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Hot Water Bathing Impairs Training Adaptation in Elite Teen Archers

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Abstract

Despite heat imposes considerable physiological stress to human body, hot water immersion remains as a popular relaxation modality for athletes. Here we examined the lingering effect of hot tub relaxation after training on performance-associated measures and dehydroepiandrosterone sulfate (DHEA-S) in junior archers. Ten national level archers, aged 16.6 ± 0.3 years (M = 8, F = 2), participated in a randomized counter-balanced crossover study after baseline measurements. In particular, half participants were assigned to the hot water immersion (HOT) group, whereas another halves were assigned to the untreated control (CON) group. Crossover trial was conducted following a 2-week washout period. During the HOT trial, participants immersed in hot water for 30 min at 40°C, 1 h after training, twice a week (every 3 days) for 2 weeks. Participants during CON trial sat at the same environment without hot water after training. Performance-associated measures and salivary DHEA-S were determined 3 days after the last HOT session. We found that the HOT intervention significantly decreased shooting performance (CON: -4%; HOT: -22%, *P* < 0.05), postural stability (CON: +15%; HOT: -16%, *P* < 0.05), and DHEA-S levels (CON: -3%; HOT: -60%, *P* < 0.05) of archers, compared with untreated CON trial. No group differences were found in motor unit recruitment (root mean square electromyography, RMS EMG) of arm muscles during aiming, autonomic nervous activity (sympathetic and vagal powers of heart rate variability, HRV), and plasma cortisol levels after treatments. Our data suggest that physiological adaptation against heat exposure takes away the sources needed for normal training adaptation specific to shooting performance in archers.

Key Words: **adolescents, archery performance, dehydroepiandrosterone sulfate, postural balance, shooting**

Introduction

Hot tub hydrotherapy is widely used by amateur and professional athletes for fatigue relief and relaxation (22), with a suggested temperature around 40°C (1). Human heat tolerance threshold, defined by the ambient temperature at which the mortality ratio beginning to rise in an exponential pattern, situates between 41-43°C depending on sex and age (7). Scientific data regarding suitability of

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hot tub intervention below heat tolerance threshold for optimizing training adaptation in performance of archers is currently lacking. Optimal archery performance demands a specific neuromuscular effort to maintain precision aiming. Minimizing sway magnitude in standing posture under high upper-body muscle tension requires enormous control of postural stability (2).

Heat imposes a potent physiological stress to human body, reflected by increased cell death (14, 16) and decreased plasma dehydroepiandrosterone sulfate (DHEA-S) (21). Plasma DHEA-S decline is associated with increased peripheral demand for cell regeneration (3, 5, 18). Training adaptations is generally thought to tightly specific to the mode of task performed (8). Only those components challenged by the training task will be strengthened. However, heat challenge is systemic, which may distract the specific demand for training adaptation. Therefore, in this study we hypothesized that hot water immersion (HOT) arranged after training routine decreases training adaptation in archery performance. To eliminate possible influence of acute effect, shooting performance was assessed 3 days after the last HOT session of a two-week training program. Low salivary DHEA-S, which is associated with poor adaptation against physical challenges for both young men and aged women (10, 11), was also measured during the trials.

Materials and Methods

Participants

A total of 10 junior archers competing at national level (8 boys; 2 girls), aged 16.6 ± 0.3 y with an average training history of 4.2 ± 0.3 y (weight 76.0 ± 4.5 kg; height 168.5 ± 2.0 cm), voluntarily participated in this study. They trained regularly (6 days a week). Their training routine included a 2-km warm-up jogging and stretching (4 times a week), visualization training (30 min, 4 times a week), archery shooting training (4 h, 6 times a week, shooting distance: 30 m and 70 m), and fitness activity (sit up: 3 × 15 repetitions, single arm support: 4 × 90 sec, and cool down, 1 h, 4 times a week). This study was approved by Institutional Review Board of University of Taipei and conduced in accordance with spirit of the Declaration of Helsinki. The purpose and experimental procedures were explained to all participants and their parents, before written informed consent was obtained. Participants were asked not to change their lifestyle during the crossover trials.

