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Muscle activity during different styles of deep water running and comparison to treadmill running at matched stride frequency

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ABSTRACT

The purpose of this study was to compare muscle activity during deep water running (DWR) and treadmill running on dry land (TMR) as well as to investigate effect of stride frequency (SF) on muscle activity while using different styles of DWR (high-knee and cross-country styles, DWR-HK and DWR-CC, respectively). Eight subjects participated in this study. The baseline condition consisted of TMR at the preferred stride frequency (PSF). The remaining conditions consisted of DWR-HK and DWR-CC at PSF, PSF−15%, and PSF+15%. Muscle activity was recorded from the rectus femoris, biceps femoris, tibialis anterior, and gastrocnemius. Rectus femoris and biceps femoris muscle activity during DWR-CC-PSF were significantly greater than that of TMR-PSF ($P < 0.05$). However, rectus femoris muscle activity during DWR-HK-PSF was significantly lower than that of TMR-PSF ($P < 0.05$). Gastrocnemius muscle activity during both DWR-HK-PSF and DWR-CC-PSF were significantly lower than that of TMR-PSF ($P < 0.05$). Furthermore, muscle activity from all tested muscles during DWR-HK and DWR-CC increased with increasing SF ($P < 0.05$). These observations indicated that muscle activity is influenced not only by running in the water but also by the style of DWR (DWR-HK, DWR-CC) used.

1. Introduction

Deep water running (DWR) has been used as a cross-training alternative to running on dry land since running performance has been shown to be maintained [1]. However, there has been an inconsistent effect of DWR training on maximal oxygen uptake which has either not changed [1] or increased [2]. The lack of consistent training responses seems to indicate that the critical features of DWR necessary for a cross-training stimulus have not been identified.

There is a strong body of research on physiological responses during DWR [2]. It may be that by understanding the mechanics of DWR will lead to a better understanding of how to use DWR to cross-train for on-land running. More specifically, it may be that the manner in which muscles are activated is a critical feature of DWR that allows for a cross-training stimulus.

There is some evidence that muscle activity patterns are similar during DWR and treadmill running (TMR) [3,4]. However, this seems to be the case more so when muscle activity patterns during a higher rating of perceived exertion (RPE) during DWR are compared to lower RPE during TMR [3]. During DWR, RPE is related to stride frequency (SF) [3]. It may be that if a similar SF was used during DWR and TMR that muscle activity would be comparable. Therefore, the main purpose of this study was to compare muscle activity during DWR and TMR when SF was matched.

A possible confounding factor when comparing results from different DWR studies is that there are different DWR styles used by runners (e.g. high-knee style, DWR-HK: cross-country style, DWR-CC) since the kinematics of the different styles are unique [5]. However, no research is available regarding the muscle activity during DWR using different running styles. Such information is important in order to refine the use of specific DWR style as a cross-training alternative to running on dry land. Therefore, a second purpose of this study was to compare muscle activity during DWR-HK and DWR-CC. We extended this work to include manipulation of SF during the DWR styles in order to gain a better appreciation of how muscle activity compared across different exercise intensities.

2. Methods

2.1. Subjects

Eight subjects (6 females, 2 males; means ± SD: age = 40.0 ± 6.5 years, height = 173.1 ± 7.2 cm, mass = 66.9 ± 11.7 kg) participated in this study. The subjects were free from any acute or chronic diseases at the time of the study. The study was approved by the University's

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Institutional Review Board and written informed consent to participate in the study was obtained from all subjects.

2.2. Instrumentation

Muscle activity was recorded (1500 Hz) using a telemetry electromyography (EMG) system (TeleMyo 2400T, G2, Noraxon, USA). Muscle activity was recorded from the following muscles on the right side: rectus femoris (RF), biceps femoris (BF), tibialis anterior (TA), and lateral head of the gastrocnemius (GA). An electrode (Dual electrodes-272, Noraxon) was placed on the muscle belly in line with the direction of the muscle fibers [6] with a ground placed in combination with the RF lead as per manufacturer design. Prior to electrode placement, the skin surface was abraded using a skin preparation gel (Skinpure, YZ-0019, Nihon Kohden, Japan) and then cleaned with alcohol pads (Suzuran, Japan). The electrodes were covered with foam pads (Foam Pad, 75A, Nihon Kohden, Japan) [3,7]. The leads (1.5-m long) were connected to a transmitting unit so that the unit could be maintained above water during DWR at all times.

During DWR, subjects did not wear any shoes while they wore shoes during TMR. All DWR conditions were conducted in a rehabilitation pool (3 m wide × 3 m long × 3 m deep) with water temperature maintained at 28 °C. Subjects wore a full-body dry suit (BARE Watersports Ultra Dry Suit) during DWR [3]. Furthermore, the subjects wore a floatation device (Aqua Jogger, Excel Sport Science, USA) which was tethered to the side of the pool.

2.3. Experimental procedures

During practice session, subjects were given a description of the DWR-HK and DWR-CC. The DWR-HK was described as being similar to stair stepping, marching in place, or bicycling with little horizontal displacement present. The DWR-CC was described as being similar to running on dry land or like cross-country skiing.

