Changes in Quadriceps and Hamstring Co-Contraction Following Landing in Microgravity Condition: Comparing Females with Different Activity Levels

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ABSTRACT

Purpose: This study aimed to examine the differences in the co-activation of the rectus femoris (RF) and biceps femoris (BF) using the co-contraction index (CI) in aquatic and land environments during a drop-landing task in active and non-active females.

Methods: In this casual-comparison study, 10 active and 10 non-active females volunteered to participate. The CI was calculated from recorded surface electromyographic (SEMG) activity of the RF and BF. To calculate CI, the amount of overlap between the linear envelopes of the agonist and antagonist muscles was found and divided by the number of data points. MathLab software (version 10) was used to process row data. Also, 2-way analysis of variance (ANOVA) assessed differences between groups and environments.

Results: Results indicated that the CI was not affected by activity level in pre- and post-contact ($P>0.05$) while it was significantly higher ($P<0.05$) in land environment compared to the aquatic environment.

Conclusion: Our findings show the differences in co-contraction of knee muscles between different environments. Our measure of co-contraction was lower in water compared to land, with no difference between the active and non-active groups. This may indicate that regardless of activity level, an aquatic environment may be an appropriate choice as an early phase in rehabilitation process.

Keywords:
Aquatic environment, Landing biomechanics, Activity level, Co-contraction

1. Introduction

Plyometrics is considered a high-intensity conditioning program. It consists of explosive exercises that require muscles to adapt rapidly from eccentric to concentric contractions [1, 2]. Plyometrics is believed to enhance muscle force and power production during the concentric phase of a given movement compared to muscle contraction solely due to concentric action [3]. In many sports, plyometric drills have been shown to play an essential role in increasing the explosive power of the low-

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er extremities [3]. Despite many benefits of jump-landing training, there is an association between musculoskeletal injuries and delayed-onset muscle soreness due to high intensity of the movement and compression forces on the joints [4]. Epidemiology data indicate that both female and male athletes who are involved in repetitive landing experience lower extremity injuries which consist 55% to 65% of all injuries [4].

Several investigations indicate the importance of neuromuscular mechanisms in joint stability [5-8]. Markolf et al. (1981) showed the enhancing mechanical joint stability via the simultaneous contraction of quadriceps and hamstrings to generate compressive forces and increase knee stiffness up to 10 times [5]. The knee stiffness which is attained by muscle co-contraction can reduce the stresses on passive structures, therefore decreasing the risk of ligament rapture. The regulation of joint stiffness through the continuous modulation of co-contraction may be an efficient mechanism to protect the joint against perturbations [8].

Additionally, observations reveal that plyometrics training in an aquatic environment yields similar results to an equivalent land-based plyometrics training program [9-12]. Aquatic settings are beneficial not only for rehabilitation but also for conditioning because of the unique properties of water, especially buoyancy and resistance resulting from its viscosity [9-10]. The buoyant properties of water reduce pressures on the musculoskeletal system, thereby decreasing the risk of overuse injuries such as tendinitis and stress fractures [13-15]. As with any alternative therapy or training method, questions arise about the comparability of neuromuscular activation in water to equivalent exercise modes on land.

Presumably, the level of physical activity may affect neuromuscular activity patterns [16]. Therefore, differences in muscle strength, attained by training, between sedentary and athletic individuals may influence the neuromuscular activity pattern [16]. However, whether landing in water, as an alternative mode of exercise, can lead to changes in co-contraction of knee joint muscles between land and aquatic environment remains unknown. The identification of possible differences in co-contraction regulation between active and non-active women would help us better understand the neuromuscular mechanisms possibly related to the difference in knee injury rates between active and non-active women. The present study compared muscular co-contraction levels on landing from a jump among women with different activity levels. Additionally, this research studies the possible difference between co-contraction levels in aquatic and land environment.

