

COMPUTERIZED DYNAMIC POSTUROGRAPHY: COMPARISON OF RESULTS OBTAINED FROM INDIVIDUALS WITH SYMPTOMATIC OSTEOARTHRITIS OF THE KNEE

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ABSTRACT

Introduction: The purpose of this study was to compare the balance of individuals with knee OA and healthy peers and to determine the effect of knee OA on balance by matching gender, age, mass, height, and BMI. **Material and Methods:** Thirty-two individuals, sixteen with knee osteoarthritis and sixteen healthy, were evaluated on balance as measured by a NeuroCom EquiTest Sensory Organization Test and Motor Control test protocol. Outcomes included an equilibrium composite score, equilibrium scores on six sensory conditions, and sensory ratios for visual, somatosensory, vestibular systems as well as ability to manage altered proprioceptive inputs. **Results:** The healthy knee group showed that significantly higher equilibrium scores, higher strategy scores, higher sensory analysis ratios, and faster latency in the analysis of sensory organization test and motor control test. **Conclusion:** The existence of knee OA affected the effectiveness of the sensory system and the use of this signal in maintaining body balance.

Key words: knee osteoarthritis, computerized dynamic posturography, balance

POSTUROGRAFÍA DINÁMICA COMPUTARIZADA: COMPARACIÓN DE RESULTADOS OBTENIDOS DE INDIVIDUOS CON OSTEOARTRITIS SINTOMÁTICA DE LA RODILLA

RESUMEN

Introducción: El propósito de este estudio fue comparar el equilibrio de individuos con osteoartritis (OA) de rodilla y sujetos sanos y determinar el efecto de la OA de rodilla en equilibrio, en función del sexo, la edad, la masa, la altura y el IMC. **Material y métodos:** Treinta y dos individuos, dieciséis con osteoartritis de rodilla y dieciséis sujetos sanos, se evaluaron en equilibrio según un protocolo de control de motor y prueba sensorial NeuroCom EquiTest. Los resultados incluyeron una puntuación compuesta de equilibrio, puntuaciones de equilibrio en seis condiciones sensoriales y relaciones sensoriales para los sistemas visuales, somatosensoriales y vestibulares, así como la capacidad para gestionar entradas propioceptivas alteradas. **Resultados:** El grupo de rodilla saludable mostró puntuaciones de equilibrio significativamente más altas, puntuaciones de estrategia más altas, proporciones de análisis sensorial más altas y una latencia más rápida en el análisis de la prueba de organización sensorial y la prueba de control motor. **Conclusión:** la existencia de OA de rodilla afectó la efectividad del sistema sensorial y el uso de esta señal para mantener el equilibrio corporal.

Palabras clave: osteoartritis de rodilla, posturografía dinámica computarizada, equilibrio

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INTRODUCTION

Falls are the leading cause of accidental or unintentional injury deaths in the U.S. (CDC, 2013). One out of three old adults aged 65 and older falls each year. (Tromp et al., 2001). Therefore, medical costs caused by falls are rising in the U.S. (Stevens, Corso, Finkelstein, & Miller, 2006), and fall prevention is obviously becoming more critical. Center for Disease Control and Prevention (2014) reported that the prevalence of falls and fall injuries is significantly higher among adults with arthritis compared to those without arthritis in the United States (Barbour et al., 2014). Among the forms of arthritis, osteoarthritis (OA) is the most prevalent and is a leading cause of disability and loss of function (CDC, 2001; Issa & Sharma, 2006). Although OA can damage any joint in the body, the knee joint is most commonly affected (Van et al., 2013). People with knee OA have pain, reduction of lower limb muscle strength, proprioception abnormality, and significant decline of mechanoreceptors compared to age-matched healthy peers (Roos, Herzog, Block & Bennell, 2011; Tarigan et al., 2009; Wylde, Palmer, Learmonth, & Dieppe, 2012). These characteristics of people with knee OA diminish the capability of balance and ability to initiate and correct movements, which is an indicator of fall risks, a common problem in knee OA. Therefore, individuals with knee OA have been reported to have reduced balance, evidenced by increased postural sway (Hinman, Bennell, Metcalf, & Crossley, 2002; Tarigan et al., 2009) and reduced dynamic balance function (Khalaj, Abu, Mokhtar, Mehdikhani, & Wan, 2014) as well as lower scores on clinical tests such as step test, single leg stance, functional reach test, and tandem stance test (Hatfield, Hammond, & Hunt, 2015; Khalaj, Abu, Mokhtar, Mehdikhani, & Wan, 2014). For maintaining balance, information that comes from sensory systems should be integrated, resulting in the reflexive adjustment of the body's orientation. As the senses required for maintaining balance weaken with disease (Takacs, Carpenter, Garland, & Hunt, 2013), they provide reduced sensory information or inadequate feedback to the system, which is a major contributor to decreased balance (Lord, 2007).

