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INDIVIDUAL FRONTAL EEG ASYMMETRY AS A PREDICTOR OF
HYDRATION STATUS DURING EXERCISE IN THE HEAT

By

AYANO KATAYAMA, Bachelor of Physical Education

Presented to the Faculty of the Graduate School of
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Master of Science

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INDIVIDUAL FRONTAL EEG ASYMMETRY AS A PREDICTOR OF
HYDRATION STATUS DURING EXERCISE IN THE HEAT

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ABSTRACT

Hydration behavior varies among individuals; continuous and correct fluid consumption behavior prevents decreased physical performance and severe dehydration, especially during extended exercise and hot environments. Therefore, the purpose of the present study was to examine individual frontal alpha EEG asymmetry index (FAI) score in eu-hydrated, hypo-hydrated, and exercise in well-trained men and assess if there is a correlation between FAI score and individual ad libitum fluid consumption behavior. Subjects were kinesiology major college students ranging from 21 to 29 years of age. Subjects were categorized either approach group (n = 8) with resting FAI score more than 0 or avoidance group (n = 3) with FAI score less than 0. All subjects performed passive dehydration trial in hot water bath and exercise trial. While larger sample sizes are needed to verify results, there was a moderate correlation between the higher change in FAI scores to water exposure (closer to the positive value) and the greater desire for fluid consumption at baseline (as expressed by 100 millimeter scale) only in the

hydration trial with no significance ($r = 0.6; p = 0.05$). Also, there was a moderate correlation between the larger change in FAI score (higher affinity) to water exposure and the more ad libitum fluid consumption during exercise in the approach group ($r = 0.72; p < 0.05$). These trends may indicate that changes in FAI score between resting and beverage exposure could provide patterns within individual ad libitum fluid consumption during exercise. However, there was no relationship between post-exercise or dehydration FAI scores and the desire for fluid consumption.

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CHAPTER I

Introduction

The importance of fluid consumption is well documented in various studies, especially during exercise and/or in hot environments. However, individuals vary within patterns of drinking behavior on a daily basis; some individuals drink lower (low drinker: LD) or higher (high drinker: HD) volumes of fluid, while normal drinkers succeed in maintaining overall eu-hydrated state throughout a day (28). In addition, during prolonged exercise and/or in hot environments, some individuals demonstrate different drinking behavior as well, and they likely develop severe dehydration and heat illness without sensation of thirst (24). Thirst can be a biomarker for hypo-hydration, but it is not always an accurate method to predict individual hydration status because the individual normally perceives it when achieving at least 1-2% of body mass dehydration (34). Therefore, individual palatability has an important role to drive fluid consumption, especially for athletes and some industrial workers; several studies were reported that temperature,

flavor, and electrolyte content (i.e., carbohydrate and sodium) of the beverage may affect the volumes of ad libitum fluid intake (8, 11, 26). Individuals are commonly hypo-hydrated in the morning due to several hours of sleeping, and concern has been expressed that nearly 90% of young athletes are hypo-hydrated when starting practice or competition (4, 5). Some studies revealed that athletes' knowledge scores about proper hydration methods were not correlated to their understanding of actual hydration statuses (5, 12, 34). It is also reported that incidences of heat-related illness in sport-related activities is the highest, especially among adolescence, and a few serious cases lead to sudden death (24). Moreover, fluid absorption is delayed in severe dehydrated conditions (i.e., during prolonged exercise and/or in hot environments) so that it is necessary to understand an individuals' ability to manage voluntary hydration and self-regulate eu-hydrated states. This study focuses on characteristics of individual frontal electroencephalographic (EEG) asymmetry index scores and examines if different hydration states and/or exercise stimulus can change EEG asymmetry scores. Faries et al. (14) found that there is a relationship between individual frontal EEG asymmetry trait

(approach or avoidance to stimuli) and food consumption behaviors. If the difference was observed in frontal EEG asymmetry index among 3 conditions, eu-hydrated, hypo-hydrated, and during exercise, it is possible that individual drinking behaviors (normal, low, or high drinker) can be predicted to encourage individuals adopting an appropriate hydration method and prevent health problems related to dehydration. Therefore, the purpose of this study was to assess individual frontal EEG asymmetry in eu-hydrated, hypo-hydrated, and exercise in individuals with different drinking behaviors and evaluate if there is a relationship between these variables.