2. Materials and Methods

To examine the hypotheses, a causal-comparison study was used. Ten active women with mean(SD) age of 21.2(2.7) years, height of 168(5) cm, weight of 63.15(7.73) kg, fat percentage of 25.2(4.1), and history of physical activity of 7.8(3) years and 10 non-active women with mean(SD) age of 20.3(2.0) years, height of 163(5) cm, weight of 60.10(7.73) kg, fat percentage of 25.9(2.1), and no history of physical activity) were selected and volunteered from female university students through nonprobability-convenient sampling method. All participants had no history of ACL injury or acute/chronic lower extremity injury within the 6 months before data collection. Physically active was defined as participating in physical activity for at least 20 minutes per session, 3 times per week [17]. All participants read and signed an informed consent form. The study was approved by the University Institutional Scientific Review Board. All data were sampled from the dominant lower extremity (i.e. limb used to kick a ball for maximal distance).

Subjects attended 2 sessions; one habituation session and one testing session. At the beginning of the habituation session, after anthropometric measurements, subjects participated in a standardized general warm up and dynamic stretching exercises lasting approximately 15 seconds for each major muscle group. Subjects were then instructed in and practiced the isometric and dynamic test exercises. Maximum voluntary isometric contractions were performed at 60 degree of knee flexion for the knee joint muscles against resistance. In addition to the isometric tests, dynamic movements, including drop-landing (DL) were performed. After preparation, all participants were asked to do 3 times DL with hands on their waists (to eliminate effect of arm motion) and land with both feet on the ground. The drop-landing performed from a height of 40 cm [18, 19]. The test session included the same general warm-up and dynamic stretching, followed by 3 minutes of rest and then 3 repetitions of voluntary isometric contractions (MVICs) performed for involved muscles for 6 seconds with 1 minute of rest between each trial. Subjects were instructed properly, including landing softly with feet approximately shoulder width apart, maintaining alignment of knees over toes and shoulders over knees, as well as stabilizing in a partial squat position. Aquatic exercises were performed in a swimming pool which water depth was matched to the xiphoid process of each subject. Throughout the laboratory experiment, the water temperature of the pool was maintained at 30°C, a degree assumed to be thermoneutral for exercising humans. The air temperature of the laboratory during the study was set at 24°C to ensure similar skin temperatures across the wet and dry conditions. All tests were performed between 9 to 12 AM in the midst of winter.

Telemetric surface EMG was used to investigate muscle activity in the biceps femoris (BF) and Rectus Femoris (RF). These muscles were chosen because of their role in stability of knee joint. EMG data were acquired with an 8-channel telemetric EMG system (DataLOG MWX8, Biometrics Inc.) and streamed continuously to a SONY laptop. This system which was composed of an A/D convertor, an amplifier, and a software for data analysis, collected the EMG signals from surface electrodes (Amplification gain 10^3 mΩ, with a bandwidth ranging from 20 to 450 Hz, common mode rejection 110 db). Differential surface electrodes (Ag-AgCl; SX 230-1000, Biometrics; interelectrode distance of 20 mm, electrode diameter of 10 mm) were placed over muscles parallel to the direction of action potential propagation to monitor muscle activity as described by Perotto (1994) [20]. The ground electrode was placed on the right ulnar styloid process. Cross-talks and proper electrode placement were verified by manual muscle testing, proposed by Hilsop (1995). Previous works support EMG as a reliable method to assess the activity of muscles during dynamic movements such as jump-landing [21] and also in water environments [22].

Several methodological notes should be considered when recording EMG signals during locomotion in aquatic environment. The important concern for EMG recording in water is waterproofing the EMG leads and monitoring the EMG signal for changes that might indicate water leakage. To preserve the integrity of the EMG signals on land and particularly in water, the skin at each site was shaved, abraded, and cleaned with alcohol before electrode placement.

