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AN ANALYSIS OF ABDOMINAL STABILITY FOLLOWING HYPERTHERMIC EXERCISE IN EUHYDRATED AND DEHYDRATED CONDITIONS

By

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An Honors Thesis

University of Connecticut

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Honors Scholar Program

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ABSTRACT

Core stability is essential for maintaining safety and optimizing performance during exercise and sport. The purpose of this study is to analyze how heat and hydration status (euhydrated USG <1.025 or dehydrated USG >1.025) can impair trunk stability in males and females (in both follicular and luteal phases) using the Trunk Stability Test (TST). Participants complete three blocks of 30 minutes of hyperthermic (35 ± 1.299 ^{o}C and 49.418 ± 5.0329% relative humidity) treadmill exercise. Exercise intensity is equivalent to 15 minutes at either 11W/kg or 7W/kg and the following 15 minutes at either 7W/kg or 4W/kg, respectively, based on individual heat production data. TST data will be collected in one familiarization trial, and 24 hours after each exercise trial. Males will complete one trial euhydrated and one dehydrated, females will complete each hydration prescription twice, once in the follicular phase and once in the luteal phase. Results showed a higher average of TST errors for euhydrated trials, regardless of gender. Males had a higher average number of errors in both euhydrated trials and in the baseline assessment. Females had a slightly more errors in the dehydrated trials. Females in the luteal phase had a higher number of errors in euhydrated trials. Follicular phase females showed a higher average TST score in dehydrated trials. No results in this analysis were statistically significant. Fatigue of the abdominal muscles can lead to increased postural swaying and instability lower in the kinetic chain that increases the risk of musculoskeletal injury, therefore it is important to understand how accessory muscle groups like the abdominals behave under hyperthermic and dehydrated stress.

INTRODUCTION

No matter a person's physical activity level or athletic ability, the fact is that biomechanics plays a heavy role in their life. The laws of physics, momentum, and gravity relate to our movement, balance, and posture whether we are conscious of it or not. Often times, however, it is not considered during play or in training protocol. It is important to comprehend the biomechanical implications of motion, especially in sport, in order to maximize performance and prevent serious injury.

The current body of research supports that optimal physical performance is indeed influenced by our biomechanics. When athletes adapt training programs and warmups to include the biomechanical stresses placed on the body during sport, improvements in performance can be measured. For example, athletes can perform jump tasks for longer periods of time while still maintaining precision and power when dynamic warm-ups are performed. The nature of this style of warm-up allows for more control of hip adduction and a greater magnitude of exertional force, meaning athletes place less strain on their ACL and can endure longer bouts of physical activity (Avedesian et. al). Similarly, one can increase maximal knee flexion angle, which in turn can assist in jumping higher during the counter-movement swing (Yang et. al). Beyond performance enhancement, studying biomechanics in sport can reduce injury risk among athletes. Muscle fatigue induces a shorter stride length and a longer reaction time (Shultz et. al). Taking longer to process a stimulus and reacting with weakened gait movements can place excessive strain on the ACL and leave athletes prone to tears or other sprains. It is therefore of great importance that athletic staff understand how biomechanics change and weaken over the course of a game or practice.

Another important fact to consider is that the differences between male and female biomechanics are often neglected. While both sexes display similar changes to Center of Mass (COM) during the same exercise (Budarick et. al), females on average have a lower muscle mass than males which reduces their force absorption and loading capacity (Montgomery et. al). Based on these differences, research needs to include analyses of differences between sexes to expand upon our understanding of how biomechanics impacts each sex separately. Additionally, within the context of this study, the menstrual cycle inherently alters female physiology in such a way that could potentially influence muscle stability. During the luteal phase, a female's internal body temperature is elevated compared to the rest of her cycle. This rise in basal body temperature, be it small, may induce a decrease in muscle contractibility due to changes in nutrient delivery and fatigue to muscles. The exact impact of this has yet to be assessed, especially on abdominal muscles.

