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Original Research

The Effect of Eight Weeks of Aquatic Training on the Kinematic and Continuous Relative Phase of Trunk-Pelvis During Gait in Patients with Chronic Back Pain

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ABSTRACT

Low back pain is one of the most common disorders that affect one's functional ability in daily life and workplace activities, as well as their general health and quality of life. The motion range and the trunk-pelvis coordination are important kinematic variables that seem to be affected by low back pain. Currently, aquatic training is one of the popular methods to treat patients with low back pain. This study aims to investigate the effect of eight weeks of aquatic training on the kinematic and continuous relative phase trunk-pelvis coordination during gait in patients with chronic back pain. In this quasi-experimental and causal-comparative study, 50 subjects with chronic back pain were divided into control and experimental groups. Noraxon IMU system was used to measure the pelvis and trunk kinematic variables during walking before and after aquatic training. The angular information of the pelvis and trunk was extracted with IMU software. Subsequently, the range of motion and continuous relative phase index were calculated. Following the pretest, the participants underwent three days a week of water walking training lasting eight weeks. Gait speed was increased after each week of gait training. The control group continued their daily activities after the pretest. For statistical analysis, the dependent t-test was used for within-group comparison, and the independent t-test was used for between-group comparison ($P \leq 0.05$). The results of this study showed that aquatic training reduces the trunk's range of motion ($P<0.05$). Aquatic training increased the coordination between the trunk and pelvis, which indicates greater coordination between the trunk and pelvis during walking ($P<0.05$). Moreover, the variability of coordination decreased significantly within and between groups after training in water ($P<0.05$). According to

the current study's results, eight weeks of water gait training at different speeds reduces the range of motion of the trunk due to the features of aquatic training, such as buoyancy and flow resistance. This decrease in the range of motion balances the movement of the trunk around the pelvis, and consequently, the coordination between these two segments increases. On the other hand, the results of this study pointed to the greater stability of walking of patients with back pain after performing the exercise, indicating that the walking pattern in high repetitions is closer to normal gait.
Keywords: Aquatic Training, Gait, Thorax-Pelvic Coordination, Kinematic

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INTRODUCTION

Low back pain (LBP) is one of the main causes of reduced quality of life. Researchers found that dysfunction and weakness of abdominal muscles and lumbar spine are related to back pain [1]. Back pain is associated with a decrease in the lumbar vertebrae's range of motion in all directions, as well as a decrease in the range of pelvis flexion when bending the trunk forward [2]. Also, the vertebrae-pelvis movement coordination is lower in people with back pain than in healthy people [3]. Chronic non-specific LBP is defined as persistent LBP for at least 12 weeks without any specific cause. It accounts for 90% of chronic LBP and is associated with depression, fatigue, sleep disorders, and stress [4].

Gait is one aspect that is impacted by back pain. A primary change that occurs in people's gait following back pain is a decrease in gait speed [5]. It appears that a slow gait is caused by pain or fear of behaviors that lead to pain, and thus, the person adjusts their gait to minimize stress on the vertebrae [6]. Apparently, people with lower back pain have higher activity of their lumbar extensor muscles when walking, and this increased activity is used as a guard to protect the lumbar vertebrae in people with LBP [7]. One potential explanation for the slower and more controlled gait observed in individuals with back pain is that a slower gait facilitates greater movement control and enhances the individual's movement control during gait [6]. However, people with back pain have a normal range of motion while walking [5], and the pain seems to decrease after nearly 10 minutes of gait [8]. It has been shown that back pain can cause a change in the movement pattern of various tasks [9]. Past research indicates that back pain causes a change in the coordination pattern of the trunk during gait [10]. Also, muscle control involves changes in muscle frequency content as well as disruption in the timing of muscle activity [6]. Therefore, it seems that these changes are due to reduced gait speed, following the feeling of need for more movement control.

Trunk and pelvis coordination and their associated muscle control are essential during walking. Coordination between trunk and pelvis segments during gait in a healthy person is out of phase. The complete out-of-phase coordination between the trunk and the pelvis indicates that if the pelvis rotates to the right, the trunk rotates to the left to the same extent. In fact, the movement of the two segments is in a synchronized rhythm but in the opposite direction. In in-phase coordination, the reverse occurs, and the motion of the two segments is in the same direction. The standard deviation of coordination, or the variability of coordination, demonstrates the stability of this coordination over multiple repetitions.