This waterproofing technique is reportedly reliable across the environments. The surface electrodes were fixed with the extreme care using adhesive tape (3M Co. Ltd., USA) before being covered with an 8×8 transparent adhesive film (Hydrofilm, 3M, St. Paul, MN, Austria) to prevent water from contacting the skin-electrode interface and electrical leakage during the tests. This method was used because no electrodes or remote telemetry equipment is commercially available for determining muscle activities in water. It was essential that the surface electrodes be adhered to the skin surface, because failure to do so would have resulted in considerable movement artifact. The covered electrode was sprayed with a waterproof adhesive (Bison International Ltd). Silicone aquarium sealant (Selsil Ltd, Turkey) was applied around electrodes to prevent water infiltration. Once the sealant had cured, a piece of adhesive tape was placed over each electrode. Taping was done in a manner that allowed free movement of the muscles tested during exercise.

To prevent damage to the adhesive due to sweat or excessive movements, aquatic exercises were performed after completion of the land exercises and the electrodes were not repositioned between land and aquatic environments. Previous studies show that waterproofing techniques do not influence EMG amplitude during land exercises [24]. In this study, the timing of foot contact was synchronized with the EMG system using a customized waterproof foot switch. The foot switch marked the instant of contact. Fat percentage was calculated through a regression equation suggested by Pollack and Jackson (1987) [25].

MathLab software(version 10) was used to process row data. With regard to MVIC data, to reduce the variability, the first and last second of each trial were discarded. Sampled data were smoothed with a 10 to 400 Hz band pass fourth-order zero-lag Butterworth filter and a centered RMS algorithm with 100 ms time constant. The peak RMS amplitude was used to normalize the EMG data during tasks. For jump-landing trials, the EMG signals were full wave rectified and then smoothed with a band pass fourth-order zero-lag Butterworth filter from 10-400 Hz. Next, they were digitally processed using a centered RMS algorithm with a 25 ms window. To determine the overlapping area of the normalized EMG signals of biceps femoris and rectus femoris muscles, a custom program was used as described by Unnithand (1996) [26]. This area of overlap (in percentage of MVIC) of each muscle represented the co-contraction (simultaneous muscular activation) of muscles tested in the study.

Data were analyzed by SPSS statistical routine (version 16). The normality was assessed using the Kolmogrov-Smirnov test. Separate 2-way repeated measures ANOVAs (environment×activity level) were used to analyze co-contraction at two different times: before and after foot-ground contact during landing from drop-jump. The α level was set at 0.05 with Bonfferoni correction.

3. Results

Results showed no significant differences in co-contraction between activity level before foot contact during landing from a jump ($F=0.01$, $P=0.92$) and the activity level x environmentinteraction ($F=0.005$, $P=0.95$). The effect of environment on co-contraction level was significant ($F=3.75$, $P=0.035$). Table 1 presents the results regarding main effects.

Table 1. Means and SDs of muscular co-contraction (MVIC%) before foot-ground contact of active and non-active women in landing from drop-jump.

Muscular co-contraction	Water Mean(SD)	Land Mean(SD)	F, P-value
Active	5.1(1.7)	9.3(2.7)	F=3.75, P=0.035*
Non-active	4.8(0.6)	8.8(2.1)	
F, P-value		F=0.01, P=0.92	
F, P-value (interaction)		F=0.005, P=0.95	

*Statistically different from land environment.

PHYSICAL TREATMENTS

Table 2. Mean and SD of muscular co-contraction (MVIC%) after foot-ground contact of active and non-active women in landing from drop-jump.

Muscular co-contraction	Water Mean(SD)	Land Mean(SD)	F, P-value
Active	4.1(0.7)	10.3(1.7)	F=4.34, P=0.045*
Non-Active	5.8(0.6)	10.7(2.3)	
F, P-value		F=0.03, P=0.07	
F, P-value interaction		F=1.1, P=0.61	

*Statistically different from land environment.

PHYSICAL TREATMENTS

No differences in co-contraction after foot contact were found between activity level group (F=0.03, P=0.07). With regard to the environment, individuals on land had significantly greater co-contraction levels than on water environment (F=4.34, P=0.045). There was not an activity level x environment interaction (F=1.1, P=0.61). Table 2 presents the results regarding main effects.