It is no surprise that external factors such as heat and hydration status can compromise biomechanical integrity in human subjects. When subjected to hyperthermic conditions, muscles receive less oxygen and become increasingly fatigued leading to a higher degree of anterior-posterior postural swaying in the torso (Hung et. al). This instability at the core can travel down the kinetic chain causing more gait variability and asymmetry in humans. When faced with both dehydration and hyperthermia, and studies have shown subjects spend more time in the double stance phase, where both legs are weight-bearing, to compensate for their decreased balance and neuromuscular control (Kong et. al). Additionally, heat and poor hydration can both impair proprioception, thus weakening muscular reflexes to changes in body position and balance, both static and dynamic (Mtibaa et. al). These concepts are reinforced by a measured increase in movement errors in the LESS and BESS tests in subjects that were both hypohydrated and hyperthermic following endurance exercise. The lower extremity muscles are too fatigued to adapt to the increased postural swaying and therefore balance is compromised. It appears that the combination of both heat and dehydration present effects of a greater magnitude than those observed in just heat or hydration alone (Distefano et. al).

Originally described by Noerhen et. al, the TST is an attempt to isolate and examine the trunk muscles in terms of neuromuscular control and stability. It involves subjects sitting on an exercise ball in 90 degrees of hip and knee flexion and neutral ankles (0 degrees dorsiflexion) with one foot raised to contralateral ankle height and hands at the hips. It is hypothesized that this position isolates the core muscles and leaves little reliance on the lower extremities for stability. The base of support during this test is unstable, therefore subjects must rely on core muscles to remain still and upright. Initially, it was observed that subjects of this test experience a greater ipsilateral trunk lean in an effort to keep their center of mass over their center of gravity (Noerhen et. al). Other experiments have found that subjects tend to increase their postural swaying in the medial-lateral plane of motion but not in the anterior-posterior plane. When in the upright position, the lower extremities provide a majority of the support in the medial-lateral plane. However, once that stability is removed as it is in the TST, the body is not as accustomed to using the abdominals to prevent medial-lateral motion (Cholewicki et. al) and weaknesses in the torso can be identified.

The aim of this study is to analyze the effects of hydration status and exercise in the heat on trunk stability as an isolated variable. The current body of research is lacking in data that specifically looks at changes to abdominal biomechanics following hyperthermic exercise and alterations to hydration status. Core stability is absolutely crucial when it comes to exercise and sport because the abdominals serve as accessory muscles in a large majority of movement patterns. The abdominals serve to stabilize the torso so we can produce more torque, power, and range of motion during exercise. They also provide safety by protecting the spine and spinal cord and assisting in keeping the body upright during motion and change of direction. In this analysis, data is presented on performance on the TST in both males and females before and after hyperthermic exercise with varying levels of hydration (euhydrated vs dehydrated). Female subject data is further explored to include trials in both hydration states in both the luteal and follicular phases of the menstrual cycle.

METHODS

Measure of Abdominal Control The TST in this study will be administered as outlined in Butowicz et. al. Subjects will sit on an exercise (Swiss) ball with both feet flat on the ground as to create 90 degrees of hip and knee flexion and 0 degrees of dorsiflexion (neutral ankles). Participants sit up straight and place their hands on their hips. They are then instructed to lift one foot into the air to the height of their contralateral ankle. When stable, the subject is to close their eyes and a twenty second timer will begin. The researcher will then count how many “errors” the subject has in that twenty second window. Errors for the TST include placing the elevated foot onto the ground, opening the eyes, taking the hands off of the hips, reaching for support, or trunk swaying greater than 30 degrees from the resting position. Each error is counted as its own, thus if the participant simultaneously opens their eyes and places their foot down, that is recorded as two errors. The subject will then complete the task with their other foot on the ground. This will be repeated two more times so there are 3 data collection points for each foot on the ground. (Butowicz et. al).

