

Contribution of the Sensory Systems to Static Balance following Exercise Training in Elderly Women (Part One: Aquatic Exercise): Quasi-experimental Study

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Original Article

Abstract

Introduction: Physiological changes induced by aging decreases balance and increases the risk of falls more specifically among women. The aim of present study was to investigate the effects of aquatic exercises on the engagement of sensory components of system that controls static balance in elderly women.

Materials and Methods: In this applied, semi-experimental study, with pre-test-post-test design and a control group, symptom-free elderly women of 60 to 70 years old were randomly assigned into aquatic, hippotherapy and control group (10 people each). The participation of sensory components of postural control system (visual, vestibular, somatosensory) in static balance was measured before and after 16 training sessions using the sensory organization test by the Synapsis® posturography system. The aquatic exercise group and the hippotherapy group participated in the relevant exercise protocol for 8 weeks, 2 sessions per week (50 minutes) and the control group continued their normal life. The data was analyzed using the paired T-test for intra-group comparisons and independent T-test to examine the between-group differences.

Results: The results showed that the aquatic exercise group had better performance in the post-test compared to the control group. Aquatic training significantly improved the vestibular system function in anterior-posterior direction, somatosensory system, static balance in anterior-posterior and medial-lateral directions in elderly women ($P = 0.001$ for all).

Conclusion: In general, aquatic exercise may be recommended as an alternative strategy in a safer environment for improving the participation of sensory components of the systems that controls static balance in elderly females.

Keywords: Sensory integration; Balance; Postural control; Elderly; Women; Aquatic exercise

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Introduction

Aging is a multifaceted biological process modulated by an interplay of genetic, environmental, and social determinants (1), typically accompanied by a progressive deterioration in physical and cognitive functions (2). This systemic decline extends to postural control mechanisms (3). Specifically, advancing age impairs the nervous system's ability to integrate visual, vestibular, and somatosensory inputs, all of which are critical physiological components of balance maintenance (4). Such dysfunction in postural control systems severely restricts functional capacity, mobility, and safe ambulation among the elderly (5). Consequently, this leads to a diminished proficiency in executing activities of daily living (ADL) and elevates the predisposition to falls and associated severe complications, including fragility fractures.

Human balance is a complex, multidimensional concept defined as an individual's ability to maintain the Center of Pressure (CoP) within the base of support to prevent falls (1). This process is regulated by an organized network of interactive systems within the body (8). Muscle activity for balance maintenance is controlled by the Central Nervous System (CNS) through the integration of somatosensory, visual, and vestibular inputs (9). Proprioception, originating from muscles and cutaneous receptors, provides information regarding the body's position in space and the relative orientation of body segments (10). Simultaneously, the visual system provides data on the external environment (11), and the vestibular apparatus transmits information concerning the direction and velocity of head movement relative to gravity (12) to the CNS. Overall, postural regulation requires the integration of sensory information via the CNS to generate an appropriate postural response that maintains stability during standing and walking; however, this response varies with the specific task and how it is performed (13). Consequently, the efficiency of these sensory systems is critical across all age groups, as any dysfunction leads to postural instability and an increased risk of injury (14). To enhance balance, it is essential to optimize the sensory input from the visual, vestibular, and somatosensory systems to activate anti-gravity muscles and improve stability (15). One recommended approach for stimulating these sensory systems is aquatic exercise, which is advised as an effective therapeutic adjunct for maintaining physical function, improving balance, and reducing the risk of falls in the elderly (11-18). The physical properties of water, combined with targeted exercises, can satisfy many of the physical objectives outlined in a balance rehabilitation program.

The aquatic environment is both safe and effective for geriatric rehabilitation, as water simultaneously influences musculoskeletal function and enhances postural balance (20). The buoyant property reduces the compressive forces acting on the joints (21), which may reduce perceived fatigue and help conserve energy (22). Furthermore, the viscosity and hydrodynamic forces of water create resistance, requiring the individual to exert greater force during movement (21). In other words, aquatic exercise enables high-intensity training and, consequently, muscle strengthening. Simultaneously, the reduced joint compression and the effects of immersion ensure greater comfort for the individual.

Various studies have demonstrated the efficacy of aquatic exercise in enhancing balance, alleviating pain, and improving overall physical function in the elderly (11, 23-25). Furthermore, aquatic exercise reduces the risk of falls in this population by increasing muscle strength and improving postural stability during standing and ambulation (11). However, limited research has examined the specific contributions of the individual sensory components of the balance control system (21). Using precision instruments such as posturography, it is possible to measure the internal adaptations of the sensory systems involved in balance control by introducing perturbations and altering environmental conditions; this allows evaluation of deficits within each sensory system and monitoring of their recovery (21). Currently, no published research has rigorously analyzed the efficacy of aquatic exercise in maintaining balance against various sensory perturbations that may occur during training, nor has it separately reported the effects on the visual, vestibular, and somatosensory systems. Therefore, the present study aims to answer the following question: How does a course of aquatic exercise influence the contribution of the sensory components of static balance control in asymptomatic older women?

Materials and Methods

This study employed a quasi-experimental applied design with a pretest-posttest control-group design. The protocol was approved by the Ethics Committee of Islamic Azad University, Najafabad Branch, and was registered in the Iranian Registry of Clinical Trials (IRCT). The current study is part of a larger project targeting asymptomatic older women. The target population consisted of older women residing near the equestrian center and the swimming pool. Participants were divided into three groups: equine-assisted therapy, aquatic exercise, and a control group. Due to the volume of analyses, the present study focuses

specifically on comparing the aquatic exercise group and the control group.

