study ever conducted, based on 70,315,919 people. And Parker et al. published a systematic review of reported vestibular diagnoses of dizziness and vertigo, and found that regardless of the specific diagnostic category, females have a higher prevalence of vestibular diagnoses than males, which could indicate a higher rate of vestibular disorders (Parker, Hartel, Paratz, Choy, & Rahmann, 2019). Although there are some studies to document a lack of vestibular and postural control in other types of arthritis and gender, there has been no study to date to measure vestibular function and how sensory information can be used for postural control in women with knee OA. Based on the author's knowledge, this is the first research to demonstrate that women with knee OA had abnormal vestibular function. In addition, the women knee OA group had a longer neuromuscular response latency to postural changes, representing a reduced ability to onset in postural control quickly after an unexpected disruption. This slow latency response may be due to a deficiency of dependence on somatosensory and vestibular information (Gauchard, Gangloff, Jeandel, & Perrin, 2003), which are used to activate and control balance corrective responses (Allum & Shepard, 1999). The vestibular system's function in women with knee OA may not be clearly discovered in this study, and whether these postural control discrepancies imply decreased functionality in knee OA women is unknown. However, several potential mechanisms such as pain, reduction of muscular strength in the lower extremities, abnormal somatosensory, and significant decline of mechanoreceptors could explain the postural control deficits observed in the individuals with knee OA.

6. Conclusions

Postural control discrepancies with considerably lower vestibular scores were observed in women with knee OA in the sensory information conflicted situations. This finding should be considered in preventing falls, especially when participants are placed in dynamic circumstances with a conflicted sensory environment, such as those present in everyday life. Moreover, as various forms of arthritis and women revealed signs of impaired vestibular functioning, extensive examinations to examine vestibular functions appear essential. The findings of this study have substantial clinical significance for understanding and managing women with knee OA, and they contribute to current research understanding by supplementing existing data. Future research comparing the postural control with male subjects and assessing the vestibular system in women with knee OA is necessary to clarify the characteristics of postural control in women with knee OA.

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Conflicts of Interest: The author declares no conflict of interest.

References

Allum, J. H., & Shepard, N. T. (1999). An overview of the clinical use of dynamic posturography in the differential diagnosis of balance disorders. Journal of Vestibular Research, 9(4), 223-252.

Amor-Dorado, J. C., Barreira-Fernandez, M. P., Pina, T., Vázquez-Rodríguez, T. R., Llorca, J., & González-Gay, M. A. (2014). Investigations into audiovestibular manifestations in patients with psoriatic arthritis. The Journal of Rheumatology, 41(10), 2018-2026.

Blagojevic, M., Jinks, C., Jeffery, A., & Jordan, 1. (2010). Risk factors for onset of osteoarthritis of the knee in older adults: A systematic review and meta-analysis. Osteoarthritis and Cartilage, 18(1), 24-33.

Bloem, B., Allum, J., Carpenter, M., Verschuuren, J., & Honegger, F. (2002). Triggering of balance corrections and compensatory strategies in a patient with total leg proprioceptive loss. Experimental Brain Research, 142(1), 91-107.

Broglio, S. P., Sosnoff, J. J., Rosengren, K. S., & McShane, K. (2009). A comparison of balance performance: Computerized dynamic posturography and a random motion platform. Archives of Physical Medicine and Rehabilitation, 90(1), 145-150.

Cohen, H., Heaton, L. G., Congdon, S. L., & Jenkins, H. A. (1996). Changes in sensory organization test scores with age. Age and Ageing, 25(1), 39-44.

Debi, R., Mor, A., Segal, O., Segal, G., Debbi, E., Agar, G., . . . Elbaz, A. (2009). Differences in gait patterns, pain, function and quality of life between males and females with knee osteoarthritis: A clinical trial. BMC Musculoskeletal Disorders, 10(1), 1-10.

Faraldo-García, A., Santos-Pérez, S., Rossi-Izquierdo, M., Lirola-Delgado, A., Vaamonde-Sánchez-Andrade, I., Del-Río-Valeiras, M., & Soto-Varela, A. (2016). Posturographic limits of stability can predict the increased risk of falls in elderly patients with instability? Acta Oto-Laryngologica, 136(11), 1125-1129.

Felson, D. T., Zhang, Y., Hannan, M. T., Naimark, A., Weissman, B. N., Aliabadi, P., & Levy, D. (1995). The incidence and natural history of knee osteoarthritis in the elderly, the framingham osteoarthritis study. Arthritis & Rheumatism, 38(10), 1500-1505.

Gauchard, G. C., Gangloff, P., Jeandel, C., & Perrin, P. P. (2003). Physical activity improves gaze and posture control in the elderly. Neuroscience Research, 45(4), 409-417.

Gauchard, G. C., Vançon, G., Meyer, P., Mainard, D., & Perrin, P. P. (2010). On the role of knee joint in balance control and postural strategies: Effects of total knee replacement in elderly subjects with knee osteoarthritis. Gait & Posture, 32(2), 155-160.