It has been shown that patients with back pain have more trunk rotations than healthy people [6], which is one of the causes of pelvis-trunk coordination disorder during gait. Coordination is one of the indicators of movement control that shows how two joints or two segments move in phase or out of phase with each other. During walking, the pelvis plays an important role in moving forward, and the rotation of the pelvis causes the swing side to move forward. On the other hand, the angular momentum of the pelvis during gait should be controlled by rotating in the opposite direction of the trunk [11]. Hence, pelvis and trunk movement during gait is coordinated and out of phase. During normal gait, the trunk-pelvis coordination changes from in-phase to out-of-phase coordination with increasing speed [5]. However, it is still unclear whether the change in trunk coordination in people with LBP is a direct effect of the back pain (an effect that follows the pain sensation) or is due to the individual's disability. Little is known about the changes in trunk and pelvis coordination following LBP and changes in muscle activity during gait. In the study of Lamoth et al. [5], it was shown that the variability in the coordination between the pelvis and the trunk is low in normal people, indicating the trunk's stiffness during movement.

The management and treatment of back pain is different for different people. Not all patients respond to the same treatment method, and no intervention is completely effective for all patients. There are various methods for treating back pain, and one of the oldest methods for managing physical disorders is aquatic training. Exercising in water is one of the physiotherapy treatments that is increasingly used for various disorders such as back pain. Aquatic exercise is designed as a therapeutic program for individuals to improve neuromuscular and musculoskeletal function. These exercises are performed and supervised by qualified personnel in a swimming pool [12]. Aquatic training is used because of its beneficial effects on the body, including warming up, muscle relaxation, pain relief, treatment of joint stiffness, mental relaxation, and warming up for exercise [13]. Patients can do endurance and strength exercises as well as movements that are normally difficult or impossible on land because of the special and supportive qualities of water (buoyancy, resistance, flow) [13]. Water-based exercises put less pressure on the joints than land exercises and provide support, assistance, and resistance.

The properties of water, such as hydrostatic pressure, buoyancy, and viscosity, increase the range of motion, muscle strength, and endurance and reduce pain, muscle tension, and damage [12]. Pires et al. [14] investigated the effectiveness of a combination of 12 sessions of aquatic training and pain neurophysiology training in 55 patients with back pain. The findings showed a significant interaction effect of treatment conditions on pain intensity. In this regard, Yelfani et al. [15] evaluated the effect of six weeks of aquatic training on the pain, disability, and performance of trunk and pelvic girdle muscles in 24 women with chronic back pain. The results showed a significant improvement in pain, disability, and trunk muscle function. Previous research has also shown that aquatic training increases back strength in middle-aged women with back pain and improves back pain in older men with back pain after 12 weeks of aquatic training [13]. Intold et al. [16] showed that participation in aquatic training programs can be beneficial in reducing the pain of patients with back pain. Further, Hossein Abadi et al. [17] showed that doing 12 weeks of aquatic training can reduce pain and improve patients' functional capabilities, such as sitting, standing, sleeping, and daily activities among overweight women with back pain. Therefore, it seems that aquatic training can help reduce pain and improve functional activities in patients with back pain and that reducing pain plays an important role in improving the performance of patients.

In this regard, one of the water exercise methods that can help improve the gait pattern of patients is a gait in water [18]. Because gaiting in water lessens the load on the joints, it can help one return to their normal range of motion more comfortably [18]. Therefore, it seems that the reduction of the applied pressure on the joints of the vertebrae and the subsequent reduction of pain and fear of pain while gaiting in water, as well as the greater resistance that physiologically exerts on the muscles, can return the normal pattern of movement of the pelvis and trunk during gait. Therefore, exercising in water is suitable for improving the return of the normal rhythm of waist and pelvis movement. As such, it is hypnotized that aquatic training reduces pain and improves the gait pattern. Because no research has been conducted on the effect of aquatic training on trunk-pelvis coordination in patients with LBP, the following question arises: what is the effect of water training on trunk and pelvis coordination and range of motion? Thus, this study aims to investigate the effect of eight weeks of training in water on the kinematic and continuous relative phase (CRP) trunk-pelvis coordination during gait in people with chronic back pain.