Sampling: Recruitment was conducted through public announcements in neighborhoods adjacent to the swimming pool of Islamic Azad University and the Chogan Espadana Equestrian Club. A convenience sampling method was used to select elderly female volunteers residing in Najafabad. The sample size was estimated using G*Power software (version 3.1.9.2, University of Düsseldorf, Germany), based on a type I error of 0.05, a power of 0.8, and an effect size of 0.3, resulting in a total of 20 participants (10 per group). >> Participants were briefed on the study objectives and procedures, after which they completed a personal information form (including age, height, weight, exercise history, and medical history) and signed an informed consent form. Inclusion criteria included the ability to follow simple instructions and the capacity to perform posturography tests, ambulate in water, and mount a horse using a platform. Exclusion criteria consisted of hypersensitivity to the pool environment or chlorine, dizziness or other balance disorders, physical impairment resulting from stroke or surgery, muscular dystrophies, severe spinal disorders, shoulder or hip dislocations, hypertension, cardiovascular diseases, and obesity. These criteria were assessed via self-reported information and, where necessary, confirmed by a certified physician. Initially, 50 individuals were selected, and participants then underwent balance testing via posturography. Then, to precisely select individuals based on the total balance score obtained from the posturography device, which was within the range of 40 to 50, 10 individuals were selected, and the details of the study were explained to them. They were given 24 hours to sign the informed consent form if willing to participate. Subsequently, 30 participants were assigned, using simple random systematic allocation, into three groups of 10 each: aquatic exercise, hippotherapy (horse-riding exercise), and control. Throughout the study, aquatic exercise and hippotherapy were the only regular physical activities performed by the exercise groups, whereas the control group engaged in no regular physical activity.

Balance Assessment: Balance was assessed using the Sensory Organization Test (SOT) for all three groups with the Synopsis Posturography System® (SPS®, version 3.0, SYNOPSIS, Marseille, France), located at the Musculoskeletal Disorders Research Center of Isfahan University of Medical Sciences. The contribution of the sensory components of the postural control system (visual, vestibular, and somatosensory) was measured one day before the start of the aquatic exercise and hippotherapy programs. Prior to the start

of the study, the system was calibrated, and to reduce examiner error, a preliminary study was conducted with 3 asymptomatic older women. This device is equipped with a movable platform that moves forward and backward and measures the individual's balance response to postural perturbations generated by the device. The degree of postural sway was assessed by measuring center-of-pressure displacements in the anterior-posterior and medial-lateral directions, expressed in millimeters (27, 28).

Based on the posturography data, the contributions of the sensory components of the postural control system (visual, vestibular, and somatosensory) and static balance were measured. The test was performed as follows: subjects were asked to stand on the device's platform barefoot, motionless, with their arms at their sides. The feet were positioned according to the designated markers, with the heels 2 cm apart and at a 30-degree angle to each other, in accordance with foot size. In addition, information such as age, height, weight, and foot size was entered into the device for each subject. The objective throughout the tests was to remain as stable as possible. The SOT is a standardized test designed to measure the contributions of the visual, vestibular, and somatosensory systems by recording responses across six sensory conditions, each examining one of the senses related to balance. This test measures postural sway in the anterior-posterior and medial-lateral directions and quantifies an individual's ability to use different sensory systems to maintain balance while standing.

In the present study, the static balance assessment consisted of six tests. In the first test, the subject stood on both feet on a firm surface with eyes open, bare feet, and arms at the sides, and normal body sway was measured. The second test was performed similarly to the first, but with the eyes closed. To eliminate visual feedback, a blindfold was used, and the subject was asked to maintain their position as still as possible. In the third test, while the eyes were open, a moving visual stimulus (a spider web pattern) was presented by a video display system in a completely dark room. This test is referred to as "sway-referenced vision," because it provides misleading visual cues about the body's position in space. The conditions in tests 4, 5, and 6 were similar to those in tests 1, 2, and 3, respectively, except that the somatosensory input was disrupted by placing a foam pad (50 × 50 × 5.5 cm) on the platform's firm surface. In other words, the fourth test was similar to the first test, standing on the foam with eyes open; the fifth test involved standing on the foam with eyes closed; and the sixth test involved standing on the foam with sway-referenced vision (creating misleading

visual cues). The sequence of test administration was identical for all subjects, as dictated by the posturography device's settings. Each test lasted 20 seconds and was repeated twice. The rest period between each repetition was 10 seconds, and between each test was 30 seconds. The subject exited the device after completing the full SOT.

The scores calculated from the SOT included the somatosensory score (values of the second test divided by the values of the first test), the visual score (values of the fourth test divided by the values of the first test), and the vestibular score (values of the fifth test divided by the values of the first test). The overall balance score is a composite score that takes into account the values of all the tests, along with the limits-of-stability test, and self-assesses the subject's ability to use

sensory inputs to maintain balance. All analyses were performed using the posturography system software.

Aquatic Exercise: Participants in the aquatic exercise group followed the protocol for 8 weeks, with 2 sessions per week, each lasting 50 minutes. During this period, the control group continued their normal daily life. One day after the exercise protocol ended, both groups were retested using the aforementioned assessments. To carry out the aquatic exercise protocol, in accordance with previous research, the exercise intensity was set at 50–75% of maximum heart rate (29). The water temperature was set at 28 to 29°C. Throughout the exercise interventions, in accordance with the overload principle, progressive levels of difficulty were applied to each exercise, as presented in Table 1.