Various research methods which have measured the balance in people with knee OA were conducted. Most of the studies used clinical screening tests such as Romberg test (Zamanian et al., 2012), Timed Up and Go test (Alghadir et al., 2015), Functional reach (Hill et al., 2013) and Step test (Hill et al., 2013), and one used computerized balance systems such as Biodex Stability System (Hsieh, Lee, Lo, & Liao, 2013). Although the balance can be assessed subjectively by clinical screening tests to identify the abnormality, computerized dynamic posturography (CDP) allows to objectively quantify and distinguish among the various possible sensory, motor, and central adaptive abnormality. A comprehensive balance assessment with measures of computerized dynamic

posturography among people with knee OA is required because falls usually occur during movement related tasks which are related to dynamic balance control (Hinman et al., 2002). Also, systems of maintaining balance can be affected by musculoskeletal, or neurological limitations, aging, underutilizing available sensory information and anthropometric factors such as height, mass, and BMI (Alonso, Brech, Bourquin, & Greve, 2011). Especially, anthropometric factors should be considered when the researcher matches experimental group with control group because the anthropometric factors correlate with the balance (Greve, Cug, Dulgeroglu, Brech, & Alonso, 2013). However, to date, no studies have been conducted to evaluate the balance of individuals with knee OA using computerized dynamic posturography with matching the anthropometric factors when they compare the groups. Therefore, the purpose of this study was to compare the balance of individuals with knee OA and age, gender, height, mass, and BMI matched-healthy peers.

METHOD

Sample size estimation

Sixteen participants per group (Healthy and Knee OA) are calculated via an a priori power analysis (G*Power™; Kiel University, Germany) to provide 95% power with an effect size of approximately 1 at $\alpha = .05$ to detect a group difference. The data used for the estimates are the results of SOT comprehensive score reported in a study done by Jones and colleagues on postural control of individuals with fibromyalgia (Jones, King, Mist, Bennett, & Horak, 2011).

Participants

Sixteen participants (13 female, 3 male) with knee OA and 16 asymptomatic controls (13 female, 3 male) aged between 27 and 64 yr were recruited through advertisements in local clubs, libraries, school listserv, and the print. The study was approved by the university's Institutional Review Board, and written informed consent was obtained from all subjects. All participants were free from (1) a concomitant medical illness that, as judged by the investigator using questionnaires such as WOMAC, medical history, health questionnaire, and visual analog scale of pain, could impair balance (for example, neurological or significant musculoskeletal disease, Meniere's disease or other inner ear disease, permanent lower-limb injury, significant psychiatric disorder, (2) unable to ambulate without an assistive device, (3) an abnormal optometric or ophthalmic examination in the 6 months. Groups were similar in gender, age, mass, height and body mass index (BMI). Participant characteristics are presented in Table 1.

TABLE 1
Presenting characteristics of OA and control participants.

Participant Characteristics	Knee OA (n=16) Mean (S.D.)	Healthy Knee (n=16) Mean (S.D.)	P value
Age (yr)	53.37(±11.19)	52(±10.72)	0.725
Height (cm)	163.67(±11.05)	162.08(±7.13)	0.633
Mass (kg)	75.65(±13.54)	73.52(±12.88)	0.652
BMI (kg/m ²)	28.31(±5.05)	27.92(±4.53)	0.819

The OA group included participants with mild to moderate knee osteoarthritis in one or both knees. Exclusion criteria for OA group included the following: asymptomatic osteoarthritis of one or both knees, incapacitating arthritis, or inflammatory arthritis, major lower extremity joint surgery (e.g., knee arthroscopy within the previous 6 months), any condition which severely limits local ambulation (e.g., amputation or stroke), use of gait aids for ambulation, and dementia or inability to give informed consent. Control participants with evidence of rheumatoid or any other type of arthritis, a history of injury to the lower extremity, or prolonged knee pain that required medication and knee surgery were excluded. And control participants with recurring or prolonged knee pain occurring within last month even if pain-free on the day of testing were excluded.