Exercise and Hydration Prescription In the overarching study, males completed two trials of three 30-minute exercise blocks with 15 minutes of rest after the first two blocks and a final 30-minute rest following the third block. One trial would be euhydrated (USG <1.025) and the other would be done while 24 hours fluid restricted (USG >1.025). Subjects will submit 24-hour food record logs, morning urine samples and collection jugs from the past 24 hours. There will be a 24-hour alcohol and 12-hour caffeine restriction leading up to each trial. Each exercise block consists of 15 minutes of 11W/kg or 7W/kg of treadmill running and the consequent 15 minutes would be completed at 7W/kg or 4W/kg, respectively to the intensity of their first 15 minutes. Males produce more internal heat than females, so intensity is based off individual data from a heat production test. Exercise was completed in conditions of an average of 35 ± 1.299 ^{o}C and 49.418 ± 5.0329% relative humidity. Female subjects would follow the same structure but would complete the set of two hydration trials twice, once in the follicular phase and once in the luteal phase for a total of 4 trials. Again, exercise intensity would vary individually based on that subject's heat production test results. The order of hydration trial completion is randomized. The TST will be administered once during a familiarization session prior to any exercise trials to allow subjects to acquaint themselves with the test prior to any experimental trials. The TST will then be administered during a follow-up session held one day after each trial. The number of errors will be recorded in the study's datasheets. Exercise protocol was terminated if rectal temperature exceeded 39 ^{o}C.

RESULTS

In this analysis, data for 10 males, 8 females in both luteal and follicular phases, 3 females in the follicular phase, and 2 females in the luteal phase is examined. Not every subject has data for familiarization and both hydration status trials. In some trial follow-up sessions, TST data was not collected due to time constraints. The average mass for male participants across all baseline and hydration trials was 70.27 +/- 11.14 kg and the average for females was 56.81 +/- 6.75 kg. Statistical significance is indicated by $p < 0.05$.

Urine Measures Average USG and urine color for females in euhydrated follow-ups was 1.016 ± 0.0076 and, and 4.62 ± 1.89. For dehydrated follow-ups, 1.021 ± 0.0055 and 4.92 ± 1.12 respectively. For males, USG and color in euhydrated follow-ups were 1.023 +/- 0.0081 and 4.67 +/- 1.63, respectively. For dehydrated trials, male USG average was 1.026 +/- 0.0079 and the color average was 5.29 +/- 1.98 (Figure 1).

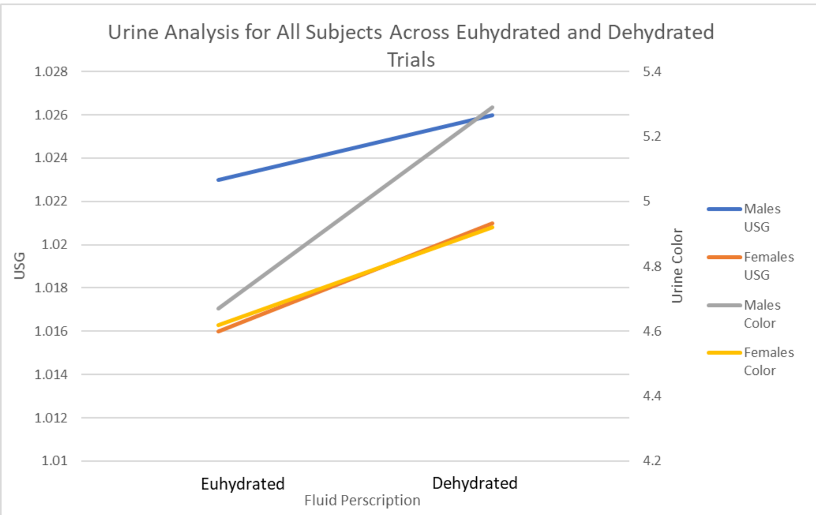

Figure 1: Urine analysis results for euhydrated and dehydrated follow-up sessions

Trunk Stability (TST) Measures. Euhydrated versus Dehydrated A large but not statistically significant ($t = 0.1373$, $p = 0.8917$) increase in the number of TST errors for the euhydrated trials was observed in comparison to the dehydrated trials, regardless of hydration prescription, gender, or menstrual phase (Figure 3).