Table 1. Aquatic Exercise Training Protocol

Phase	Exercise	Repetition-Distance
Warm-up (10 minutes)	Entering the water, pushing water with hands and feet while walking, side-stepping (left and right), stepping forward and backward, side-stepping with crossover leg movements (left and right), sitting and standing up with rotational arm movements	50 to 200 meters (2 to 8 widths of a 25-meter pool)
Main program activities (30 minutes)	Walking with lengthened strides	50 to 200 meters
	Walking forward-backward while performing head movements (flexion and extension, lateral flexion, and rotation to both sides) with coordinated arm movements	50 to 200 meters
	Military-style marching (in place)	50 to 200 meters
	Standing on one leg	30–60 seconds (2–4 repetitions)
	Standing on the toes of one foot with eyes open and closed	30–60 seconds (2–4 repetitions)
	Standing on one leg while performing head movements (flexion and extension, lateral flexion, and rotation to both sides) with eyes open and closed	30–60 seconds (2–4 repetitions)
	Standing on one leg and raising the arms upward with eyes open and closed	30–60 seconds (2–4 repetitions)
	Standing on one leg while performing figure-8 movements with the other leg, with eyes open and closed	8–15 repetitions
	Standing on one leg while flexing and extending the hip joint of the other leg, with simultaneous arm movements, eyes open and closed	30–60 seconds (2–4 repetitions)
	Walking in different directions and at different speeds with arm movements in all directions	50 to 200 meters
	Walking in different directions and at different speeds while raising the arms unpredictably at the instructor's command	50 to 200 meters
	Unpredictable changes of direction at the instructor's command	50 to 200 meters
	Walking forward-backward with coordinated head and arm movements (flexion and extension)	50 to 200 meters
	Walking sideways with coordinated head and arm movements (rotational movements)	50 to 200 meters
	Trunk rotation while displacing water with the hands	8–15 repetitions
	Hip flexion and extension in a semi-squat position	8–15 repetitions
	Flexion-extension, abduction-adduction, and rotation movements of the shoulder, elbow, wrist, hip, knee, and ankle joints, according to each joint's degree of freedom	8–15 repetitions per joint
	Squat movement	8–15 repetitions
	Squat movement while walking sideways (left and right)	8–15 repetitions
	Toe-squat movement while walking sideways (left and right)	8–15 repetitions
	Butterfly movement with eyes open and closed	8–15 repetitions
	Scarecrow movement with eyes open and closed	8–15 repetitions
Cool-down (10 minutes)	Slow walking with deep breathing, performing arm and leg stretching movements, floating/lying on the water	50 to 200 meters

Table 2. Descriptive Statistics of Demographic Variables of the Participants

Variable	Group	Sample Size	Mean $\pm$ SD	P value
Age (years)	Aquatic exercise	10	66.21 $\pm$ 5.04	0.38
	Control	10	64.98 $\pm$ 5.37	
Height (m)	Aquatic exercise	10	161.90 $\pm$ 6.43	0.31
	Control	10	163.21 $\pm$ 4.21	
Weight (kg)	Aquatic exercise	10	65.40 $\pm$ 7.12	0.27
	Control	10	66.38 $\pm$ 8.37	
Body mass index (kg/m ²)	Aquatic exercise	10	24.97 $\pm$ 4.13	0.52
	Control	10	24.93 $\pm$ 4.58	

All exercise programs were conducted by an exercise specialist (holding a degree in sports science) who held a Level 3 coaching certification in aquatic exercise.

Descriptive statistics were used to summarize the data; the Shapiro-Wilk test was used to assess the normality of the data distribution; the paired t-test was used for within-group comparisons; and the independent t-test was used to examine between-group differences. Finally, the data were analyzed using SPSS software (version 23, IBM Corporation, Armonk, NY) at a significance level of 0.05.

Results

Thirty participants were divided into three groups of 10: aquatic exercise, hippotherapy (horse-riding exercise), and control. All participants in each group completed all stages of the study (dropout rate = 0%). The results of the Shapiro-Wilk test indicated that all examined variables were normally distributed ($P < 0.05$); therefore, parametric statistical tests were used for data analysis. The demographic information

of the groups is presented in Table 2.

There was no significant difference between the mean values of age, height, weight, and body mass index (BMI) of the groups at the pre-test stage ($P < 0.05$). Furthermore, according to the data in Table 3, the results of the within-group comparison (paired t-test) showed that in the control group, at the end of the study period, there was no significant change in the measured variables compared to the assessment before the start of the study ($P > 0.05$).

The results of the paired t-test in the aquatic exercise group showed a significant difference in the vestibular, somatosensory, and total balance (anterior-posterior and medial-lateral) variables ($P = 0.001$). In contrast, no significant change was observed in the other variables.

According to Table 4, the between-group comparison (independent t-test) of the measured variables showed no significant difference between the aquatic exercise and control groups at the pre-test stage ($P < 0.050$).