Research Questions

RQ 1: Does an individual's affinity for fluid consumption (as measured through frontal asymmetry) differ during eu-hydrated and hypo-hydrated conditions?

RQ 2: Do correlations exist between frontal asymmetry index changes and ad libitum fluid consumption during exercise in a hot environment?

RQ 3: How does exercise impact affinity as in RQ1?

CHAPTER 2

Review of Literature

Exercise in the Heat

During intense and/or prolonged exercise, the human body requires higher oxygen consumption and higher volume of cardiac output to increase energy production; body fluid is used to reduce core temperature and increase blood volume and velocity (15). Although the majority of people will maintain core temperature and body fluid loss in normal conditions, rapid fluid loss leads to hyperthermia during exercise in the heat. Also, hot environments disturb the mechanisms of physiological homeostasis (i.e. conduction, convection, and radiation) and are strongly associated with cardiovascular instability, dehydration, higher rating of perceived exertion, and performance decline compared to exercise in cool environments (15, 24).

Nichols (24) claimed that the most serious outcome of exertional heat-related illness is on-the-field sudden death due to exertional heat stroke. According to the National Center for Catastrophic Sports Injury Research

database, 15.6% (38 cases) of all reported sport-related deaths between 1990 and 2010 among US high school and college football players were identified as heat illness (24). Moreover, 1,518 cases of heat-related injuries including heat cramps, heat syncope, heat exhaustion, heat stress, and heat stroke were reported to be treated only in emergency departments in the United States between 1997 and 2006 (23). An estimated 53,465 cases were treated in other departments or not treated in a hospital. Among actual emergency visits, 1,378 (90.4%) cases were released during the same day, while 140 (9.6%) cases were hospitalized. Also, 48.0% of cases were actually diagnosed as heat-related illness, and 72.7% of them were heat exhaustion (18.7% dehydration; 9.7% heat syncope; 5.4% heat cramps; 1.9% heat stress; and 1.8% heat stroke). Also, the majority of cases (75.5%) were related to sport and exercise; football involved in 48.0% of sport-related heat injuries among boys ages under 19 years. Heat-related injuries per 100,000 U.S. populations were 2.5 in 2006 (23).

Ad Libitum Fluid Intake

Humans consume fluid from food and beverage to replace body

water deficits incurred by sweating, urine production, and respiration. Ad libitum fluid consumption is normally controlled by thirst sensation to maintain eu-hydration states at resting conditions (16). However, Sawka et al. (28) reported that free-living adults consume most of their daily volume of fluid from water or other beverages with food, which drives thirst sensation, and are only eu-hydrated after mealtime. Campagnolo et al. (6) conducted a study monitoring subjects who ingested either water, a carbohydrate-electrolyte sports drink (CHO), or a milk-based liquid meal supplement and snacks ad libitum during 4-hour recovery periods after exercise achieving 1.8% of body weight loss due to dehydration. Subjects consumed higher volumes of total fluid in CHO, water, and supplements respectively and reported significantly higher rates of thirst sensation during supplement trials than water and CHO trials.

Engell et al. (13) suggested that higher rates of perceived thirst sensation are correlated to an increase of ad libitum fluid consumption so that thirst is an effective signal which enhances fluid intake to improve hydration states. According to Yeargin et al. (34), thirst can stimulate fluid intake for

improving hydration when body weight loss reaches 1 to 2% of normal body weight. Sawka et al. (28) claimed that thirst sometimes increases fluid intake after 2% of body fluid deficit. Moreover, under hot environments and/or during prolonged exercise, the human body cannot replace all fluid loss with ad libitum drinking and will gradually be dehydrated (voluntary dehydration) (19). Therefore, thirst sensation is considered insufficient to prevent voluntary dehydration. In the study conducted by Yeargin et al. (34), heat-acclimatized young male athletes voluntarily consumed higher volumes of fluid and well self-regulated their body fluid balance as correlating to an increase in sweat rate. However, they demonstrated moderate dehydration (replaced approximately two-thirds of total body fluid loss) at post-training compared to the beginning of the training throughout 10-days observation of football practice in the summer (34). Various studies have reported ad libitum fluid consumption can replace only about 60 to 80% of fluid loss during exercise (18, 19, 34). Even if individuals have sufficient time and opportunity for fluid consumption, they show very different hydration statuses which are affected by environmental conditions, intensity of exercise, sweating rate, and

volume of drinking (18, 29). Also, individuals sweat differently by temperature, humidity, position, clothes, body size, and physiological characteristics such as metabolic rate (29).