MATERIAL AND METHODS

A quasi-experimental and comparative study was conducted with a pretest-posttest design. The statistical population consisted of adult men (30 to 50 years old) with non-specific chronic back pain who met the following criteria: had a back pain history exceeding three months, was devoid of neurological symptoms and widespread lower limb pain (e.g., sciatica symptoms), and had not undergone any surgical procedures or specialized treatments to alleviate back pain. Moreover, the Roland Morris Disability Questionnaire score of patients had to be 4 or higher. This study used participants who did not do regular physical exercises. Subjects with dehydration of the disc, protrusion, protrusion, extrusion, and degeneration were excluded from the study if present. A clinician performed all stages of clinical evaluation. Patients agreed to refrain from physical therapy for two months, except for experimental treatments. Those with increased back pain and inability to continue treatment were excluded from the study.

A purposeful and convenient sampling process was employed to assign 25 individuals to the control group (Ctr group) and 25 individuals to the experimental group (Hyd group) using G*power software (with a test power of 0.8). In the experimental group, subjects participated in the exercises, and the control group continued their lives under supervision and participated in the study tests only in the pretest and posttest. Pretests were conducted before the training program started. In order to measure the angle of the segments, IMU sensors made by Noraxon were used, and the validity and reliability of these systems have been confirmed in comparison with the Vicon motion analysis system [19]. For this purpose, a sensor is placed on each of the pelvic segments (between the superior posterior iliac spines, PSIS) and the trunk (corresponding vertebrae in line with the sternum lower than the last cervical vertebra) [20]. Moreover, the calibration steps were performed using the IMU device software. As the subjects walked on the 10-meter path, kinematic information was recorded in a synchronized manner along with the impact time information (foot switch). Kinematic data, including the absolute angle of the horizontal plane of the trunk and pelvis segments, were recorded at a rate of 200 Hz. Information on 10 consecutive steps is required for variability analysis [6].

The training in the water included three weekly sessions for the training group. The temperature of the pool water varied between 27 and 30. The aquatic training protocol entailed walking at different velocities in the pool. For this purpose, the participants performed the exercises in a pool with a water level above their sternum. The exercise protocol included 30 minutes of walking in water. The first and last five minutes of each exercise session were spent warming up and cooling in the water. In the first two weeks, the walking speed was adjusted based on the person's normal and desired walking speed. In the third week, the speed of the rhythm increased to three times the person's desired walking speed. In the fifth week, the walking speed was increased by six times the person's desired walking speed, and in the seventh week, the walking speed was increased by nine times the person's desired walking speed [18]. The training intensity of the subjects was adjusted using a metronome connected to the speaker.

In order to process the data, first, the angle data of the sensors was filtered by a 6 Hz low-pass Butterworth filter. Subsequently, the angles related to the horizontal plane movement (rotation) of the pelvis and trunk segments were extracted in five intermediate steps. In the next step, the difference between the minimum and maximum rotation angle of the trunk and pelvis during walking was calculated, and the range of motion of rotation of these segments was computed. After recording the trunk and pelvis rotation angles, CRP and variability of coordination between these segments were calculated [6].

$$\varphi(t) = \tan^{-1}\left(\frac{\omega_i(t)}{\theta_i(t)}\right)$$

$$CRP = \varphi_p - \varphi_d$$

Here, φ is the phase angle of the segment, ω is the normalized angular velocity, and θ is the normalized angular position of the segment.
The following relations were used to calculate the speed (w) and the normalized angle (θ).

$$\theta_i = \frac{2 \times [\theta_i - \min(\theta_i)]}{\max(\theta_i) - \min(\theta_i)}$$

$$\omega_i = \frac{\omega_i}{\max[\max(\omega_i), \max(-\omega)]}$$

After calculating the CRP in all the data, time normalization of the data was done. The mean and standard deviation of the CRP were extracted in each dataset. The mean of CRPs was used as a coordination index, and the standard deviation of the CRPs was employed to determine the degree of variability in coordination. The CRP ranged from 0 to 180 degrees, with angles closer to zero indicating more out-of-phase coordination and those closer to 180 degrees indicating more in-phase coordination.

Descriptive statistics were used to describe the data, and the Shapiro-Wilk test was applied to check the normality of the data distribution. The Levene test was used to determine the homogeneity of variances, and independent and paired t-tests were utilized to compare variables in the two groups before and after training. The significance level was set to P<0.05 for all tests.