Table 3. Results of the Paired t-test for the Measured Variables in the Participating Groups

Group	Variable (mm)	Pretest	Posttest	T statistic	df	P value
Control	Visual anterior-posterior	95.33 $\pm$ 4.64	95.66 $\pm$ 4.01	0.43	9	0.680
	Visual medial-lateral	93.41 $\pm$ 5.03	93.61 $\pm$ 4.53	0.23	9	0.820
	Vestibular anterior-posterior	78.21 $\pm$ 6.39	79.90 $\pm$ 5.30	0.21	9	0.840
	Vestibular medial-lateral	82.50 $\pm$ 6.48	81.20 $\pm$ 5.92	0.16	9	0.810
	Somatosensory anterior-posterior	69.20 $\pm$ 7.88	70.66 $\pm$ 6.69	1.40	9	0.190
	Somatosensory medial-lateral	74.50 $\pm$ 7.72	75.66 $\pm$ 7.29	0.62	9	0.550
	Total balance anterior-posterior	68.73 $\pm$ 6.32	69.41 $\pm$ 7.83	0.50	9	0.630
	Total balance medial-lateral	73.66 $\pm$ 4.48	74.30 $\pm$ 6.48	0.83	9	0.430
Aquatic exercise	Visual anterior-posterior	95.33 $\pm$ 4.64	95.66 $\pm$ 4.01	0.43	9	0.680
	Visual anterior-posterior	95.70 $\pm$ 4.59	96.69 $\pm$ 3.98	1.43	9	0.190
	Visual medial-lateral	92.60 $\pm$ 4.89	93.91 $\pm$ 5.26	1.35	9	0.210
	Vestibular anterior-posterior	79.60 $\pm$ 6.94	92.60 $\pm$ 5.28	7.98	9	0.001
	Vestibular medial-lateral	83.70 $\pm$ 4.12	86.50 $\pm$ 5.74	1.94	9	0.080
	Somatosensory anterior-posterior	68.75 $\pm$ 7.95	96.20 $\pm$ 3.15	22.86	9	0.001
	Somatosensory medial-lateral	77.58 $\pm$ 7.18	94.85 $\pm$ 3.01	8.57	9	0.001
	Total balance anterior-posterior	69.81 $\pm$ 5.69	86.70 $\pm$ 6.56	5.68	9	0.001
	Total balance medial-lateral	72.38 $\pm$ 4.01	84.18 $\pm$ 5.96	5.28	9	0.001

Table 4. Results of the Independent t-test for the Measured Variables in the Participating Groups

Variable	Time	Group (i)	Group (j)	Mean difference (j-i)	T statistic	df	P value
Visual anterior-posterior (mm)	Pre-test	Aquatic exercise	Control	0.5	0.309	18	0.761
	Posttest	Aquatic exercise	Control	0.9	0.62	18	0.543
Visual medial-lateral (mm)	Pre-test	Aquatic exercise	Control	0.8	0.397	18	0.696
	Posttest	Aquatic exercise	Control	0.3	0.197	18	0.846
Vestibular anterior-posterior (mm)	Pretest	Aquatic exercise	Control	1.4	0.959	18	0.351
	Posttest	Aquatic exercise	Control	14.2	7.20	18	0.001
Vestibular medial-lateral (mm)	Pre-test	Aquatic exercise	Control	0.9	0.527	18	0.605
	Posttest	Aquatic exercise	Control	4.7	1.95	18	0.067
Somatosensory anterior-posterior (mm)	Pretest	Aquatic exercise	Control	0.7	0.4	18	0.694
	Posttest	Aquatic exercise	Control	26.1	16.98	18	0.001
Somatosensory medial-lateral (mm)	Pre-test	Aquatic exercise	Control	2.9	1.63	18	0.119
	Posttest	Aquatic exercise	Control	18.1	10.92	18	0.001
Total balance anterior-posterior (mm)	Pretest	Aquatic exercise	Control	0.3	0.133	18	0.895
	Posttest	Aquatic exercise	Control	17.3	6.70	18	0.001
Total balance medial-lateral (mm)	Pre-test	Aquatic exercise	Control	1.1	0.551	18	0.588
	Posttest	Aquatic exercise	Control	9.6	3.99	18	0.001

The results of the between-group comparison at the post-test stage also indicated that there were significant differences between the aquatic exercise group and the control group in the anterior-posterior vestibular, somatosensory, and anterior-posterior ($P = 0.001$) and medial-lateral ($P = 0.001$ for all) variables; however, no significant difference was observed between the aquatic exercise and control groups in the medial-lateral vestibular ($P = 0.011$), anterior-posterior visual ($P = 0.543$), and medial-lateral visual ($P = 0.841$) variables.

Discussion

The anatomical and physiological changes resulting from the natural course of aging impair the body's balance in postural control and weaken the normal functioning of the neuromuscular and proprioceptive systems, leading to incidents such as falls (5). For this purpose, the present study examined the effects of aquatic exercise on the sensory components of the balance control system in older women through a 16-session training program (2 sessions per week for 8 weeks, 50 minutes each session). The approach of this study was to examine balance function with an emphasis on related parameters, including the proprioceptive, vestibular, and visual systems. In this study, using the Synapsis® posturography device, the contribution of the sensory systems (visual, vestibular, and proprioceptive) to static balance control in the anterior-posterior and medial-lateral directions was assessed, and the results showed a significant improvement in the function of the proprioceptive and vestibular systems in static balance. However, no effect was observed on visual system function during static balance control.