After practicing DWR, subject's test-speed and preferred SF (PSF) was obtained on the treadmill. The test-speed was determined by having the subject self-select a running speed that could be maintained for a 20–30 min. The speed display was hidden from the subject with the subject giving instructions to increase or decrease speed until the desired speed was reached. Each time the subject selected a speed, PSF was determined by measuring the time to complete 20 strides. This process was repeated three times with the test-speed and PSF determined by averaging across the three trials.

The subject returned to the laboratory for a second time at least 2 days after completing the practice session. Following a warm up, subjects were instrumented so that EMG could be recorded. Then, 5-s isometric maximum voluntary contraction (MVC) of tested muscle was made on land before performing running trials.

The baseline condition consisted of TMR at the test-speed and PSF (TMR-PSF). The remaining conditions consisted of DWR using either DWR-HK or DWR-CC at PSF, PSF−15%, and PSF+15%. A digital audio metronome was used to achieve the correct SF. Once the SF was achieved, EMG data were recorded for at least 20 s and no more than 60 s for each condition. Actual SF was measured, in order to confirm that the target SF was achieved. SF was determined to be not different between modes (i.e. TMR, DWR-CC, DWR-HK, $P > 0.05$) but was different between intensities as planned ($P < 0.05$, Table 1).

2.4. Data reduction

EMG data were normalized to the greatest 1-s average during MVC. Average (AVG) EMG and root mean square (RMS) were calculated for each muscle across 15-s after removing any zero offset and full-wave rectifying the signal. To analyze the muscle activity patterns, EMG data were further processed by smoothing using a fourth-order, Butterworth, zero-phase lag low pass filter (cutoff frequency = 4 Hz). EMG data were extracted between consecutive maximum knee extension occurrences to yield data for 15 consecutive strides. Stride time was normalized to 100% with an average muscle activity pattern over the 15 strides calculated for each subject–condition combination.

Table 1
Stride frequency during deep water running (high-knee and cross-country styles) and treadmill running on dry land (strides min^{-1}).

Modes	PSF−15%	PSF	PSF+15%
DWR-HK	70.0 ± 5.1	80.6 ± 9.2	92.0 ± 11.6
DWR-CC	68.2 ± 6.8	83.5 ± 11.5	92.6 ± 12.5
TMR		81.6 ± 6.0	

DWR-HK, high-knee style of deep water running; DWR-CC, cross-country style of deep water running; TMR, treadmill running on dry land; PSF, preferred stride frequency. Values are means ± standard deviation.

2.5. Statistical analysis

Two statistical analyses were used to compare muscle activity between the conditions. In both cases, the dependent variables were AVG and RMS for each muscle (i.e. 8 dependent variables in total). For the first analysis, a 1 (intensity: PSF) × 3 (mode: TMR, DWR-HK, DWR-CC) repeated measures ANOVA was used for each dependent variable. Simple effects post hoc testing consisted of contrasting TMR-PSF vs. DWR-CC-PSF and TMR-PSF vs. DWR-HK-PSF.

For the second analysis, all variables were analyzed using a 2 (mode: DWR-HK, DWR-CC) × 3 (intensity: PSF, PSF−15%, PSF+15%) repeated measures ANOVA. When the omnibus *F*-ratio was significant for intensity, polynomial post hoc tests were computed to determine if the dependent measure increased linearly or non-linearly across changes in intensity (i.e. SF). Statistical significance was set at $\alpha = 0.05$. The muscle activity patterns during TMR, DWR-CC, and DWR-HK were compared qualitatively.

3. Results

Muscle activity during DWR and TMR at each SF condition is presented in Figs. 1 (AVG) and 2 (RMS). AVG and RMS of the RF, BF, and GA were significantly different between modes ($P < 0.05$) whereas TA (AVG or RMS) muscle activity was not influenced by mode of exercise ($P > 0.05$). Specific comparisons were as follows:

DWR-CC-PSF vs. *TMR-PSF*. RF and BF (AVG and RMS) were greater during DWR-CC-PSF than TMR-PSF ($P < 0.05$). GA AVG during DWR-CC-PSF tended to be lower ($P = 0.08$) and GA RMS was lower than that of TMR-PSF ($P < 0.05$).

DWR-HK-PSF vs. *TMR-PSF*. RF (AVG and RMS) during DWR-HK-PSF was lower than during TMR-PSF ($P < 0.05$). GA (AVG and RMS) during DWR-HK-PSF was significantly lower than that of TMR-PSF ($P < 0.05$) while BF (AVG and RMS) was not different ($P > 0.05$).

From the second analysis, RF, BF, and GA were not influenced by the interaction of style and SF ($P > 0.05$). AVG and RMS of the RF ($P < 0.01$) and BF ($P < 0.05$) were different between styles whereas there was no style main effect for GA ($P > 0.05$). AVG and RMS of the RF ($P < 0.001$), BF ($P < 0.001$) and GA ($P < 0.001$) were different between SF conditions. Linear effect test indicated that the AVG and RMS of RF, BF, and GA increased linearly across SF conditions ($P < 0.01$) but not quadratically ($P > 0.05$). The TA was influenced by the interaction of style and SF ($P < 0.05$). Using post hoc test for linearity, it was determined that TA (AVG and RMS) increased