RESULTS

The Mean±SD values of height, weight, and age in the control group were 170.62±6.8, 81±6.63, and 44.74±5.92, respectively. In the experimental group, they were 167.16±7.62, 78.32±8.01, and 43.66±5.32, respectively. Table 1 presents the results of descriptive statistics, including the mean and standard deviation, as well as the minimum and maximum range of motion of the trunk and pelvis before and after the implementation of the exercise program in the experimental and control groups. Likewise, Table 2 displays the results of descriptive statistics, including the mean and standard deviation as well as the minimum and maximum values of coordination and variability of trunk and pelvis coordination in experimental and control groups before and after implementing the training program.

Table 1. Results of descriptive statistics including mean and standard deviation as well as the minimum and maximum range of motion values of trunk and pelvis

Variables	Condition	Average	SD	Max	Min	t	Sig
Trunk ROM Hyd Group	Pre test	10.89	1.72	16.62	8.53	9.27	0.00
	Post test	8.01	1.8	15.5	5.87		
Trunk ROM Ctr Group	Pre test	10.46	2.23	16.62	6.48	1.97	0.06
	Post test	10.09	1.8	15.5	6.45		
Pelvis ROM Hyd Group	Pre test	8.11	1.57	9.88	4.5	1.76	0.09
	Post test	8.76	1.22	11.23	5.3		
Pelvis ROM Ctr Group	Pre test	7.94	1.66	16.62	4.6	1.87	0.07
	Post test	7.03	1.34	10.74	5.04		

Hyd=Aquatic training Group, Ctr=Control Group

Table 2. Results of descriptive statistics including mean and standard deviation as well as the minimum and maximum CRP and Variability

Variables	Condition	Mean	SD	Max	Min	sig	t
CRP Hyd Group	Pre test	87.72	4.64	98.19	81.46	0.00	23.97
	Post test	35.61	8.36	55.75	16.47		
CRP Ctr Group	Pre test	86.75	4.25	96.95	80	0.9	0.19
	Post test	86.71	2.95	93.58	82.37		
Variability Hyd Group	Pre test	37.35	2.97	44.87	31.83	0.00	12.56
	Post test	23.06	5.45	43.96	15.36		
Variability Ctr Group	Pre test	37.52	4.03	44.87	30.56	0.21	1.25
	Post test	36.32	5.29	43.96	15.36		

Hyd=Aquatic training Group, Ctr=Control Group

Diagrams of the angular changes of the trunk and pelvis during walking as a percentage of the walking cycle are shown in Figure 1.

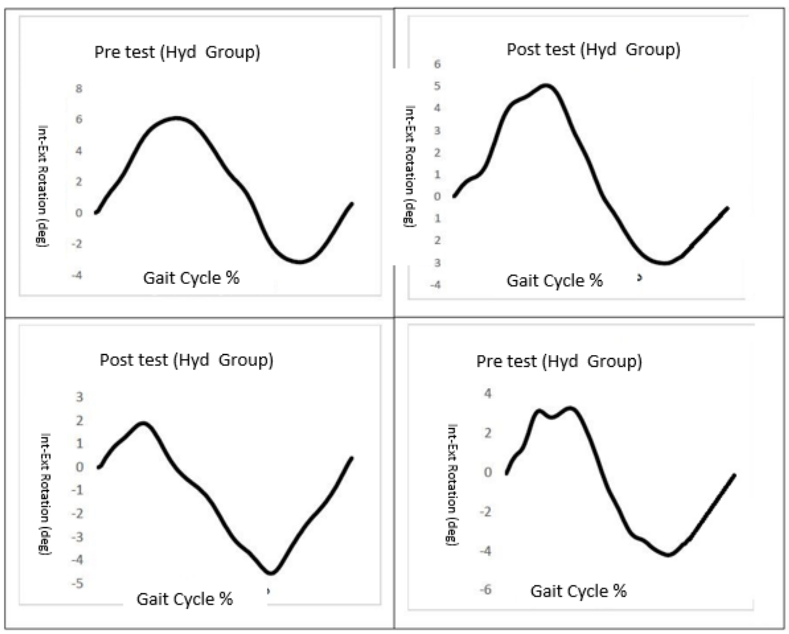

Figure 1. ROM of trunk and pelvis in aquatic training group in pretest and post test of one subject

The results of the within-subjects comparison using the paired t-test are presented in Tables 1 and 2. Moreover, the results of the between-subjects comparison using the independent t-test are presented in Table 3. Statistical comparisons indicate that aquatic training decreases the angle of the trunk while walking ($P<0.05$) and increases the range of motion of the pelvis, but not significantly. Also, the results of this research show that after exercising in water, out-of-phase coordination in trunk and pelvis movement increases ($P<0.05$), and subsequently, variability in coordination decreases ($P<0.05$).