Computerized posturography assessments

Computerized dynamic posturography tests were administered using the NeuroCom EquiTest® (NeuroCom International, Clackamas, OR) to obtain the center of pressure data needed to calculate measures of balance. This device consists of a movable dual forceplates on a medial-lateral rotational axis with the capability of measuring vertical forces applied by a person's feet and a moveable surrounding visual screen in which the participants stand within. Both the forceplates and a screen visual screen can be tilted in response to the participants' sway. The participant's anterior-posterior sway is recorded by measuring vertical force. The electrical signals from the forceplate were collected at a sampling rate of 100 Hz and stored for later analysis.

Sensory organization test (SOT)

The sensory organization test (SOT) challenges postural control via sway referencing by altering the availability and/or accuracy of sensory information from three systems: the visual, vestibular, and somatosensory systems. Sway referencing synchronizes the rotation of the platform and/or surroundings with the person's anterior-posterior postural sway; that is, as the individual sways forward, the platform and/or surrounding room sways forward synchronously. The sway-referenced platform minimizes or alters the accuracy

of somatosensory information, whereas the sway-referenced surrounding, extending beyond the visual periphery, provides inaccurate visual sensory information. By reducing the quality of sensory feedback regarding postural sway, these methods challenge postural control. The six sensory conditions of the SOT are (1) eyes open with fixed platform (condition 1); (2) eyes closed with fixed platform (condition 2); (3) eyes opened with sway-referenced surrounding (condition 3); (4) eyes opened with sway-referenced platform (condition 4); (5) eyes closed with sway-referenced platform (condition 5); and (6) eyes open with sway-referenced platform and surroundings (condition 6). Three trials for each sensory condition were presented in the manufacturer’s suggested order, with increasing difficulty from condition 1 through condition 6 (Table 2).

TABLE 2
Description of the six sensory organization test tasks.

Condition	Environment		Expected Sensory System Response	
	Vision	Surface	Disadvantage	Using
1	Eyes open	Fixed		Somatosensory
2	Eyes closed	Fixed	Vision	Somatosensory
3	Sway-referenced visual surrounding	Fixed	Vision	Somatosensory
4	Eyes open	sway-referenced surface	Somatosensory	Vision
5	Eyes open	sway-referenced surface	Somatosensory & Vision	Vestibular
6	Sway-referenced visual surrounding	sway-referenced surface	Somatosensory & Vision	Vestibular

The equilibrium score (ES) indicates how well the participant’s sway remains in the expected angular limits of stability during SOT trials. The ES is generated from forceplate data of each trial (20 seconds @ 100Hz, 2000 data points) via NeuroCom software (NeuroCom, Clackamas, OR). An ES is computed for each trial using the following equation:

$$ES = \frac{12.5 - [\theta_{max} - \theta_{min}]}{12.5} * 100$$

Where the angular difference between calculated maximum anterior-posterior center of gravity (COG) displacements and a theoretical maximum are compared. For healthy individuals, 12.5 degrees are usually considered the theoretical limits of stability. The result is provided as an inverse percentage of 0-100. While no movement results in an ES of 100, a fall results in a score of 0.

This outcome measure is clinically accepted and has been used extensively in motor control research (Cavanaugh, Mercer, & Stergiou, 2007; Wrisley et al., 2007). Computation of the ES allows for comparison of an experimental group with a large existing database of healthy populations of various age groups.

Sensory analysis

The sensory analysis ratios are combined with the equilibrium score to identify the significance of each sensory system influencing the postural control allowing the determination of the use of somatosensation (SOM), visual (VIS), and vestibular (VEST) information, as well as the ability to manage altered proprioceptive inputs (PMAN).

TABLE 3
Descriptions of Sensory analysis (Gauchard, Vançon, Meyer, Mainard, & Perrin, 2010).

Ratios	Formula	Significance
SOM	Condition2/ Condition1	Question: Does sway increase when visual information is removed? Low scores: Poor use of somatosensory references
VIS	Condition 4/ Condition1	Question: Does sway increase when somatosensory information is removed? Low scores: Poor use of visual references
VEST	Condition5/ Condition1	Question: Does sway increase when visual information is removed, and the somatosensory information is incorrect? Low scores: Poor use of vestibular information or no vestibular information.
PMAN	(Condition4+ Condition n5 + Condition 6)/ (Condition 1+ Condition 2+ Condition 3)	Question: Does inaccurate somatosensory information result in increased sway compared to accurate somatosensory information? Low scores: Poor compensation for disruptions in selected sensory inputs.