Hame, S. L., & Alexander, R. A. (2013). Knee osteoarthritis in women. Current Reviews in Musculoskeletal Medicine, 6(2), 182-187.

Hatfield, G., Hammond, C., & Hunt, M. A. (2015). Clinical tests of balance in the knee osteoarthritis population: A systematic review. Osteoarthritis and Cartilage, 23, A374.

Hinman, R. S., Bennell, K. L., Metcalf, B. R., & Crossley, K. M. (2002). Balance impairments in individuals with symptomatic knee osteoarthritis: A comparison with matched controls using clinical tests. Rheumatology, 41(12), 1388-1394.

Hirsch, M. A., Toole, T., Maitland, C. G., & Rider, R. A. (2003). The effects of balance training and high-intensity resistance training on persons with idiopathic parkinson's disease. Archives of Physical Medicine and Rehabilitation, 84(8), 1109-1117.

Horak, F. B., & Nashner, L. M. (1986). Central programming of postural movements: Adaptation to altered support-surface configurations. Journal of Neurophysiology, 55(6), 1369-1381.

Hülse, R., Biesdorf, A., Hörmann, K., Stuck, B., Erhart, M., Hülse, M., & Wenzel, A. (2019). Peripheral vestibular disorders: An epidemiologic survey in 70 million individuals. Otology & Neurotology, 40(1), 88-95.

Khalaj, N., Abu Osman, N. A., Mokhtar, A. H., Mehdikhani, M., & Wan Abas, Wan Abu Bakar. (2014). Balance and risk of fall in individuals with bilateral mild and moderate knee osteoarthritis. PloS One, 9(3), e92270.

Lord, S. R. (. R., 1957-. (2007). Falls in older people : Risk factors and strategies for prevention (2nd ed.. ed.). Cambridge: Cambridge : Cambridge University Press.

Parker, I. G., Hartel, G., Paratz, J., Choy, N. L., & Rahmann, A. (2019). A systematic review of the reported proportions of diagnoses for dizziness and vertigo. Otology & Neurotology, 40(1), 6-15.

Paulus, W., Straube, A., & Brandt, T. H. (1987). Visual postural performance after loss of somatosensory and vestibular function. Journal of Neurology, Neurosurgery & Psychiatry, 50(11), 1542-1545.

Qiu, F., Cole, M. H., Davids, K. W., Hennig, E. M., Silburn, P. A., Netscher, H., & Kerr, G. K. (2012). Enhanced somatosensory information decreases postural sway in older people. Gait & Posture, 35(4), 630-635.

Roos, E. M., Herzog, W., Block, J. A., & Bennell, K. L. (2011). Muscle weakness, afferent sensory dysfunction and exercise in knee osteoarthritis. Nature Reviews Rheumatology, 7(1), 57-63. doi:10.1038/nrrheum.2010.195

Sharma, L., Kapoor, D., & Issa, S. (2006). Epidemiology of osteoarthritis: An update. Current Opinion in Rheumatology, 18(2), 147-156. doi:10.1097/01.bor.0000209426.84775.f8

Shumway-cook. (2001). Motor control. Theory and practical applications. Willams & Wilkins.

Takacs, J., Carpenter, M. G., Garland, S. J., & Hunt, M. A. (2013). The role of neuromuscular changes in aging and knee osteoarthritis on dynamic postural control. Aging and Disease, 4(2), 84.

Tarigan, T. J. E., Kasjmir, Y. I., Atmakusuma, D., Lydia, A., Bashiruddin, J., Kusumawijaya, K., & Prihartono, J. (2009). The degree of radiographic abnormalities and postural instability in patients with knee osteoarthritis. Acta Medica Indonesiana, 41(1), 15-19.

Toole, T., Hirsch, M. A., Forkink, A., Lehman, D. A., & Maitland, C. G. (2000). The effects of a balance and strength training program on equilibrium in parkinsonism: A preliminary study. NeuroRehabilitation, 14(3), 165-174.

van der Pas, S., Castell, M. V., Cooper, C., Denkinger, M., Dennison, E. M., Edwards, M. H., . . . Deeg, D. J. H. (2013). European project on osteoarthritis: Design of a six-cohort study on the personal and societal burden of osteoarthritis in an older european population. BMC Musculoskeletal Disorders, 14(1), 138. doi:10.1186/1471-2474-14-138

Vouriot, A., Gauchard, G. C., Chau, N., Benamghar, L., Lepori, M., Mur, J., & Perrin, P. P. (2004). Sensorial organisation favouring higher visual contribution is a risk factor of falls in an occupational setting. Neuroscience Research, 48(3), 239-247. doi:https://doi.org/10.1016/j.neures.2003.11.001

Wylde, V., Palmer, S., Learmonth, I. D., & Dieppe, P. (2012). Somatosensory abnormalities in knee OA. Rheumatology (Oxford, England), 51(3), 535-543. doi:10.1093/rheumatology/ker343

Yilmaz, S., Erbek, S., Erbek, S. S., Ozgirgin, N., & Yucel, E. (2007). Abnormal electronystagmography in rheumatoid arthritis. Auris Nasus Larynx, 34(3), 307-311.