Table 3. The Independent t-test results of ROM, CRP and Variability of Trunk and Pelvis between Control and aquatic training group

Variables	Condition	Leven	sig	t
Trunk ROM (deg)	Pre test	0.055	0.93	0.084
	Post test	0.053	0.00	5.66
Pelvis ROM (deg)	Pre test	0.176	0.32	0.91
	Post test	0.36	0.00	5.67
CRP (deg)	Pre test	0.36	0.43	0.79
	Post test	0.13	0.00	25.66
Variability (deg)	Pre test	0.57	0.45	0.76
	Post test	0.59	0.00	10.67

DISCUSSION

This study aimed to investigate the effect of eight weeks of water walking training on kinematics and pelvis-trunk coordination during walking among people with chronic back pain. The results of statistical comparisons show that training in water reduces the range of motion of the trunk during walking and leads to a slight increase in the pelvis's range of motion after training. The results of this study also demonstrate that, following eight weeks of aquatic training, there is an increase in out-of-phase coordination in trunk and pelvis movement (the number approaching zero indicates an increase in out-of-phase coordination, and as the number increases closer to 90 degrees, less coordination occurs between the two segments) and, consequently, a decrease in coordination variability, which is a measure of more stable movement.

The findings of this study regarding the effectiveness of aquatic training on improving the walking of patients with back pain are confirmed by other studies that indicate the positive effect of water therapy on improving the functional capabilities of patients with back pain. In this regard, Hossein Abadi et al. [17] highlighted the positive effect of 12 weeks of aquatic training on improving functional abilities, including walking, among women with chronic specific back pain. Baena-Beato et al. [19] mentioned the positive effect of aquatic training on pain reduction and the quality of life of patients with chronic back pain. Kim and Chang [18] stated that only four weeks of water walking training (such as the training protocol used in this study) can improve the walking ability of people with stroke. Also, Yelfani et al. [15] emphasized that six weeks of exercise in water can help reduce pain and improve balance and muscle endurance in patients with chronic back pain.

The results of this study indicated the positive effect of aquatic training on walking in patients with back pain. The unique properties of water, including buoyancy and flow resistance, allow patients with back pain to perform movements that are normally difficult or impossible on the ground [13]. Aquatic training lowers the compressive pressure brought on by weight on the vertebrae joints, which is one reason for chronic back pain. It also improves range of motion, muscle strength and endurance, pain, and muscle tension thanks to the buoyancy and viscosity of water [12]. In this regard, this study was conducted with the assumption that walking in water can correct the normal range of motion, especially in the trunk and pelvis, which are most affected by back pain [6]. As a result, this study confirmed this assumption, showing that walking with a certain frequency and gradually increasing the intensity in water can improve people's ability to walk outside water.

LBP affects daily life activities and job performance. It also affects the kinematics of joints during common movements such as gait [23, 24]. The movements of the trunk and pelvis are highly important in walking, especially in the forward part of walking. It seems that these segments are greatly affected by back pain [25]. In previous studies, it has been shown that CRP is affected in people with back pain [6]. While walking, it is necessary to maintain trunk and pelvis coordination and muscle control of these segments to maintain a stable balance so that the energy consumption during walking is minimized and the person can maintain their balance against destabilizing conditions [6]. Coordination is one of the indicators of movement control that shows whether two joints or two segments move together in phase or out of phase rhythm. During walking, the pelvis and trunk play an important role in moving forward, and the rotation of the pelvis causes the swing side to move forward. Walking therefore involves coordinated, out-of-phase hip and trunk movement. This means that the rotation to one side of the pelvis is accompanied by the rotation of the trunk to the opposite side to control the angular momentum of the pelvis in the horizontal plane [11].