In this study, the aquatic exercise program was

designed so that half of the exercises were performed in the shallow-water section (closed kinetic chain) and the other half in the deep-water section (open kinetic chain), while wearing a noodle belt. In the shallow section, the water was chest-deep, allowing participants to control weight-bearing on the joints while increasing movement speed and exercising the joints through their full range of motion and in different directions, according to each joint's degree of freedom. In fact, the shallow section of the water reduces buoyancy and increases ground reaction force, whereas in the deep section, buoyancy and immersion are greater; consequently, the neuromuscular activation pattern of the engaged muscles differs across sections of the pool (30).

One of the findings of this study indicates improved static balance in older women following an aquatic exercise program, consistent with previous research (23, 25, 31-33). However, the effect of aquatic exercise on balance-recovery strategies appears to differ between older men (31, 34) and elderly women (32, 35). Nevertheless, part of the difference reported in these studies could be due to differences in how fall risk was assessed—using advanced motion analysis equipment (34) or clinical tests (32, 36, 37). In any case, previous findings suggest a possible difference in the effectiveness of these exercises between women and men, which was one reason for conducting the present study in older women. Interestingly, according to previous studies, participants' cognitive status (36) or the presence of knee osteoarthritis (38) does not weaken this effect. However, unlike in asymptomatic older adults (39), improvement in static balance following exercise in the shallow section of the pool has been reported to be greater than that following

exercise in the deep section for individuals with knee osteoarthritis (38).

On the other hand, the present results were in contradiction with some of the findings of previous researchers (38, 40, 41). For example, despite improvements in static balance (single-leg standing time test) and dynamic balance (Y-balance test) in the dominant leg across all three directions, dynamic balance in the non-dominant leg improved only anteriorly, with no improvement observed in the two posterior directions. These discrepancies can be attributed to differences in the types of exercises taught, participant characteristics, training duration, or the type of test used to measure balance, which makes quantitative comparison of their findings difficult.

Aquatic exercise is a unique form of exercise that, in addition to simultaneously challenging aerobic and strength-training system readiness, provides a safe and, indeed, calming environment for elderly individuals (41). Using water's buoyant properties, three training methods can be used to teach individuals: assistance, support, and resistance. In this way, the hydrostatic pressure of the water supports the immersed body and creates a lower-gravity environment, which reduces the risk of falling (42). On the other hand, the viscosity property of water exerts natural resistance against body movements, which strengthens neuromuscular function in performing various exercises (43), and by increasing the time required to perform movements and reducing movement speed (44), it increases reaction time (43); consequently, individuals have more time available to generate a response and reaction (44). This property also causes the muscular resistance used to be 10 times greater than in air exercise, which contributes to greater engagement of the brain's motor cortex (facilitation of the nervous system). As a result, motor neuron firing and motor cortex activity increase in elderly individuals. This improves motor unit synchronization and motor neuron excitability, which manifest as increased muscle strength and improved balance in elderly individuals (45). With improved muscle strength, the sensitivity of muscle spindles and other kinesthetic receptors increases, ultimately improving neuromuscular control. In a closed loop, this increases the speed of mechanical and physiological responses, leading to activation of alpha and gamma motor neurons and facilitation of muscle contraction (46).

The first sensorimotor integration in balance control involves the stretch reflex, mediated by muscle spindles (47). These reflexes rapidly counteract unexpected changes in muscle length through a very simple circuit in the spinal cord (48) and support

myriad functions while remaining highly flexible/adaptable. Under normal conditions, stretch reflexes are shaped by peripheral physiology and involve neural circuits in the spinal cord, brainstem, and cerebral cortex (49). When a muscle is stretched, the muscle spindles within it are stretched, and the firing rate of the muscle spindle afferents increases (50); therefore, increased sensitivity of the muscle spindles and improved neuromuscular control may be among the reasons for the improvement in balance following aquatic exercise. The results of the present study showed that, following the aquatic exercise program, proprioceptive system function improved more than that of the vestibular and visual systems, consistent with Conte et al. (51).

According to the results of this study, vestibular system function improved following aquatic exercise. The vestibular system, together with the visual and proprioceptive systems, significantly affects multiple dimensions of balance (52). Changes in head and body position during flexion, extension, lateral flexion, and rotation of the head with eyes open and closed, as well as sudden changes in direction during aquatic exercise, may affect the balance system. Neural information from balance-controlling receptors is transmitted to the cerebellum, and commands issued from the cerebellum maintain balance through various muscles of the body (53). Repeated eye and head movements and head and shoulder rotation during aquatic exercise provide the information needed for the vestibular system to orient the body in space. In other words, the vestibular nuclei are responsible for integrating signals from the vestibular organs with inputs from the visual system, cerebellum, and even the spinal cord. By integrating the received messages in the vestibular nuclei, these messages are sent to various regions of the brain, including vestibular areas, the thalamus, the proprioceptive cortex, the cerebellum, the spinal cord, and the oculomotor nuclei (54). This complex vestibular network helps individuals spatially orient their bodies with respect to gravity and recognize when they need to rotate their heads and bodies. Perhaps one reason why, following aquatic exercise, elderly individuals—especially in the event of a sudden loss of balance—can find an appropriate orientation and improve their balance is the improved vestibular system function resulting from these exercises. According to research, repeated postural control exercises in various positions during aquatic exercise cause the vestibular system (through its descending pathways) to directly and indirectly influence extensor muscle groups, thereby maintaining standing posture and reflexively controlling balance during unexpected

changes (55). It appears that aquatic exercise stimulates cutaneous afferents and facilitates vestibular input; for this reason, these exercises can be used to enhance the transmission of sensory messages to the relevant level in the central nervous system (56). In previous studies, it has been established that aquatic exercise is highly effective in patients with peripheral vestibular disorders and, by improving vestibular system function, reduces the incidence, severity, and duration of dizziness complaints (57).