Most free-living people are hypo-hydrated on a daily basis without sensation of thirst (4, 5). Arnaoutis et al. (4, 5) reported that 88.7% and 89.8% of young athletes were classified hypo-hydrated before practice based on urine specific gravity. In addition, although athletes have knowledge that fluid intake is an important factor to enhance performance and prevent heat illness, their knowledge scores and drinking behaviors are not correlated (5, 12, 34). Additionally, some studies suggest that hypo-hydrated states at pre-training enhance rehydration during exercise (3, 19, 34). In two previous studies, Armstrong et al. (3) and Maresh et al. (19) conducted the same protocol; subjects walked 90 min after being either eu-hydrated or hypo-hydrated and then were allowed to consume either water ad libitum or no fluid during exercise. In both trials, hypo-hydrated state at pre-training enhanced volume and frequency of fluid intake during exercise compared to eu-hydrated state at pre-training. Subjects' post-training body weights were

also higher only in water consumption trials following hypo-hydration (gain of 0.9%); subjects lost 1 to 1.5% of pre-training body weight during other 3 trials (3).

Drinking water and other beverages is a primary source to replace body fluid loss, and it covers approximately 80% of total daily fluid ingestion in European countries and the United States (27). Each country establishes their own recommendation/guideline for daily fluid intake; intake of 3.7 and 2.7 liters of water per day are recommended for US and Canadian (men and women), respectively, and 2.5 and 2.0 liters of water per day are recommended for European men and women, respectively (27). However, Perrier et al. (27) suggested that individuals display much variability in drinking behaviors; 0.5 liters to more than 4 liters of water and other beverages per day in France. They categorized individuals that habitually drink low volumes (less than 1.2 liters per day) of water as low drinker (LD) and individuals that habitually drink high volumes (more than 2 liters per day) of water as high drinker (HD) and assessed their usual fluid intake habits using electronic daily questionnaire for 3 weekdays. While fluid

consumptions from water and beverages were 0.74 liters per day in LD and 2.70 liters per day in HD, no significant difference (LD: 0.55 liters; and HD: 0.68 liters) was reported in volume of fluid intake from food between LD and HD. The study also indicated that both LD and HD well maintained plasma osmolality levels by regulating urine volume. However, habitual hypo-hydration may increase a risk of chronic kidney problems and disturb an ability to self-regulate hydration status in severe conditions.

Also, there are people who can be classified as reluctant drinkers.

Reluctant drinkers consume similar volumes of fluid to normal drinkers and can successfully replace sweat loss during exercise when they are eu-hydrated, but at hypo-hydrated states, their drinking behavior is not correlated to their hydration status (3). Therefore, it is possible that even people categorized as normal drinkers in daily basis may not be able to regulate hydration status under hot environments and/or during prolonged exercise. In addition to football players (elicit highest rate of heat-related illness because of heavy equipment use), athletes participating in other team sports need extra care for their hydration status in hot environments. They are often restrictions in

regards to their opportunity to replace their body fluid losses due to insufficient time, interval, and frequency of rehydration breaks thereby varying hydration states widely among athletes (18).

Palatability and Hydration Status

It is known that voluntary fluid intake is enhanced by individual preference such as flavor, fluid temperature, and levels of electrolyte content. Therefore, palatability is an important factor to control volumes of ad libitum fluid intake and maintain body fluid balance (7, 8, 26). In addition to enhancement of fluid intake due to food consumption, several studies have shown that individuals prefer and consume more flavored, cool, and sodium added drink compared to water (6, 7, 8, 18, 26, 28, 33). Even though voluntary fluid intake fails to replace 100% of total body fluid loss, Sawka et al. (28) claimed that combination of cooling and flavored drink could increase 20% of fluid intake compared to consumption of warmer plain water.

Most commercially available sports drink contain carbohydrate (CHO), which enhances fluid intake due to its sweetness compared to water, but higher amount of CHO also delay fluid absorption and interrupt

rehydration. Coso, Estevez, Baquero, and Mora-Rodriguez (11) studied fluid retention when subjects consumed 100% of body fluid loss during exercise with water, 6% of CHO and 22 millimoles per liter (mmol/L) of sodium, 8% of CHO and 22 mmol/L of sodium, and 8% of CHO and 10 mmol/L sodium contained beverage. Results indicated that water significantly increased urine production and gastric fullness compared to other beverages, and two beverages containing 22 mmol/L of sodium maintained Na⁺ level compared to other two beverages. No difference was observed between 6% and 8% of CHO contained beverages in gastric fullness or body fluid balance, but better rehydration status (higher plasma volumes) were observed in water and 6% of CHO trials compared to 8% of CHO trial with no significant difference. The study suggested that fluid absorption is not significantly inhibited by 8% of CHO contained beverage. On the other hand, low sodium drinks may inhibit body fluid replacement.