Previous researchers have shown that following back pain, the coordination of the trunk and pelvis is in phase, and a similar movement occurs by the two segments [25]. Furthermore demonstrated is the fact that in-phase coordination observed in back pain sufferers also exists in other patients, including those with stroke and Parkinson's disease [26]. Thus, it seems that the in-phase coordination of the trunk and pelvis in people with back pain is a compensatory reaction that is related to the change in the extent and timing of trunk rotation in the walking cycle. On the other hand, it has been shown that patients with back pain have more trunk rotations than healthy people [6, 26], which is one of the reasons for hip-trunk coordination disorder during walking. In fact, due to back pain and the possible presence of pain or fear of pain in the joints near the pelvis, the range of motion of the pelvis is reduced. The results of this study showed that this compensatory strategy can be modified after training in water. According to the present study's findings, the trunk's range of motion during walking decreases significantly after training in water. It seems that the reduction of the range of motion of the trunk due to the possible effects of training in water, such as strengthening muscles or reducing pain, has improved the ratio and timing of trunk-to-pelvis movement and subsequently increased the out-of-phase coordination between these two segments. Likewise, a previous study revealed that people in the control and healthy groups exhibited more stability in their hip and trunk coordination than people with back pain and that the variability of the coordination index in different repetitions was lower [25]. The results of this study also confirmed the effectiveness of aquatic training, showing that the variability of pelvis-trunk coordination decreases after aquatic training, which indicates greater stability in movement. The limitation of this study was the lack of investigation of the durability effect of training in water, which was not possible due to the lack of access to subjects.

CONCLUSION

Based on this study's results, eight weeks of water walking training at different speeds can increase hip and trunk coordination while walking due to the features of aquatic training, such as buoyancy and flow resistance. This improved coordination, in turn, reduces the trunk range of motion. On the other hand, the results of this study pointed to a decrease in the variability of coordination during walking of patients with back pain after the implementation of the exercise, which indicates that the walking pattern in high repetitions is closer to normal walking. According to this study's results, walking in water at increasing speeds can be used as a suitable method to correct the compensatory hip-trunk movement pattern during walking among people with chronic non-specific LBP.

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اثر هشت هفته تمرین در آب روی کینماتیک و فاز نسبی پیوسته تنه-لگن در افراد مبتلا به کمردرد مزمن غیر اختصاصی

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چکیده:

هدف این مطاللعه بررسی اثر هشت هفته تمرین در آب روی کینماتیک و فاز نسبی پیوسته تنه-لگن حین راه رفتن افراد مبتلا به کمردرد مزمن بود. در این مطالعه نیمه تجربی با طرح پیش آزمون-پس آزمون ۵۰ آزمودنی مبتلا به کمردرد غیر اختصاصی مزمن به ۲ گروه کنترل و تجربی تقسیم شدند. اطلاعات کینماتیکی تنه و لگن با استفاده از سنسورهای آی ام یو مدل نوراکسون اندازه گیری شد. گروه کنترل فعالیت های تحت نظارت خود را ادامه می داد و گروه تجربی به مدت هشت هفته و هفته ای سه جلسه تمرین راه رفتن در آب را با فرکانس های افزایشی گام انجام میداد. اطلاعات کینماتیکی برای محاسبه دامنه حرکتی تنه و لگن و همچنین محاسبه فاز نسبی پیوسته تنه و لگن مورد استفاده قرار گرفتند. به منظور تحلیل آماری از آزمون تی مستقل و وابسته استفاده شد ($P \leq 0.05$). نتایج این مطالعه نشان داد تمرین در آب دامنه حرکتی تنه را کاهش داده ($P<0.05$) و هماهنگی بین تنه و لگن که از نوع غیر هم فاز است را افزایش می دهد ($P<0.05$). نتایج این مطالعه همچنین نشان داد تغییرپذیری در هماهنگی بین تنه و لگن نیز به دنبال تمرین در آب به طور معناداری افزایش می یابد ($P<0.05$). نتایج این مطالعه نشان داد انجام هشت هفته تمرین راه رفتن در آب با سرعت های افزایشی به دلیل خواص تمرین در آب نظیر شناوری و مقاومت جریان موجب کاهش دامنه حرکتی تنه در افراد کمردرد و متعاقباً استفاده بیشتر از لگن و بازگشت الگوی راه رفتن به الگوی نرمال می شود. افزایش هماهنگی و تغییرپذیری در ماهنگی تأیید کننده بازگشت الگوی حرکتی تنه و لگن به حال عادی هستند. با توجه نتایج مطالعه تمرین راه رفتن در آب با سرعت های افزایشی می تواند به عنوان یک گزینه درمانی مناسب برای بیماران مبتلا به کمردرد به منظور بهبود راه رفتن این افراد در نظر گرفته شود.

واژگان کلیدی: تمرین در آب، راه رفتن، هماهنگی تنه-لگن، کینماتیک.