4. Discussion

This study aimed to compare co-activation of knee muscles during jump-landing task in water and on land between active and non-active adult females. To our knowledge, this study reports for the first time co-contraction during jump-landing tasks in water. The investigated subjects were immersed in water at xiphoid level where the apparent body weight is about 70% of body weight [27]. Based on the results, the co-activation of muscles before and after foot contact showed significant differences (decrease in values).

Before foot contact phase of landing, muscle activity commences to prepare for impact with the ground. This pre-activation reflects the strategies which CNS anticipate in order to absorb the impact. Differences in neuromuscular responses between aquatic and land environment in current study support the findings obtained by previous studies showing that EMG activity of lower extremities during underwater exercises decreased compared to that during similar exercises on land [28-30]. Bressell et al. (2011) also proposed that hydrostatic pressure and buoyancy may result in less stabilizing role in trunk muscles during locomotion in water, which reduce their EMG activity [31]. The low EMG amplitude is directly associated with the decreased muscle activity. Pöyhönen and Avela (2002) concluded that immersion in water induced deterioration in neuromuscular function via impulses from mechanoreceptors over the entire body. They observed a substantial reduction in the Hoffman reflex during immersion in water [30]. The other proposed mechanism may be related to hydrostatic pressure. The hydrostatic pressure stimulates mechanoreceptors mechanoreceptor impulses that trigger the presynaptic inhibitory mechanisms via interneuron pathways. Furthermore, partial weightlessness may have some influence. Findings from the previous studies on microgravity simulations indicate that the reduced effect of gravity during immersion is related to decreased stimulation of gravoreceptors in muscles, vestibular system, and skin [32].

Water environment results in significant decrease in co-contraction level after initial contact. In many everyday movements, our interactions with the environment are often characterized by large transient reaction forces, especially during landing. Upon landing the body experience impact forces, which are input signals into locomotor system. These forces can be modified by different factors such as task and surface [33]. Furthermore, muscle activity has to be modulated appropriately in reaction to the ground reaction force (GRF) to absorb the kinetic energy of the body. Previous investigations showed that peak GRF and impulse significantly reduced (33%-54% and 19%-54%) when performing jump-land exercise in water compared to land [34]. Donoghue (2011) reported that peak landing GRF occurred after 50 ms in counter-movement jump. In addition, the rate of force development significantly reduced in water. Since, the reduction in GRF has been demonstrated in water, this may be an explanation for deceased muscle activity.

Training background does not have any effect on co-contraction in water or land environment. These results do not support the evidence indicative of co-contraction caused by training [8]. Previous studies found that sedentary women showed higher levels of co-contraction compared to active women before heel strike during walking. However, it should be noted that our study subjects were recreationally active women, not necessarily elite athletes. The conclusion drown from this study can only be applicable to women who are recreationally active.

The current study has several limitations. Our results are limited to observations in healthy female subjects. To generalize our findings, further studies are needed to compare both genders, different athletic sports, physically active and pathologic population. Also jump-landing tasks were performed in a laboratory setting with various equipment attached to the subjects. The examination of the lower extremity and GRF with EMG would be helpful to study jump-landing tasks in water.

Our findings show the differences in co-contraction of knee muscles between different environments. Our measure of co-contraction values were lower in water than those on land, with no difference between the active and non-active groups. This may indicate that regardless of activity level, an aquatic environment may be a proper first step in training. Environmental observations may point toward aquatic plyometrics as being safer than land-based plyometrics. Researchers, coaches, and athletic trainers should recognize that performing jump-landing movements in aquatic environment alter pre-landing and post-landing neuromuscular activity of lower extremity muscles as joint stabilizers. The present findings provide valuable information that will help with the design of water-based exercise programs that can be safely applied for the rehabilitative and recreational purposes. We propose the use of aquatic environment as an early phase in rehabilitation process.

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Conflict of Interests

The authors declared no conflict of interest.

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