Study Design

A randomized crossover design was conduced. Archers were randomized into HOT and control (CON) trials in a counterbalanced fashion, with a crossover following a two-week washout period. During the intervention period, training activity of archers remained unchanged. Participants during the HOT trial were asked to sit in the pool (40°C, two sessions of 15-min hot water immersions separated by a 5-min room temperature sitting on the side) at a depth such that the water was chest high with head out. HOT was conducted one hour after archery training in the evening (after 17:00 pm), twice a week (every 3 days) for 2 weeks. Participants during the CON trial were asked to sit on the side of the hot tub at room temperature with the HOT counterparts. Drinking water (600 mL) was provided to all participants during both trials. All outcome variables, including postural instability, shooting performance, physiological stress markers (salivary DHEA-S and cortisol), and heart rate variability (HRV), were measured at baseline and 3 days after the last session of each trial under an overnight fasted condition.

Shooting Performance

During the performance test, archers were requested to shoot 6 rounds of 6 arrows per round with a 30-m distance from a 10-ring target. Each round was completed in 4 min. Total score was calculated by summing points of the 36 arrows. The archery shooting performance was evaluated followed the most recent official Olympic archery rules and judging guideline in accordance with the most recent version of World Archery rulebook (issued by the World Archery Federation).

Muscle Electromyographic (EMG) Activity

Surface EMG activity of the drawing arm during aiming was recorded on the middle deltoid, biceps brachii, upper trapezius, infraspinatus, and serratus anterior muscles using a Noraxon telemetry EMG system (TeleMyo 2400T, Noraxon Inc., Scottsdale, AZ, USA) at 3000 Hz. To maximize conductance, skin was shaved and cleaned with alcohol. Surface electrodes then were placed on the muscle belly parallel to the direction of the muscle fibers. Interelectrode distance was 20 mm away. Electromyographic data of maximum voluntary isometric contraction was recorded for each muscle by the same observer for 5 sec using standardized manual muscle testing. These data were processed for normalization of each corresponding muscle group during the aiming stage. Root mean square (RMS) EMG of this stage was calculated for data analysis. An electromagnetic motion analysis system (Liberty, Polhemus, Colchester, VT, USA) was used to deter-

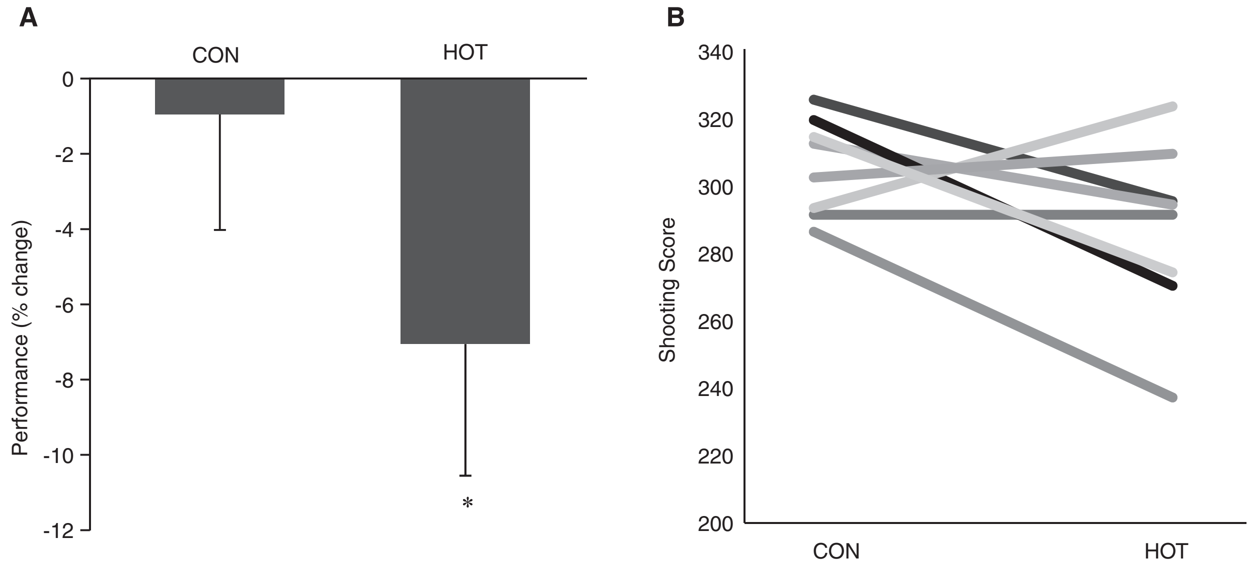

Fig. 1. Shooting performance of archers (% change from Pre) (A). Shooting scores decreased 3 days after the last HOT. Individual data are presented (B). Values are expressed as mean ± SE. * Significant difference between the CON and HOT trials, $P < 0.05$. Pre: before intervention; CON: control trial; HOT: hot tub trial.