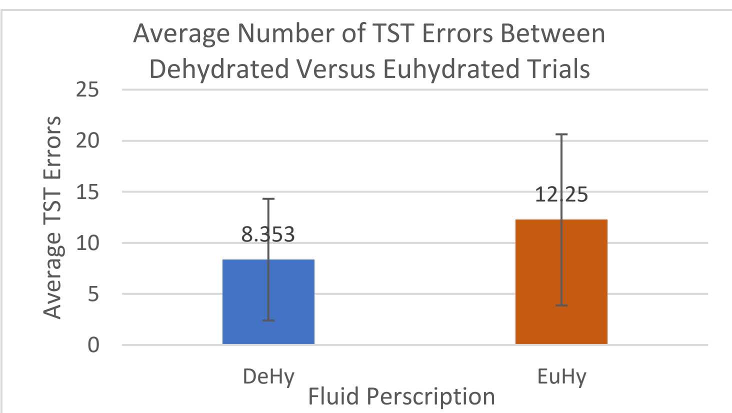

Figure 3: Comparison of average TST errors across all subjects between dehydrated (DeHy) and euhydrated (EuHy) trials

Male versus Female In both males and females, euhydrated individuals had more errors than those who were dehydrated prior to exercise. Males posted a higher, but not statistically significant, number of errors in both baseline familiarization sessions ($t = 0.5142$, $p = 0.6118$) and in euhydrated trials ($t = 0.3749$, $p = 0.7127$). Across all dehydrated trials, females had a slightly higher number of errors ($t = .9490$, $p = 0.3569$), though this result is not considered significant (Figure 2). For both males and females, the average number of TST errors was higher during the baseline test than for both euhydrated and dehydrated trials.

Luteal versus Follicular Phases For females, little correlation between the phase of the menstrual cycle and number of TST errors can be concluded. Euhydrated females had more, but not significantly, higher ($t = 0.5662$, $p = 0.5851$), errors in the luteal phase than those that completed their euhydrated exercise in the follicular phase. In contrast, follicular females that completed exercise while dehydrated had a higher average number of TST errors than dehydrated, luteal females ($t = 0.4392$, $p = 0.6721$, not significant). In comparing all female trials, there was no significant difference in TST errors ($t = 0.9879$, $p = 0.3363$) when in the luteal phase versus the follicular phase, however it was slightly higher in the luteal phase (Figure 4).

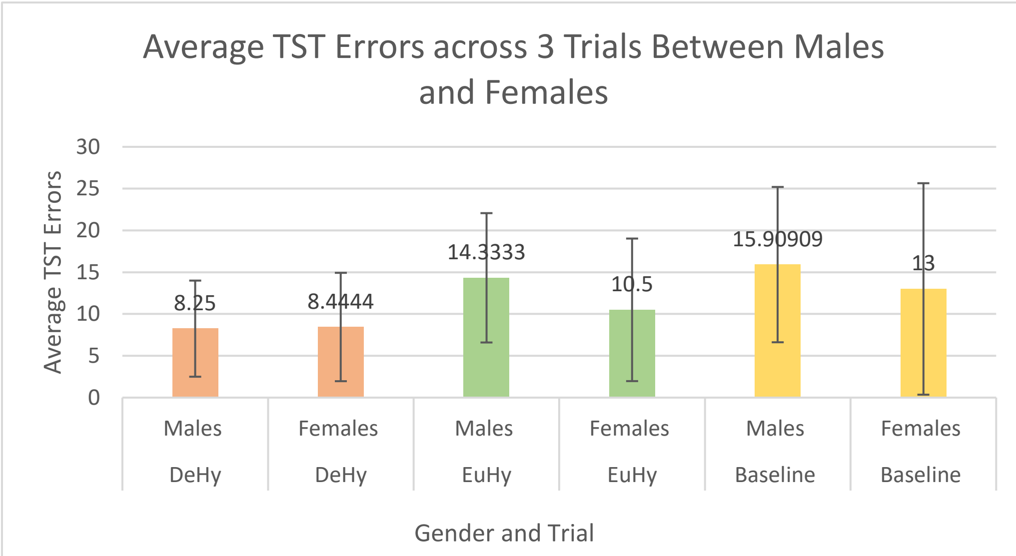

Figure 2: TST errors between males and females across baseline, euhydrated, and dehydrated trials. DeHy, dehydrated; EuHy, euhydrated