In several studies, it was reported that higher sodium drinks increased voluntary fluid consumption due to higher sensation of thirst, and also maintained body fluid balance compared to water or lower sodium

contained drinks (6, 8, 30, 33). Clapp et al (8) reported that subjects consumed sodium contained beverages more than flavored placebo and water during repeated exercise in industrial work settings. Subjects were provided lime-colored water, flavored placebo, commercially available electrolyte-carbohydrate drink contained 18 milliequivalent per liter (mEq) of sodium (ECHO18), and 36 mEq/L of sodium (ECHO36) ad libitum while they performed repeated 12 min walk and 3 min arm-curl for 30 min and 30 min rest (up to 4 hours). Although there was no significant difference in volume of fluid consumption between ECHO36 and ECHO18, subjects gained more weight during ECHO36 trial compared to ECHO18 trial. Consumptions of placebo and water were significantly lower than two ECHO trials. There was no difference between consumption of unflavored-colored water and flavored water although some studies report flavored drink enhances fluid intake compared to water. Wemple et al. (32) reported that subjects ingested 25 mmol/L of sodium contained drink more than 0 or 50 mmol/L of sodium drink. Higher amount of sodium could lead to higher thirst sensation, but it may not necessarily correlate to volume of fluid ingestion due to palatability

(6). Moreover, Park et al. (26) monitored drinking behavior of subjects who consumed either 10°C water, 10°C sports drink, 26°C water, or 26°C sports drink ad libitum during 90 min recovery period after 2% dehydration. As a result, subjects consumed more 10°C sports drink compared to other drinks (26°C sports drink > 10°C water > 26°C water) with no significant difference (p= 0.113). Although sodium level and flavor seemed to influence people's palatability more than fluid temperature, cooler beverages (10°C > 26°C) enhanced ad libitum fluid intake compared to warmer beverages. It is reported that the most preferred fluid temperature is between 15° and 21°C (26).

Since individuals have different combinations of palatability, variety of drink selection needs to be provided to increase voluntary fluid consumption, especially in the heat (8, 18). Up to 8% of CHO may contribute to enhancement of glycolysis without an increase of gastric fullness, and higher amounts of sodium contained beverages lead to hypertonic state and enhance higher volumes of ad libitum fluid intake in addition to lower fluid temperature.

Electroencephalographic (EEG)

Frontal EEG asymmetry reflects individual trait or trait-like measures, psychopathology, function of state changes in emotion, and emotional changes and responses (negative or positive response to experience). Based on measures of frequency, amplitude, shape, and recording site, EEG waveforms are generally classified into 4 kinds (alpha, beta, theta, and delta). Alpha and beta waves appear at awakening in all age groups; alpha waves are generally observed at resting (non-focused and relaxed condition) more common in adults, and more prevalent to visual stimuli, whereas beta wave appears when focused attention, task committing, and problem solving. Theta and delta waves generally appear during sleep and are abnormal in awaking adults. In addition, alpha wave could show individual current mental condition and associate with emotion (e.g., happy, sad, or angry) and arousal levels. Therefore, it is accepted that individual personality and emotional/mood change (behavioral motivation) can be determine by analyzing alpha power (10). Also, it is widely known that greater left activity is associated with general approach, or behavioral activation motivational

system, and greater right activity is associated with general avoidance or withdrawal system (9, 31). Normal and abnormal human behaviors have been interpreted by using the Behavioral Inhibition and Behavioral Activation Systems (BIS/BAS): greater BIS is related to increased attention, arousal, vigilance, and anxiety; BAS is related to feelings of optimism, joy, and aggression. However, recent studies revealed complex interpretation of BIS. Amodio, Master, Yee, and Taylor (2) reported that BIS may be related to interruption of action but not related to avoidance behavior emotion, and BAS is corresponding to motivational action.