Strategy analysis

Strategy scores are yielded by comparing the peak-to-peak amplitude of the shear oscillation to the maximum possible shear of 25 pounds. High-frequency oscillations centered about zero show periods of hip movements. This comparison is expressed as a percentage, with scores near 100 indicating little, if any, shear (i.e., full ankle strategy), while scores are approaching zero mean maximum shear (i.e., full hip strategy). The ankle strategy is primarily used to maintain balance when the perturbation is small, and the support surface is firm. And larger, faster perturbations cause the hip strategy, especially, when the surface is unstable.

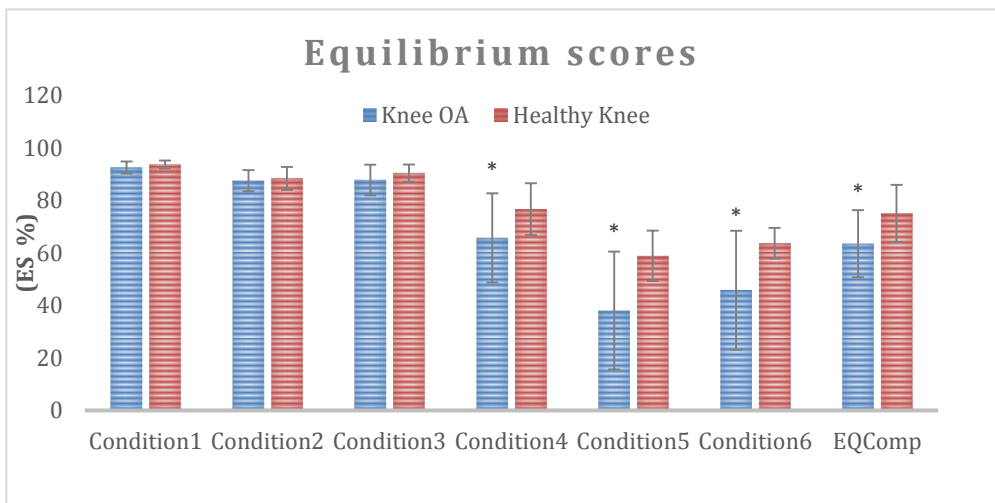
Latency (LAT)

The latency (LAT) is defined as the time in milliseconds between the onset of translation during the MCT (motor control test) and the onset of the participants' response to the support surface translation movement. Latencies were the averaged performance of the right and left feet. All participants maintained their eyes open, and the surround remained stationary throughout the MCT. The MCT required 6 conditions: graded backward (3) and forward (3) translations. Each translation moved at a constant velocity and transferred constant forward or backward angular momentum to the participant's body.

Statistical analysis

Demographic variables assessed for this study included (a) gender, (b) age, (c) height, (d) mass and (e) body mass index (BMI). These data, as well as the equilibrium score, sensory analysis ratio, strategy analysis and latency results, were analyzed using either the t-Student test or Mann-Whitney U test (for those cases where the t-Student test criteria were not fulfilled). The results of the evaluation of the significance of the differences were represented by the significance coefficient (p). The level of statistical significance was indicated by: "*" – $p < 0.05$.