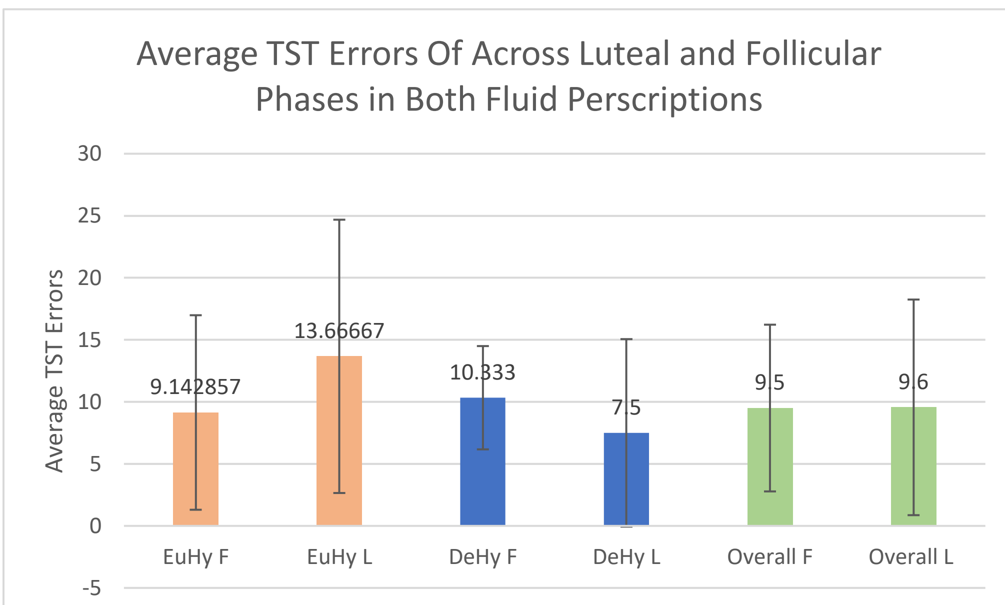

Figure 4: Comparison of menstrual phase and hydration status on average number of TST errors. EuHy, euhydrated; DeHy, dehydrated; F, follicular phase; L, luteal phase