Affective response patterns, increased and decreased arousal, are observed during exercise, and that is associated with EEG activity (17). EEG can predict affective responses following exercise stimulus that is equivocally strenuous. In a study conducted by Hall et al. (17), subjects performed VO₂ max test (1) and completed the Activation Deactivation Adjective Check List at pre- and post-exercise. Their frontal EEG asymmetry was recorded at pre- (baseline) and post-exercise during 20 min recovery period. The result showed that there was positive relationship between calmness and tiredness

(greater relative left-sided brain activity was seen) so that tiredness may not be associated with negative response.

Nybo and Nielsen (25) studied correlations between EEG activity and rate of perceived exertion (RPE) based on the research that increased core body temperature leads to higher RPE by inhibiting the cerebral ability to stimulate muscle effort. In this study, subjects performed cycling at up to 60% of individual VO_2 max to exhaustion in a hot environment (40°C) and also cycled 1 hour in cool environment (18°C). Exercising muscle electromyogram (EMG) and EEG were recorded. No difference was observed in EMG activity between exercise in hot and cool environments throughout the trial, while subjects' RPE in hot environment was significantly higher (20 ± 0) at the end of the trial (50 ± 3 min) compared to the cool environment (12 ± 1 at 60 min; $p < 0.001$). Also, no relationship was observed between hyperthermia and muscle ability for generating force. These results indicate that at least moderate exercise does not affect subjects' RPE, while hot environments (related to increased core temperature) alter brain activity and RPE. Therefore, normal function of brain may be inhibited by hyperthermia so that EEG can differ

from resting state and/or during exercise in cool environments.

Faries et al. (14) studied individual differences of eating habits stimulated by affective motivation. Subjects' weight and body mass index (BMI) and BMI category, and total body fat were measured and presented to them. Resting EEG was recorded for 2 minutes before and after weight and body measurements. Their status of physical activity and dietary intake before the trial and 7 days after trials were compared to evaluate how approach or avoidance motivation affected behaviors. Results indicated that there was no significant change in dietary behavior between pre- and post-trial among approach group whose frontal asymmetry relatively increased (left frontal activity > right) while avoidance group (right frontal activity > left) demonstrated an increase (approximately 0-1 to 3-4 times) of desserts/sweets intake during 7-day post-trial period. Faries et al. (14) indicated that it is difficult to predict people's acute response to stimuli because affective response leads to both positive (approach) and negative (avoidance) motivation for coping problems. However, they also suggested that combination of feeling state scale, arousal scale, and the BIS/BAS model

may be able to contribute to predict individual dietary behavior.

CHAPTER 3

Methodology

This study examined effects of dehydration and exercise in individual frontal alpha EEG asymmetry index (FAI) scores. Eleven well-trained college-aged males participated in two trials (passive dehydration trial and exercise trial), consisting of approximately 150 minutes per trial. For the present study, well trained were defined as engaging in some combination of cardiovascular and strength training activities a minimum of 3 days per week for 12 weeks prior to participation. Prior to the trials being performed, each subject participated in a familiarization session regarding equipment and individuals they worked directly with. Written informed consent sheets were obtained from all participants prior to familiarization session.

During the familiarization session, subjects were asked to keep a written log of what they had eaten during the 24 hours prior to their trial to assist in replicating meals for future trials. Each subject were asked to abstain from consuming alcohol, caffeine, energy drinks, or any other supplements

24 hours prior to their trial. Subjects were instructed to consume 500ml of water at 2100 hours the evening before each trial to help ensure eu-hydration upon arrival to the lab the following day (20). Subjects were asked to abstain from strenuous exercise on the day prior to, and the day of testing. Each subject had their informed consent read to them, asked to sign the form, as well as completed the AHA/ACSM health questionnaire (Appendix A). The subject's height and weight were measured using a Detecto scale (Webb City, MO). Percent body fat was estimated using the three-site method (chest, abdomen, and thigh) following the protocol set by the American College of Sports Medicine (1). Skinfold measurement was obtained using Lang calipers (Cambridge, MD). Furthermore, each participant performed the Bruce Protocol treadmill test to volitional failure to predict individual maximal oxygen consumption (VO_{2max}) using the regression equation (VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$) = $58.443 - (0.215 \cdot age) - (0.632 \cdot BMI) - (68.639 \cdot grade) + (1.579 \cdot time)$) (1). Predicted VO_{2max} will be established to set workloads for the exercising trial. All subjects had a recovery period of at least 24-hours between trials (VO_{2max} testing, passive dehydration, and exercise trials).