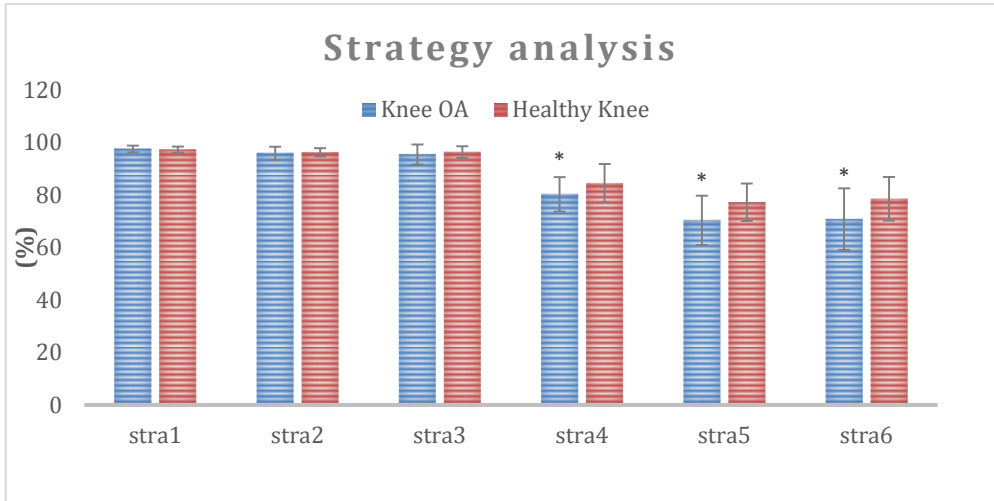
RESULTS



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

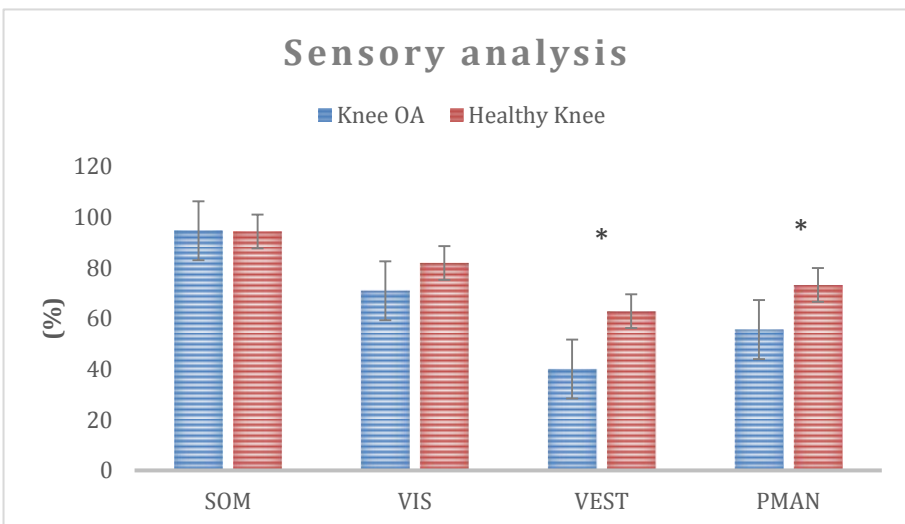
FIGURE 1. Equilibrium scores in the sensory organization test.

Figure 1 shows the SOT equilibrium score (EQ) results for both groups. An analysis of sensory organization test showed significant differences in



condition 4 ($p=0.035$), condition 5 ($p=0.003$), condition 6 ($p=0.029$), and EQ Comprehension values ($p=0.003$). This parameter was higher for healthy knee group. * Statistically significant mean difference ($p < 0.05$)

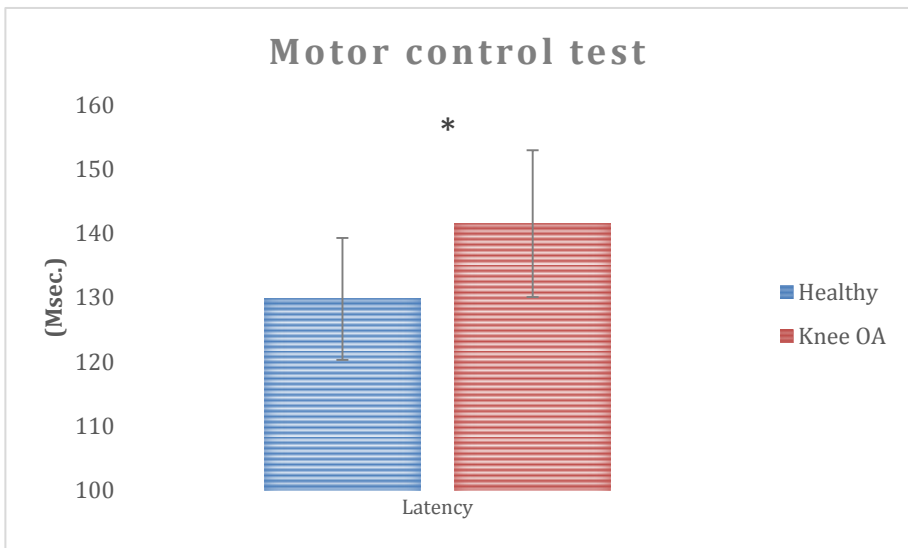
FIGURE 2. Results of strategy analysis.