Table 1: Baseline and Trial Data for All Subjects

Subject #	Trial	M/F	L/F	R1	R2	R3	L1	L2	L3	TOTAL	TRIAL ORDER	WEIGHT	USG	COLOR	TRIAL TEMP	TRIAL HUMIDITY
1	Baseline	F	-	6	7	3	5	2	3	26		70.12	1.013	2		
1	EuHy	F	F	1	0	0	0	0	1	2	1	73.18	1.02	6	33.34	51.05
2	Baseline	F	-	3	3	1	1	0	0	8		56.48	1.023	4		
2	EuHy	F	L	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2	55.98	1.021	6	33.22	53.27
2	DeHy	F	L	0	1	0	0	0	0	1	4	56.2	1.021	4	33.59	50.98
2	EuHy	F	F	0	1	0	0	0	0	1	3	56.36	1.026	6	33.46	51.25
2	DeHy	F	F	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1	56.14	1.024	6	32.84	53.89
4	Baseline	F	-	5	2	1	3	3	4	18		51.32	1.014	4		
4	DeHy	F	F	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1	N/A	N/A	N/A	N/A	N/A
5	Baseline	F	-	0	3	2	3	0	1	9		58.82	1.013	5		
5	DeHy	F	L	3	4	4	1	1	2	15	1	59.36	1.028	6	33.04	42.05
5	EuHy	F	F	N/A	N/A	N/A	N/A	N/A	N/A	N/A	3	61.24	1.016	4	33.83	50.23
5	DeHy	F	F	4	3	0	5	2	1	15	2	60.35	1.028	4	33.55	51.35
7	Baseline	F	-	10	8	5	8	3	3	37		45.44	1.006	4		
7	EuHy	F	L	N/A	N/A	N/A	N/A	N/A	N/A	N/A	4	46.56	1.003	1	33.28	43.85
7	DeHy	F	L	4	5	6	0	1	2	18	3	46.12	1.023	6	33.55	50.48
7	EuHy	F	F	4	4	5	0	0	1	14	1	45.66	1.011	7	38.75	36.5
7	DeHy	F	F	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2	46.48	1.021	6	33.67	49.63
9	Baseline	F	-	1	0	0	0	3	1	5		52.26	1.013	4		
9	EuHy	F	L	0	0	1	0	0	0	1	2	51.66	1.01	3	36.01	32.85
9	DeHy	F	F	0	2	0	4	0	1	7	1	51.26	1.009	4	33.49	50.56
10	Baseline	F	-	3	1	0	3	0	0	7		60.36	1.007	2		
10	DeHy	F	L	0	1	0	0	1	1	3	2	59.66	1.024	4	33.72	51.26
10	EuHy	F	F	1	4	0	2	0	1	8	3	59.74	1.01	4	33.6	50.35
10	DeHy	F	F	5	0	2	2	0	0	9	1	60.26	1.024	6	32.88	53.13
11	Baseline	F	-	0	2	1	1	2	2	8		62.86	1.011	3		
11	EuHy	F	L	3	3	2	6	2	3	19	2	62.96	1.008	2	33.97	50.38
11	EuHy	F	F	2	2	2	4	1	3	14	1	62.36	1.018	6	33.81	50.72
14	Baseline	F	-	0	2	0	0	0	1	3		60.36	1.015	4		
14	EuHy	F	L	N/A	N/A	N/A	N/A	N/A	N/A	N/A	3	61.46	1.017	3	33.5	50.67
14	DeHy	F	L	0	1	3	0	2	2	8	1	60.04	1.013	3	32.24	52.2
14	EuHy	F	F	2	7	3	3	4	3	22	2	60.14	1.03	6	32.91	52.9
15	Baseline	F	-	1	2	1	3	2	3	12		54.34	1.014	1		
15	DeHy	F	L	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1	55.14	1.015	4	33.83	50.39
16	Baseline	F	-	1	0	0	0	0	1	2		48.94	1.012	3		
16	DeHy	F	F	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1				36.7	51.53
17	Baseline	F	-	8	4	4	6	8	10	40		48.87	1.017	6		
17	EuHy	F	L	6	5	4	2	1	3	21	1	49.4	1.023	6	33.59	51.79
18	Baseline	F	-	2	1	0	0	2	1	6		57.84	1.006	1		
18	DeHy	F	L	0	0	0	0	0	0	0	2	57.58	1.024	5	33.64	50.7
18	DeHy	F	F	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1	57.96	1.024	6	33.62	51.36
19	Baseline	F	-	0	0	0	0	1	0	1		71.18	1.021	6		
31	Baseline	M		2	2	1	3	3	0	11		62.36	1.025	6		
31	EuHy	M		5	5	6	4	4	4	28	2	59.6	1.03	6	32.89	52.41
31	DeHy	M		3	2	4	2	2	2	15	1	60.76	1.03	6	33.69	54.44
33	Baseline	M		4	2	3	2	4	2	17		68.04	1.029	7		
33	EuHy	M		1	3	2	1	1	2	10	2	68.78	1.03	6	33.27	50.02
33	DeHy	M		0	2	5	1	0	0	8	1	68.74	1.031	6	33.68	56.57
34	Baseline	M		3	0	3	3	1	1	11		86.32	1.023	4		
34	EuHy	M		3	4	2	3	0	2	14	2	86.45	1.02	4	33.57	51.58
34	DeHy	M		0	0	0	0	0	0	0	1	84.6	1.034	7	32.83	53.62
35	Baseline	M		3	2	1	4	3	4	17		65.66	1.012	2		
35	EuHy	M		1	2	0	4	1	0	8	1	65.06	1.015	2	36.56	45.27
35	DeHy	M		0	0	0	0	6	2	8	2	65.5	1.016	3	35.65	37.67
36	Baseline	M		7	2	4	8	5	2	28		69.92	1.02	7		
37	Baseline	M		0	1	1	3	0	1	6		65.88	1.02	6		
37	DeHy	M		1	0	1	4	1	0	7	1	66.76	1.014	2	36.65	40.9
40	Baseline	M		3	3	1	1	2	1	11						
40	EuHy	M		1	0	0	2	3	2	8	1					
40	DeHy	M		2	0	0	0	0	0	2	2					
41	Baseline	M		4	5	4	7	4	6	30		70.38	1.02	6		
41	EuHy	M		4	3	3	2	3	3	18	1	68.96	1.029	6	33.46	51.3
41	DeHy	M		3	1	2	3	5	3	17	2	66.08	1.031	7	33.6	50.8
45	Baseline	M		1	0	0	0	0	0	1		57.34	1.029			
45	DeHy	M		1	2	1	2	1	2	9	1	58.08	1.024	6	33.46	46.26
46	Baseline	M		8	5	5	3	4	2	27		61.12	1.026			
48	Baseline	M		2	2	1	3	4	4	16		95.06	1.005	2		
48	EuHy	M		N/A	N/A	N/A	N/A	N/A	N/A	N/A		94.68	1.012	4	33.84	50.56