The lack of significance in visual system scores for static balance may be due to the high baseline function score for this system on the posturography tests. In general, elderly individuals rely more heavily on visual input for balance control and depend more on the visual system to maintain balance (58). In fact, vision is one input that can compensate for deficiencies in other senses (59). Studies have shown that the sensory receptors controlling body orientation exhibit reduced sensitivity in elderly individuals (10). This reduced sensitivity is compensated for by excessive reliance on vision (58, 60). Excessive reliance on visual input may be a natural compensatory strategy for coping with poor balance in the elderly (61). This explains the high baseline score for the visual system and probably accounts for why changes in its score were not significant.

Limitations

Among the limitations of the present study is the lack of control over certain confounding variables, such as sleep duration and activity level before the assessment sessions, which may have affected participants' responses during testing. Additionally, this study was conducted only on women. Given the differences in balance indices between women and men (62), the results of this study cannot be generalized to men.

Recommendations

Given the benefits of the aquatic exercise program for balance in asymptomatic older women observed in the present study, it can likely be recommended to improve quality of life and physical fitness in the elderly. It would also be worthwhile to compare the effects of aquatic exercise with other methods for improving balance in asymptomatic elderly individuals and in individuals with various balance-related diseases.

Conclusion

It appears that in healthy older women, proprioceptive and vestibular function improved following a period of aquatic exercise, leading to improved static balance.

Balance control involves complex neuromuscular activities that enable individuals to make rapid, precise postural adjustments to maintain balance. Therefore, examining the function of the visual, vestibular, and proprioceptive systems in static balance control may help identify the type of impairment in different individuals. The risk of impairment in the balance control systems helps physicians select targeted physical exercises to improve balance control and to develop and implement personalized programs and fall-prevention strategies for elderly individuals. Additionally, the physical properties of water (temperature, buoyancy, hydrostatic pressure, and viscosity) can provide a safe, effective, and comfortable environment for exercise in individuals who have difficulty with land-based exercises.

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Authors' Contribution

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Conflict of Interest

The authors did not have a conflict of interest.

References

- Rodrigues LP, Teixeira VR, Alencar-Silva T, Simonassi-Paiva B, Pereira RW, Pogue R, et al. Hallmarks of aging and immunosenescence: connecting the dots. *Cytokine & growth factor reviews*. 2021;59:9-21.
- Lockie RG, Dawes JJ, Kornhauser CL, Holmes RJ. Cross-sectional and retrospective cohort analysis of the effects of age on flexibility, strength endurance, lower-body power, and aerobic fitness in law enforcement officers. *The Journal of Strength & Conditioning Research*. 2019;33(2):451-8.
- Kanekar N, Aruin AS. Aging and balance control in response to external perturbations: role of anticipatory and compensatory postural mechanisms. *Age*. 2014;36:1067-77.
- Alcock L, O'Brien T, Vanicek N, editors. The effect of age on the somatosensory, visual and vestibular contributions to the maintenance of postural equilibrium. XXV Congress of the International Society of Biomechanics; 2015: Newcastle University.
- Michalska J, Kamieniarz A, Sobota G, Stania M, Juras G, Słomka KJ. Age-related changes in postural control in older women: Transitional tasks in step initiation. *BMC geriatrics*. 2021;21:1-9.
- Gregg EW, Pereira MA, Caspersen CJ. Physical activity, falls, and fractures among older adults: a review of the epidemiologic evidence. *Journal of the American Geriatrics Society*. 2000;48(8):883-93.
- Winter DA, Prince F, Frank JS, Powell C, Zabjek KF. Unified theory regarding A/P and M/L balance in quiet stance. *Journal of neurophysiology*. 1996;75(6):2334-43.
- Paillard T. Relationship between muscle function, muscle typology and postural performance according to different postural conditions in young and older adults. *Frontiers in Physiology*. 2017;8:281498.
- Manchester D, Woollacott M, Zederbauer-Hylton N, Marin O. Visual, vestibular and somatosensory contributions to balance control in the older adult. *Journal of gerontology*. 1989;44(4):M118-M27.
- Goble DJ, Coxon JP, Wenderoth N, Van Impe A, Swinnen SP. Proprioceptive sensibility in the elderly: degeneration, functional consequences and plastic-adaptive processes. *Neuroscience & Biobehavioral Reviews*. 2009;33(3):271-8.
- Wade MG, Jones G. The role of vision and spatial orientation in the maintenance of posture. *Physical therapy*. 1997;77(6):619-28.
- Angelaki DE, Cullen KE. Vestibular system: the many facets of a multimodal sense. *Annu Rev Neurosci*. 2008;31:125-50.
- Coppé J-P, Desprez P-Y, Krtolica A, Campisi J. The senescence-associated secretory phenotype: the dark side of tumor suppression. *Annual review of pathology: mechanisms of disease*. 2010;5:99-118.
- Ha V-AT, Nguyen TN, Nguyen TX, Nguyen HTT, Nguyen TTH, Nguyen AT, et al. Prevalence and factors associated with falls among older outpatients. *International journal of environmental research and public health*. 2021;18(8):4041.
- Geigle PR, Cheek Jr WL, Gould ML, Hunt III CH, Shafiq B. Aquatic physical therapy for balance: the interaction of somatosensory and hydrodynamic principles. *The Journal of Aquatic Physical Therapy*. 1997;5(1):4-10.
- Kim Y, Vakula MN, Waller B, Bressel E. A systematic review and meta-analysis comparing the effect of aquatic and land exercise on dynamic balance in older adults. *BMC geriatrics*. 2020;20:1-14.
- Melo RS, Cardeira CSF, Rezende DSA, Guimarães-do-Carmo VJ, Lemos A, de Moura-Filho AG. Effectiveness of the aquatic physical therapy exercises to improve balance, gait, quality of life and reduce fall-related outcomes in healthy community-dwelling older adults: A systematic review and meta-analysis. *PLoS one*. 2023;18(9):e0291193.
- Karaçal R, Sarı C. Hydrotherapy for Fall Prevention In Elderly Individuals. *Experimental and Applied Medical Science*. 4(1):469-75.
- Becker BE. Aquatic therapy: scientific foundations and clinical rehabilitation applications. *Pm&r*. 2009;1(9): 20. 859-72.
- Verhagen AP, Cardoso JR, Bierma-Zeinstra SM. Aquatic exercise & balneotherapy in musculoskeletal conditions. *Best Practice & Research Clinical Rheumatology*. 2012;26(3):335-43.
- Miyoshi T, Shirota T, Yamamoto S-I, Nakazawa K, Akai M. Effect of the walking speed to the lower limb joint
- angular displacements, joint moments and ground reaction forces during walking in water. *Disability and Rehabilitation*. 2004;26(12):724-32.
- Wilcock IM, Cronin JB, Hing WA. Physiological response to water immersion: a method for sport recovery? *Sports medicine*. 2006;36:747-65.
- Alikhajeh Y, Hosseini SRA, Moghaddam A. Effects of hydrotherapy in static and dynamic balance among elderly men.