Upon entering the lab, subjects were fitted with an electroencephalogram (EEG) mono-polar cap (Electro-Cap International; Eaton, Ohio) at F3 and F4 sites, in order to assess frontal alpha EEG asymmetry (i.e. approach/reward, avoidance/non-reward) motivational orientations. All EEG data were collected and analyzed utilizing a Biopac MP150 system (Biopac Systems Inc., CA, USA) and Acknowledge 4.2 software. A 5-minute nature video (control) was used to stabilize mood, followed by 2 minutes of resting EEG recordings. During resting EEG recordings, subjects were provided a neck pillow and asked to relax. Immediately following the resting EEG measurements, subjects' frontal asymmetry were assessed for 3 additional minutes while being presented with glasses of ice water and 2 different commercially available carbohydrate-electrolyte beverages on the table in front of them, and instructed to observe, but not consume. Frontal asymmetry was re-assessed in the same manner following a dehydration trial to determine changes in frontal asymmetry during eu-hydrated and hypo-hydrated states. All EEG testing was performed in a thermo-neutral environment.

Upon completion of the frontal asymmetry pre-test, urine voids were collected, and urine specific gravity (USG), as well as urine color (UC) were measured to assess subject's hydration levels (Reichert, Inc. Depew, NY). Passive dehydration trials were performed in a controlled hot water bath at a mean temperature of 102.2°F (39°C). The subject's heart rate was monitored throughout the protocol using a Polar chest strap and watch (Polar Accurex II, Finland). Core body temperature was monitored throughout the protocol using rectal thermocouples (Physitemp Inst., Clifton N.J.). A core body temperature of >38.7°C was set as criteria for removal of the subject from the hot water bath for safety purposes. Core body temperature and heart rate were recorded at 5-minute increments (Isothermex, Columbus Inst., Columbus OH).

During the dehydration trial (hot water bath), subjects were seated and submerge to the level of the sternum. Subject's dry body weight was monitored periodically in order to achieve 2% of initial body weight water loss.

During all pre and post EEG trials, subjects were asked to report

several perceptual measures consisting of the Feeling Scale (FS; Appendix B) and the Felt Arousal Scale (FAS; Appendix C). FS is a single-item, 11-point measure designed to assess affective valence (i.e. positive or negative feeling states). The FS ranges from -5 (very bad) to +5 (very good), with an anchor at zero (neutral). FAS is a single-item, 6-point measured designed to measure intensity of perceived activation (i.e. arousal). The FAS ranges from 1 (low arousal) to 6 (high arousal). 100 mm scale was used to examine subjects' desire to consume fluid (Appendix D). Subjects were asked to draw a vertical line on 100 mm horizontal line which left side shows no desire and right side shows great desire for fluid consumption.

Upon achieving 2% dehydration, subjects were removed from the hot water bath, and monitored during cool down periods. Subject's post-trial weight were measured and recorded to assess subject's sweat rate during trials. A second urine void was collected, and USG and UC were measured to determine the subject's hydration status at the end of each hot water bath trial. Subjects then participated in a final frontal asymmetry assessment as described previously.

Trial 2 consisted of an exercise trial being performed in a controlled environment (mean 35°C). Pre and post exercise EEG were recorded in the same manner as trial 1. Unlimited fluid was provided for ad libitum consumption throughout the trial. Water and two different commercially available carbohydrate-electrolyte beverages (15°C) were peripherally available and provided to subjects in 500 ml aliquots. Consumptive rates were calculated to the nearest milliliter for each beverage provided. All subjects walked on a Woodway treadmill (Woodway, Weil am Rheine, Germany) at a light intensity (less than 40% of VO₂ max). Exercise trials were terminated if subject's core temperature exceeded >38.7°C, age predicted maximal heart rate reached, 2% dehydration was achieved, or volitional fatigue was experienced.

The Detecto scale was utilized before and after the exercise trial in order to quantify body water changes. Urine voids were collected before and after trials to assess USG and UC for determination of hydration status (Reichert, Inc. Depew, NY). Sweat rates were calculated using fluid intake values, urine volumes, and variation in body weight (sweating rate =

pre-exercise body weight - post-exercise body weight + fluid intake - urine volume/exercise time in hours) (22).