M/F indicates gender. L/F indicates menstrual phase for female subjects. R1-L3 indicate individual trials for the TST on each leg. Trial order indicates the order of hydration exercise trials for each subject. Weight, urine USG, and urine color are recorded post-exercise. Trial temperature (°C) and trial humidity (RH%) are recorded as average throughout entire exercise trial.

DISCUSSION

No results in this study were shown to be statistically significant, however, there were observed differences between males and females, dehydrated and euhydrated exercise, and between the luteal and follicular phases of the menstrual cycle that could negatively affect abdominal stability during and after exercise in the heat and humidity.

Urine Analysis While not statistically significant, for both males and females USG and color were higher in dehydrated follow-ups, indicating the 24-hour recovery window from the end of dehydrated exercise was not enough time to restore normal hydration levels. These results were seen regardless of the order the exercise trials were completed; thus, they can be attributed to hydration status instead of the total amount of exercise completed.

TST Analysis The Trunk Stability Test is a relatively new laboratory measure aimed at evaluating isolated abdominal balance. It is set up in an effort to remove lower extremity influence on core stability by providing an unstable sitting surface. A higher number of TST errors indicates poor neuromuscular control in the abdominal muscles which can influence lower extremity biomechanics further down the kinetic chain. Figure 2 illustrates that exercise performed in hyperthermic and hypohydrated conditions yielded a lower average of TST errors than hyperthermic exercise while euhydrated. Familiarization with the TST was eliminated as a cause of this result because subjects did not all complete the exercise

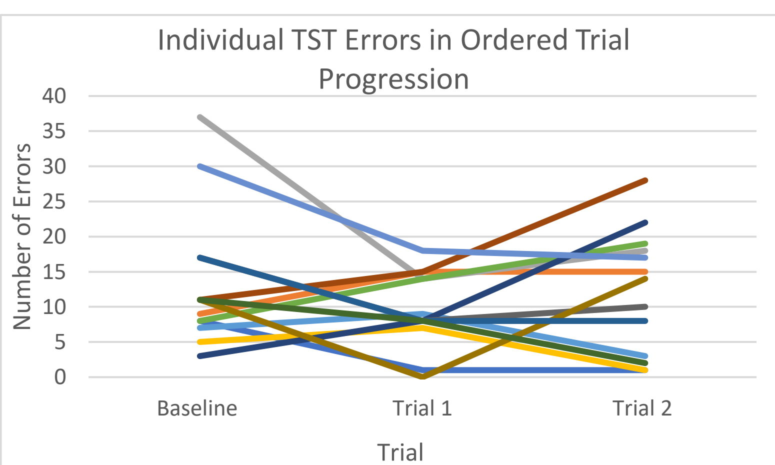

Figure 5: Individual subject data for TST errors across 3 trials. Each subject contains data for a baseline, a euhydrated trial, and a dehydrated trial and are graphed in the order completed. r = 0.02737