- Procedia-Social and Behavioral Sciences. 2012;46:2220-4.
26. Ferreira DL, Campos DM, Vassimon-Barroso V, de Oliveira JC, Souza IS, Christoforetti G, et al. Aquatic exercise training for falls and potentially modifiable risk factors of falls in older people: A blinded randomized controlled trial protocol. *European Journal of Integrative Medicine*. 2020;39.
 27. Morris DM. Aquatic therapy to improve balance dysfunction in older adults. *Topics in Geriatric Rehabilitation*. 2010;26(2):104-19.
 28. Eslait FJG, Triviño PAE, Vergara YVG, García MAM, Gutiérrez VFL. Implementation outcomes of a sensory integration therapy program with computerized dynamic posturography in patients with balance and sensory dysfunction. *Journal of Otology*. 2023;18(1):26-32.
 29. Fawzan S, Kozou H, Baki F, Asal S. Fall risk assessment and effect of vestibular rehabilitation in the elderly population. *The Egyptian Journal of Otolaryngology*. 2022;38(1):88.
 30. Abdelmoteleb H, Sobhy O, Bassiouny M, Elsherif M. Evaluation of postural stability and vestibulo-ocular reflex in adults with chronic suppurative otitis media. *European Archives of Oto-Rhino-Laryngology*. 2023;280(2):897-905.
 31. Vasconcelos BB, Protzen GV, Galliano LM, Kirk C, Del Vecchio FB. Effects of high-intensity interval training in combat sports: a systematic review with meta-analysis. *The Journal of Strength & Conditioning Research*. 2020;34(3):888-900.
 33. Beyranvand R, Sahebozamani M, Daneshjoo A. The effect of 8-week aquatic exercise on postural control and balance recovery strategy of elderly men. *MED SPORT*. 2018;71:284-95.
 34. Jain PP, Kanase SB, Rainak A. Effect of Aquatic Exercises on Postural Control in Elderly population. *NeuroQuantology*. 2022;20(16):5349.
 35. Resende SM, Rassi CM. Effects of hydrotherapy in balance and prevention of falls among elderly women. *Brazilian Journal of Physical Therapy*. 2008;12:57-63.
 36. So BC, Kwok MM, Fung VC, Kwok AH, Lau CW, Alison L, et al. A study comparing gait and lower limb muscle activity during aquatic treadmill running with different water depth and land treadmill running. *Journal of Human Kinetics*. 2022;82(1):39-50.
 37. Beyranvand R, Sahebozamani M, Daneshjoo A, Seyedjafari E. Assessment and comparison the effect of exercise in different depth of water on postural stability and balance recovery strategies of older people: a clinical trial. *The Scientific Journal of Rehabilitation Medicine*. 2023;11(6):1002-15.
 38. Bento PCB, Lopes MdFA, Cebolla EC, Wolf R, Rodacki AL. Effects of water-based training on static and dynamic balance of older women. *Rejuvenation research*. 2015;18(4):326-31.
 39. Nahand MS, Najafabadi MG, Naghdi N, Sheikh M, Shaw BS. Effect of combined aquatic and cognitive training on quality of life, fall self-efficacy, and motor performance in aged with varying cognitive status: a proof-of-concept study. *Journal of exercise rehabilitation*. 2020;16(2):148.
 40. Kang K-J, Lee J-S, Yang J-O, Park J-S, Han K-H. Effect of aquatic walking exercise on gait and balance parameters of elderly women. *Korean Journal of Sport Biomechanics*. 2020;30(1):73-81.
 41. Zamanian F, Vesalinasheh M, Nourollahnajafabadi M, Asadysaravi S, Haghighi M, Najafabad I. Comparison of the effects of aquatic exercise in shallow and deep water on Postural Control in elderly women with chronic knee Osteoarthritis. *Life Sci J*. 2012;9(4):5768-71.
 42. KohanzadehBajestan Z, Ghasemi A, Naeimikia M. The Effect of 8 Weeks Shallow and Deep Water Exercises on Static Balance and Dynamic Balance of Elderly Women. *SOREN Student Sports & Health Open Researches*
 43. *E-Journal: New-Approaches*. 2021;2(1): 31–7.
 44. Azimzadeh E, Aslankhani MA, Shojaei M, Salavati M. Effect of hydrotherapy on static and dynamic balance in older adults: Comparison of perturbed and non-perturbed programs. *Iranian Journal of Ageing*. 2013;7(4):27-34.
 45. Hosseini-mehr SH, Anbarian M, Mohammadi Z. Effects of 12 weeks water training in shallow and deep part of pool on balance and lower limb muscles strength in elderly. *Studies in Sport Medicine*. 2022;14(33):97-114.
 46. Carregaro RL, Toledo AMd. Efeitos fisiológicos e evidências científicas da eficácia da fisioterapia aquática. *Revista movimenta*. 2008;1(1).
 47. Cugusi L, Manca A, Bergamin M, Di Blasio A, Monticone M, Deriu F, et al. Aquatic exercise improves motor impairments in people with Parkinson's disease, with similar or greater benefits than land-based exercise: a systematic review. *Journal of physiotherapy*. 2019;65(2):65-74.
 48. Winter DA. *Biomechanics and motor control of human movement*: John Wiley & sons; 2009.
 49. Behm DG, Anderson KG. The role of instability with resistance training. *The Journal of Strength & Conditioning Research*. 2006;20(3):716-22.
 50. Punakallio A. Balance abilities of workers in physically demanding jobs with special reference to firefighters of different ages (Tasapainon hallinta fyysisesti kuormittavaa työtä tekeillä, erityisesti eri-ikäisillä palomiehillä): Kuopion yliopisto; 2004.
 51. Aflalo J, Quijoux F, Truong C, Bertin-Hugault F, Ricard D. Impact of sensory afferences in postural control quantified by force platform: a protocol for systematic review. *Journal of personalized medicine*. 2022;12(8):1319.
 52. Bhattacharyya KB. The stretch reflex and the contributions of C David Marsden. *Annals of Indian Academy of Neurology*. 2017;20(1):1-4.