mine the aiming stage. Frequency of data collection was set at 120 Hz. The changes in percentage of RMS EMG during the aiming stage for each experimental period were calculated for statistical analysis.

Balance Control

Postural balance during the aiming stage was assessed using a Bertec force plate (4060-NC-2000, Bertec Corporation, Columbus, OH, USA) synchronized with the electromagnenetic motion analysis system (Liberty, Polhemus, Colchester, VT, USA) at the frequency of 120 Hz. Sway ranges of the center of pressure (CoP) in both anterior-posterior and medial-lateral direction (aiming direction) were derived from the force plate data. The sway velocity of the CoP (cm/sec) was calculated using total sway distance divided by the duration of aiming stage. The changes in percentage of these postural stability variables for each experimental period were calculated for statistical analysis.

DHEA-S and Cortisol

Fasting saliva samples were collected from participants at 8:00 am for DHEA-S and cortisol measurements using oral collection Salimetrics oral swab. All samples were centrifuged at 3,000 rpm for 10 min at 4°C to obtain the saliva supernatant and stored at -20°C until analysis. DHEA-S and cortisol concentrations were analyzed using Salimetrics enzyme-linked immunosorbent assay (ELISA) kits (Cortisol CAT#: 1-3002; DHEA-S: CAT#: 1-1252) according to the manufacturer's instructions (Salimetrics, LLC, PA, USA). All plates were read using a TECAN Genios ELISA reader (Salzburg, Austria), and the optical density was used to estimate the concentration of each hormone in the saliva samples.

HRV

Resting HRV was measured using an Autonomic Nervous System Analyzer (TTDC Inc., Taipei, Taiwan) with frequency-domain analysis. The isolated environment in which HRV was measured was kept quiet and dimly lit, and temperature was maintained at 23°C to minimize possible external influences on HRV results. All participants rested 5 min in a sitting position before the 5-min HRV data collection began, and HRV test was performed in the same position. The high frequency (HF) value represents parasympathetic activity, as well as the low frequency in normalized units (LF n.-u.) represents sympathetic activity.

Statistical Analysis

Values are expressed as mean ± standard error (mean ± SE). For the probability of Type I error, significance was set at $P < 0.05$. Two-way analysis of variance (ANOVA) with repeated measure was used for mean comparison. Fisher's post hoc test

Table 1. Posture instability of archers during aiming increased in the HOT trial.

	Pre	CON	Δ %	HOT	Δ %
CoPx range (cm)	1.5 ± 0.2	1.1 ± 0.1	-24.0%	1.6 ± 0.2	+15.4%*
CoPz range (cm)	1.4 ± 0.1	1.4 ± 0.1	-1.5%	1.4 ± 0.1	+5.5%
CoP velocity (cm/s)	3.6 ± 0.8	2.8 ± 0.7	+2.6%	4.8 ± 2.0	+5.6%

CoP: Center of Pressure. CoPx range: CoP sway range in anterior-posterior direction, CoPz range: CoP sway range in medial-lateral direction. High CoP range represents low posture stability. * Significant difference against the CON trial ($P < 0.05$).

Table 2. Muscle EMG activity (RMS EMG) of archers during aiming.

Muscle group	Pre	CON	Δ %	HOT	Δ %
Middle deltoid	30.4 ± 4.6	44.3 ± 12.4	32%	34.4 ± 4.6	26%
Biceps brachii	28.6 ± 5.1	34.3 ± 11.2	36%	29.3 ± 4.3	23%
Infraspinatus	28.4 ± 3.8	16.7 ± 3.1	-31%	32.2 ± 6.2	16%
Upper trapezius	23.1 ± 4.7	33.1 ± 13.5	59%	27.3 ± 2.1	29%
Serratus anterior	27.6 ± 5.4	14.3 ± 4.2	-49%	8.0 ± 2.2	-36%

Values are expressed as mean ± SE.

was utilized to distinguish significant differences between pairs of conditions. Power estimation was calculated to determine sample size. A total of 6 participants would have been required for 80% power.