trials in the same order, i.e. euhydrated then dehydrated or vice versa. The order was randomized, and Figure 5 indicates no correlation between the order of trial and performance on the TST ($r = 0.02737$). Had familiarization been a factor, there would have been a steady, patterned decrease in the number of errors from baseline to trial 1 and trial 1 to trial 2. This finding opposes the initial hypothesis because previous research has shown that hypohydration reduces nutrient delivery to the muscles and impairs the vestibular system, therefore reducing their functional capacity, which is thought to then increase instability. It could then be that the hyperthermic exercise itself could have a more profound effect on trunk stability than hydration status alone.

In both the euhydrated follow-up sessions and the baseline sessions, men yielded a higher average number of TST errors than females, with the dehydrated trials posting a near-identical average. Males typically have a higher center of gravity, making them physiologically more likely to have more instability. Therefore, it can be inferred that hyperthermic exercise can enhance the inherent instability of male subjects and disrupt abdominal stability to a greater extent than in female subjects.

Females had a larger percent change in their USG levels between their euhydrated and dehydrated trials versus males, 0.4921% compared to 0.2932%, respectively. This could indicate that females had a more profound physiological change to the dehydration than males did. This is supported by the fact that in the dehydration trials, females had a larger, though not statistically significant, average of TST errors than males. As previously stated, females generally have a lower center of gravity than males and tend to have better stability. Since the dehydration trial was the only one observed to show females having a higher number of average errors, it could be hypothesized that hydration status has a heavier impact on female stability than it does in males.

In the luteal phase of menstruation, females have a higher internal body temperature. Here, it was observed that in euhydrated follow-up sessions and in baseline data, females in the luteal phase had slightly higher averages of TST errors. This finding may signify that in the luteal phase, the higher internal body temperature may couple with the presented external hyperthermic exercise environment to further decrease trunk stability. Dehydrated females showed less, but not statistically significant, errors in the luteal phase than in the follicular phase. The exact reasoning for this result is unknown. Therefore, with the presently available data set, little correlation can be concluded between the phase of the menstrual cycle and abdominal stability following hyperthermic exercise in either a hypohydrated or euhydrated state.

A large limitation of this study is that data for individual subjects across all 3 data collection points were not able to be obtained for every subject. For some subjects, only data for baseline and one trial was able to be collected. Therefore, it was difficult to observe trends for subjects from their beginning to completion of the study. Each subject also has a different internal physiology, meaning individuals may respond differently to hydration changes and menstrual fluctuations, so without complete data sets across all trials it is hard to analyze data. Since some subjects were only able to provide data for one trial, each condition had a different number of data points, which could have skewed the results. This reasoning can also explain the large standard deviations calculated; averages are based on unpaired data points in some cases. In order for more concrete conclusions to be made, a more complete data set is required.

CONCLUSION

Across both males and females, a state of dehydration was shown to decrease the average number of errors in the TST meaning hydration state may not have as an exclusive effect on abdominal balance as previously hypothesized. In comparison of luteal females versus follicular females, it was observed in this data set that luteal females had more errors in the TST while euhydrated but follicular females posted a higher average number of errors in the dehydrated trials. Overall, no matter the menstrual phase or hydration status, women posted a lower average of errors than men, except in the dehydrated condition where averages were near identical. Results from this study show that hydration and heat can impair core stability which leaves humans prone to higher musculoskeletal injury rates and compromised performance. Therefore, it is crucial that proper hydration and heat acclimation precautions are taken during training and physical activity.

Works Cited

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