Statistical Analysis

Variables assessed were heart rate, core body temperature, body weight change (body fluid balance), volume of fluid consumption, perceptual scores, and frontal EEG asymmetry. The subjects with an index of greater than 0 were categorized as behavioral approach, and other subjects with an index of less than 0 were categorized as behavioral inhibition. Mean FAI scores at resting, post-dehydration (trial 1), and post-exercise (trial 2) were created by using right alpha power minus left alpha power ($\log F4 - \log F3$); higher scores represent relatively greater activity in the left hemisphere. The mean change in FAI scores between resting and beverage exposure at baseline, post-dehydration, and post-exercise trials were analyzed using paired t test.

Subjects' volumes of ad libitum fluid consumption and sweat rate during exercise trial were assessed to evaluate individual hydration status. Subjects' fluid replacement status after exercise trials and mean change in FAI score due to beverage exposure were assessed to investigate if the frontal

alpha EEG activity was associated with individual fluid consumption behavior. Each data set was analyzed using non-parametric tests (Wilcoxon Signed Rank Test and Spearman Rank Order Correlation).

CHAPTER 4

Results

Based on pre-trial resting EEG, 11 subjects were categorized either in the approach group with the FAI score more than 0, and 3 subjects were categorized in the avoidance group with the score less than 0. All 11 subjects completed both the passive dehydration and exercise trials. The passive dehydration trials (102 ± 32 minutes) were conducted in mean dry temperature of $33.71 \pm 2.09^{\circ}\text{C}$ and mean hot water bath temperature of $38.62 \pm 0.45^{\circ}\text{C}$. The exercise trials were conducted in mean dry temperature of $34.88 \pm 0.45^{\circ}\text{C}$. Means and standard deviations of subjects' physical characteristics and change of physiological variables are shown in Table 1. There was no significant difference in subjects' hydration status (body weight, USG, and UC) at baseline between the 2 trials ($p = 0.88, 0.94, 0.7$ respectively). During the exercise trials, subjects lost an average of 1675 ± 612 ml of sweat and consumed 1552 ± 736 ml of fluid (mean of 123 ± 848 ml of body fluid loss at post-exercise). During the passive dehydration trials, subjects lost mean of

1864 ± 258 ml of sweat (mean of 2.23 ± 0.31% of initial weight) (Table 1).

Table 1. Means (SD) for subjects' physical characteristics and physiological variables.

Variables	Baseline	Exercise		Dehydration	
		Pre	Post	Pre	Post
Age	23.7 (2.3)				
Height	175.1 (5.6)				
Estimated % Body Fat	12.2 (7.1)				
Estimated VO2 max	46.5 (7.3)				
Weight (kg)	85.7 (10.3)	84.7 (8.6)	84.5 (9)	85.1 (9.2)	83.3 (9.1)
USG		1.019 (.007)	1.018 (.008)	1.019 (.007)	1.022 (.007)
UC		2.5 (0.8)	2.5 (1.5)	2.4 (0.9)	3.4 (1)
Total Sweat Rate (ml)			1675 (612)		1864 (258)
Fluid Intake (ml)			1552 (736)		-

Perceptual Score and Sweat Loss

Means and standard deviations of subjects' perceptual scores at pre- and post-trial as well as scores during the trials are shown in Table 2.

Table 2. Pre-, under-, and post-trial means (SD) for perceptual scores and fluid loss.

Variable	Exercise			Passive		
	Pre	Under Trial	Post	Pre	Under Trial	Post
Feeling Scale	3.8 (1.2)	1.9 (2.0)	3.4 (1.9)	4.0 (0.9)	1.1 (2.2)	2.4 (2.2)*
Felt Arousal Scale	1.4 (0.7)	2.7 (1.9)	1.5 (0.5)	1.3 (0.6)	2.7 (1.0)	1.5 (0.7)
100 mm Scale	39 (23)		45 (25)	42 (18)		66 (25)*
Rating of Perceived Exertion		11.1 (2.7)			10.5 (3.7)	

*Significant change from pre- to post-trial ($p < 0.05$).