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

FIGURE 3. Results of sensory analysis: the somatosensory (SOM), visual (VIS), vestibular (VEST), management of proprioceptive input (PMAN).

The SOT parametric values for the Strategy Analysis are shown in Figure 2. It was noticed that the Strategy Analysis were significantly different on knee OA for Stra4 ($p=0.026$, Eyes open, Sway-referenced surface), Stra5 ($p=0.026$, Eyes closed, Sway-referenced surface), and Stra6 ($p=0.04$, Eyes open, Sway-referenced surrounding, and surface). However, there was no significant effect of knee OA in SOT condition 1-3 (stationary platform). Also, Figure 3 shows the Sensory analysis results for both groups. A sensory analysis showed significant differences in VEST values ($p=0.002$) and PMAN ($p=0.004$). This parameter was higher for healthy knee group.



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

FIGURE 4. Results of latency.

Figure 4 shows the latency result for both groups. A motor control test showed significant differences in latency values ($p=0.024$) between groups.

DISCUSSION

The purpose of the present study was to compare the balance between people with knee OA and matched healthy controls. The study showed significant differences between the presence of knee OA and the EQ score results for condition 4, condition 5, condition 6, and EQcomp (Fig. 1). Significantly lower condition 4, 5, 6 and EQcomp values for knee OA group are evidence of larger displacements of the center of gravity in the forward-backward direction. The EQcomp score represents an overall performance level of the knee OA group, and a lower score suggests that the knee OA group was unable to maintain balance and a stable position during the SOT test procedure.

Previous research concluded that condition 4, 5, 6 scores are meaningful and highly correlated (Hirsch, Toole, Maitland, & Rider, 2003; Toole, Hirsch, Forkink, Lehman, & Maitland, 2000). According to Hirsch and colleagues (2003), condition 4, 5, 6 scores indicates performance under the most difficult test conditions when the support surface is sway-referenced and visual cues are misleading or absent and has been shown to be an accurate indicator of balance function (Hirsch, Toole, Maitland, & Rider, 2003; Toole, Hirsch, Forkink, Lehman, & Maitland, 2000). Therefore, those lower scores may imply the overall balance deficit of the knee OA group is related to an off-balance center of gravity, hip or ankle dominant strategy analysis or abnormal sensory analysis score. As a result, significantly lower Stra 4, 5, 6 values for Strategy Analysis were observed in knee OA group (Fig. 2). It indicates that when the support surface is unstable and visual information is misleading or absent from the eyes, knee OA group showed a greater hip-muscle activity and lesser ankle-muscle activity in comparison to healthy control group. The anticipatory strategy, in general, is critical to perform the dynamic postural tests properly, involving the ankle joint rather than the hip joint (Horak & Nashner, 1986). The previous research has shown that the triggering of automatic balance corrections depends on hip and trunk proprioceptive inputs and knee inputs provide a supplementary trigger signal, allowing the generation of the very early part of the *triceps surae* responses (Bloem et al., 2002; Gauchard et al., 2010). The current study shows that existing OA in the knee joint inhibits the generation of an adequate strategy, resulting in using hip joints more to regulate balance than the healthy controls. Furthermore, in condition 4, 5, 6, the differences between groups were the higher than differences of condition 1, 2, 3 which were easier task conditions. These results demonstrate that the balance differences appeared when the difficulty of the tests increased, especially in situations of conflicted sensory inputs. These results show that the balance differences appeared when the difficulty of the tests increased, especially in situations of conflicted sensory inputs.

Sensory Analysis results showed that individuals with knee OA had lower VEST and PMAN ratios. These results suggest a lower use of vestibular and somatosensory afferents compared with the healthy knee controls. The VEST ratio demonstrated the usefulness of the signal from a vestibular system in maintaining body balance, traditionally indicating the quality of the vestibular afferent (Gauchard, Vançon, Meyer, Mainard, & Perrin, 2010). In condition 5, 6, all participants had to compensate for the visual deprivation and the inaccurate somatosensory information with an increased use of vestibular referential and correct their posture by selecting a more suitable strategy involving re-organization of the different components of balance control (Vouriot et al., 2004). The previous study has shown that poor balance was related to the

lower reliance on vestibular afferent in the construction of balance control strategy (Cohen, Heaton, Congdon, & Jenkins, 1996). And Figueiro and colleagues (2011) stated that people with deficits in the vestibular system relied heavily on visual cues, and they lost balance if the visual information was removed by eyes closed (Paulus, Straube, & Brandt 1987). In this study, the similar results were observed where the visual input was removed and somatosensory inputs altered, a significantly decreased EQ scores followed.