Results

As shown in Figure 1, shooting performance decreased significantly during the HOT trials but not during the CON trial. Postural instability (standing CoP sway range) during aiming is shown in Table 1. No significant differences in CoP sway range and sway velocity of the medial-lateral direction (the aiming direction) was observed between two trials. However, CoP sway range in the anterior-posterior direction significantly increased during the HOT trial, but not during the CON trial. No difference in muscle EMG activity for middle deltoid, biceps brachii, upper trapezius, infraspinatus, and serratus anterior muscles during aiming was detected between both trials (Table 2). Data for DHEA-S and cortisol are shown in Fig. 2. Salivary DHEA-S decreased significantly during the HOT trial, but not during the CON trial. Data for HRV are presented in Table 3. No significant difference was detected between two trials for sympathetic (LF n.-u.) and parasympathetic powers (HF).

Discussion

The novel finding of the study is a decreased shooting performance of archers when HOT relaxation is incorporated after their archery training routines, only twice a week for 2 weeks. This performance decline is closely associated with increased postural instability during aiming, evidenced by an enlarged CoP sway range in anterior-posterior direction. It is noteworthy that the performance assessment was conducted 3 days after the last HOT session, suggesting that this intervention decreased the training adaptation for archers rather than its acute influence on performance. Taken together, the present study provides convincing evidence to suggest that hot tub, as a popular relaxation method for athletes, should be avoided after training for competing archers.

In this study, we hypothesized an improved shooting performance by incorporating hot tub relaxation 1 h following training, based on a human study describing an exercise training-like effect of hot tub hydrotherapy on diabetes patients (9) and an animal study showing an improved muscle adaptation to endurance exercise training (19). It is not exactly clear for the explanation of discrepancy between our expectation and actual outcome. We speculate that this is associated with the different adaptation specificity against archery training and hot tub heat stress. Archery training challenges mostly the neuromuscular components of human body responsible for bowstring pulling, precision aiming, and shooting. Such challenge helps the re-

Table 3. HRV of archers before shooting.

	Pre	CON	Δ %	HOT	Δ %
Sympathetic power (LF n.u.)	0.14 ± 0.03	0.11 ± 0.03	-9.4 %	0.11 ± 0.02	-5.0%
Vagal power (HF)	0.05 ± 0.01	0.04 ± 0.01	+12.2 %	0.05 ± 0.01	+12.0%

Values are expressed as mean ± SE.