53. Reschechtko S, Pruszynski JA. Stretch reflexes. *Current Biology*. 2020;30(18):R1025-R30.
54. Eccles RM, Lundberg A. Supraspinal control of interneurons mediating spinal reflexes. *The Journal of physiology*. 1959;147(3):565.
55. Conte A, Khan N, Defazio G, Rothwell JC, Berardelli A. Pathophysiology of somatosensory abnormalities in Parkinson disease. *Nature Reviews Neurology*. 2013;9(12):687-97.
56. Feshki F, Banaeifar A, Kasbparast M. The effects of a 6-week selected balance and cawthorne-cooksey exercises on static balance and mobility in female patients with multiple sclerosis. *Physical Treatments-Specific Physical Therapy Journal*. 2020;10(3):169-76.
57. Abbaspourany M, Shariat Zadeh M, Lotfi G, Naghavi Alhoseini J. The effect of balance & strength exercise training on static balance and isometric strength in girl students with mental retardation. *Motor Behavior*. 2016;8(23):33-48
58. Ribeiro AdSB, Pereira JS. Balance improvement and reduction of likelihood of falls in older women after Cawthorne and Cooksey exercises. *Brazilian journal of otorhinolaryngology*. 2005;71(1):38-46.
59. Pudjiastuti SS, Zubaidi A. Penggunaan Medial ARCH Support dan Keseimbangan Dinamis pada Kondisi Flat Foot. *Interest: Jurnal Ilmu Kesehatan*. 2012;1(1).
60. Ruoti RG, Morris DM, Cole AJ. Aquatic rehabilitation. (No Title). 1997.
61. Pereira CMM, Vale JdSPd, Oliveira WPd, Pinto DdS, Cal RVR, Azevedo YJd, et al. Aquatic physiotherapy: a vestibular rehabilitation option. *Brazilian Journal of Otorhinolaryngology*. 2021;87:649-54.
62. Howcroft J, Lemaire ED, Kofman J, McIlroy WE. Elderly fall risk prediction using static posturography. *PLoS one*. 2017;12(2):e0172398.
63. Gallahue DL. Understanding motor development: Infants, children. Adolescents. 1989:200-36.
64. Simoneau M, Teasdale N, Bourdin C, Bard C, Fleury M, Nougier V. Aging and postural control: postural perturbations caused by changing the visual anchor. *Journal of the American Geriatrics Society*. 1999;47(2): 235-40.
65. Bugnariu N, Fung J. Aging and selective sensorimotor strategies in the regulation of upright balance. *Journal of neuroengineering and rehabilitation*. 2007;4:1-7.
66. Puszczalowska-Lizis E, Bujas P, Jandzis S, Omorczyk J, Zak M. Inter-gender differences of balance indicators in persons 60–90 years of age. *Clinical Interventions in Aging*. 2018:903-12.