Recently, Amor-Dorado and colleagues (2017) published an interesting study evaluating vestibular and balance function in people with psoriatic arthritis. The study concluded that psoriatic arthritis might cause vestibular damage that can decline the ability to maintain balance in people with psoriatic arthritis, and people with psoriatic arthritis demonstrated abnormal balance control of vestibular origin. Also, the research using electronystagmography suggested an association of rheumatoid arthritis with vestibular system dysfunction (Yilmaz, Erbek, Erbek, Ozgirgin, & Yucel, 2007). Although some existing research is available to document such lack of vestibular and balance function in other types of arthritis such as psoriatic, rheumatoid, to date, there is no study to evaluate the vestibular function and how sensory information can be used to maintain balance in individuals with knee OA. The current study is the first study, in the author's knowledge, to suggest the abnormal vestibular function of people with knee OA. Furthermore, knee OA group displayed a longer neuromuscular response latency to postural perturbations. Vouriot et al. (2004) stated that this long latency response could also result from the lack of dependence on somatosensory and vestibular information (Gauchard, Gangloff, Jeandel, & Perrin, 2003) which are used to activate and modulate balance correcting responses (Allum, & Shepard, 1999).

The function of the vestibular system in knee OA people may not be unambiguously identified in this study, and whether these balance deficits reflect reduced functionality in individuals with knee OA remain unknown. However, several potential mechanisms may account for the balance deficit observed in the OA group, although this cross-sectional study does not allow these to be confirmed. Individuals with knee OA often exhibit several factors that affect the balance negatively, including muscle weakness, impaired somatosensory and significant decline of mechanoreceptors compared to age-matched healthy peers. For example, Wylde and colleagues (2012) concluded that individuals with knee OA showed somatosensory abnormalities, most common ones being tactile hypoesthesia and pressure hyperalgesia. Tactile hypoesthesia and pressure hyperalgesia were found at the pain-free forearm, suggesting more widespread changes within the central nervous system (Wylde, Palmer, Learmonth, & Dieppe, 2012). Also, Shakoor, Agrawal, & Block (2007) showed that the vibratory perception threshold (VPT) is reduced to the

lower extremity (first metatarsophalangeal joint, medial malleolus, lateral malleolus, medial femoral condyle, and lateral femoral condyle) of individuals with knee OA. Abnormal somatosensory is commonly associated with knee OA and highly assumed that the abnormal balance could occur along with other characteristics of knee OA.

Also, all knee OA participants of this study had mild-moderate knee joint pain when they were assessed. Joint pain associated with the knee OA may play a role in lower equilibrium scores and slower latency, leading a reduced ability to maintain balance. Joint pain changes the responses and affects the muscle activity during the automatic response (Takacs, Carpenter, Garland, & Hunt, 2013). Experimentally-induced thigh pain results in larger sway area, increased sway displacement, increased electromyographic (EMG) activity, and increased time to return to an equilibrium position after unexpected perturbation (Hirata, Ervilha, Arendt-Nielsen, & Graven-Nielsen, 2011). Arvidsson, Eriksson, Knutsson & Arner (1986) concluded that pain might reflexively inhibit the voluntary muscles activation around the knee, which could compromise efficient and timely motor responses for maintaining balance.

In conclusion, balance deficits with significantly lower vestibular score can be identified in individuals with knee OA using computerized dynamic posturography, especially, in the sensory conflicted situation. This observation should be taken into account in the fall prevention, especially, participants should place in dynamic situations with the conflicted sensory environment, as these are found in daily life. And the comprehensive tests which evaluate vestibular functions in this population appear necessary as other types of arthritis showed the evidence of abnormal vestibular functions. The complex relationship between the sensory system and the motor system in maintaining balance is determined by individual's characteristics such as age, height, BMI, and gender. The findings of this study which matched these factors have clinical implications meaningfully for the understanding and management of individuals with knee OA and contribute to current understanding of the research by complementing the extant data.

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