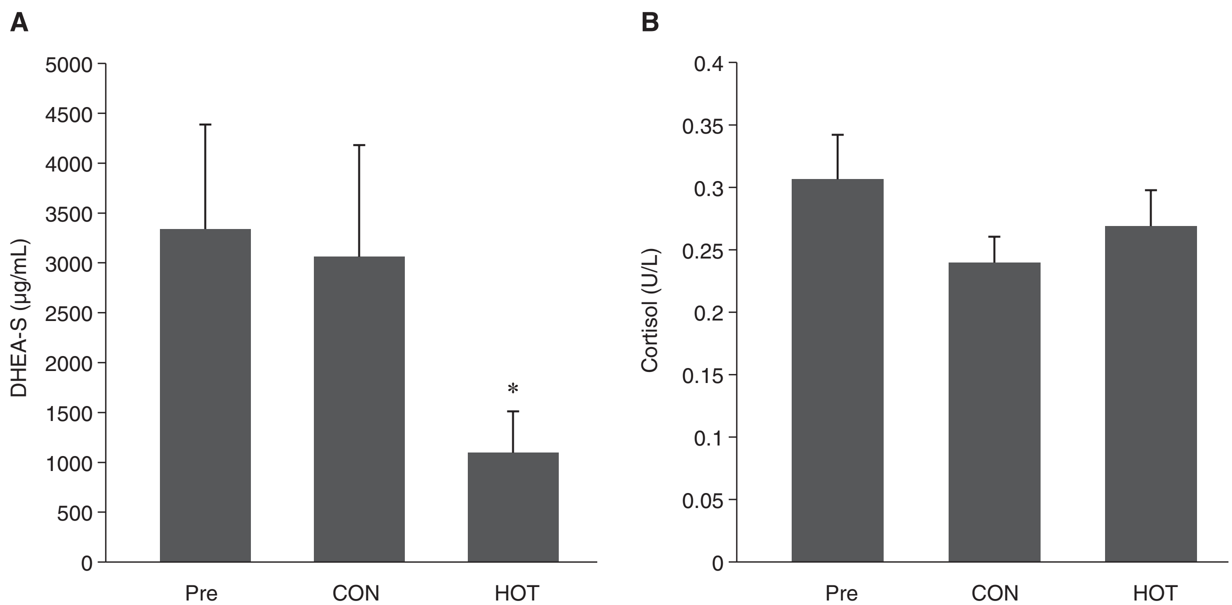

Fig. 2. Physiological stress markers of archers. Salivary DHEA-S (A) decreased 3 days after the last HOT, whereas cortisol (B) remained unchanged. Values are expressed as mean ± SE. * Significant difference from Pre, $P < 0.05$. Pre: before intervention; CON: control trial; HOT: hot tub trial.

spective systems to attract more biological source essential for adaptation. On the other hand, hot tub intervention imposes tremendous challenges on the heat-dissipating components of human body, notably the skin function. Therefore, arranging hot tub relaxation following archery training may cause a dilemma due to competition of endogenous sources essential for adaptation between two physiological components, leading to incomplete training adaptations.

Skin has a short lifespan. Since heat exposure accelerates skin cell death (4), cell regeneration has to be elevated to maintain homeostasis. This creates a large demand on the endogenous carbon source essential for adaptation. Unhealthy or aged skin cells are most likely the population susceptible to heat stress, which would have been damaged and replaced by new cells. Thus, a beneficial effect can be expected due to its consequence on lowering the average age of skin cell population. This is the likely explanation for the health benefit of hot tub reported previously (9).

DHEA-S might be the key endogenous sources required for adaptation, competed by two physiological components against dual challenges. A decline in DHEA-S during the HOT trial fits well with idea of competing demand on the circulating endogenous source for adaptation. This is consistent with the previous observation of significant decreased plasma DHEA-S level among subjects experienced an acute bout of hot spring immersion (41°C for 30 min) (21). An increased DHEA-S clearance rate occurs during high cell proliferation phase in women (5) and adaptation period after external challenge in men (11). We have previously found a decreased plasma DHEA-S level several days after a muscle-damaging workout (12, 20). The result of the present study on salivary DHEA-S decline was observed 3 days after the last bout of HOT exposure. DHEA-S has been found to enhance functional recovery following traumatic damage (6). Since physical training also demands DHEA-S for adaptation (12, 20), competing DHEA-S by skin for thermal adaptation against brain and muscle may compromise training adaptation of archers.

The major limitation of the study is the young age of participants, which may not allow us to generalize the knowledge to adult athletes. We must aware that heat-dissipating mechanism is not fully developed in adolescence. Both pre-pubertal and pubertal boys had a lower sweat excretion rate than adult men at rest (13) and exercise-challenged conditions (17). Therefore, athletes at younger age may be more sensitivity to temperature change than adult athletes, and may tax more endogenous source like DHEA-S for adaptation. Furthermore, DHEA-S levels among junior athletes have not yet reaching peak of their lifetime (15), and therefore coping capacity against dual challenges may not fully developed like adults. Another limitation is the fact that it is not possible to blind or double-blind the hot tub treatment. However, we believe such possibility is minimal, since most of participants actually anticipated an improved performance after HOT.

Conclusion

The results of the study provide direct evidence, which suggests that hot tub relaxation should be avoided after training to prevent performance loss in archers. The decreased shooting performance is associated with an impaired postural balance capacity observed 72 h after the last HOT session. Installing hot tub relaxations after training may trigger heat acclimatization mechanism, which can compete endogenous DHEA-S reserve against training adaptation specific to archery.

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Conflict of Interests

The authors declare that they have no competing interests.

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