There was no significant difference in FS, FAS, and 100 mm scale between the exercise and passive dehydration trials at baseline ($p = 0.67, 0.79, 0.46$ respectively). In the exercise trials, FS scores slightly decreased from 3.8 ± 1.2 to 3.4 ± 1.9 with no significant difference, and there was no difference between pre- and post-FAS (from 1.4 ± 0.7 to 1.5 ± 0.5). Subjects' desire to consume

fluid (100 mm scale) increased between pre- (39 ± 23) and post-exercise trial (45 ± 25) with no significant difference ($p = 0.41$). In the passive dehydration trials, FS significantly decreased from 4.0 ± 0.9 to 2.4 ± 2.2 ($p < 0.05$), and FAS slightly increased from 1.3 ± 0.6 to 1.5 ± 0.7 with no significant difference between pre- and post-trials ($p = 0.7$). The 100 mm scale score was significantly increased from 42 ± 18 to 66 ± 25 between pre- and post- passive dehydration trials ($p < 0.05$) and also compared to the exercise trial ($p < 0.05$). Mean FS score during the exercise was slightly higher compared to during the hot tub submergence with no significance ($p = 0.11$), but there was no significant difference in FAS score between the exercise and dehydration trials. Moderate correlation was seen between pre-exercise 100 mm score and fluid replacement status within all the subjects with no significance ($r = 0.58$; $p = 0.06$) (Figure 1). No correlation was found between post-exercise 100 mm score and the fluid replacement status within all the subjects ($r = 0.3$; $p = 0.37$) (Figure 1).

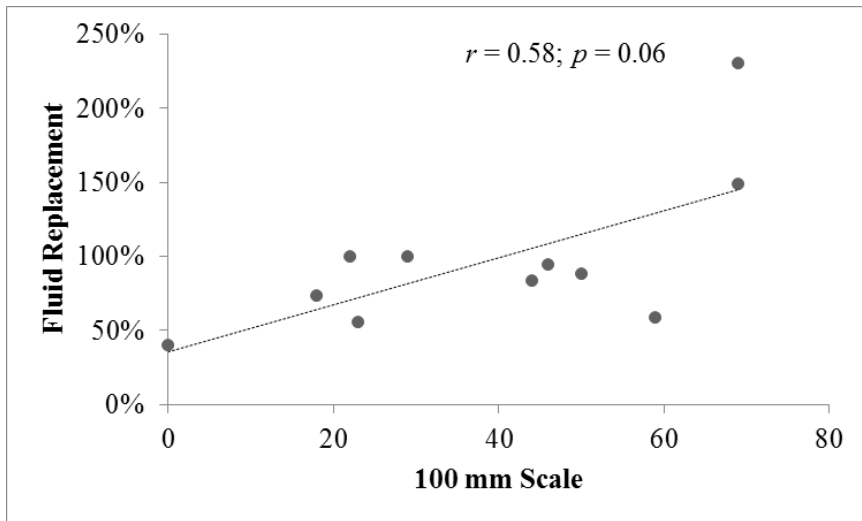


Figure 1. Correlation between pre-exercise 100 mm score and fluid replacement status within all subjects.

Frontal EEG Asymmetry Index (FAI score)

Mean FAI score at each point of EEG recording and mean change in FAI score between resting and beverage exposure for all the subjects, approach, and avoidant groups are shown in Table 3.

Table 3. Pre- and post- trial means for frontal EEG asymmetry index score at resting and beverage exposure.

FAI Score	Exercise				Passive			
	Pre		Post		Pre		Post	
	Resting	Stimulus	Resting	Stimulus	Resting	Stimulus	Resting	Stimulus
Total (n=11)	-0.0764	-0.0732	-0.0591	-0.1528	-0.0623	-0.0393	0.0942	0.1020
Change		0.0032		-0.0937		0.0229		0.0079
Approach (n=8)	0.0214	0.0153	0.0028	0.0035	0.0436	0.0687	0.0437	0.0437
Change		-0.0061		0.0007		0.0250		-0.0001
Avoidance (n=3)	-0.3373	-0.3093	-0.2241	-0.5695	-0.3447	-0.3274	0.2286	0.2576
Change		0.0280		-0.3454		0.0173		0.0290

Within all subjects, there was no significant difference in baseline FAI score between the 2 trials ($p = 0.33$). FAI score did not significantly change due to beverage exposure (stimulus) between pre- and post-exercise trials and also pre- and post-dehydration within all the subjects ($p = 0.53$ and 0.37 respectively). The mean FAI score showed greater than 0 throughout all trials in the approach group while the avoidance group showed negative mean FAI score at all points except after the dehydration trials. The mean FAI score change in the avoidance group greatly decreased after the exercise trials compared to the approach group and other points of EEG recording (Figure 2 and 3). However, no significant relationship was observed between FAI score change due to stimulus throughout all EEG recording and fluid consumption rate during exercise in neither the approach and avoidant groups.

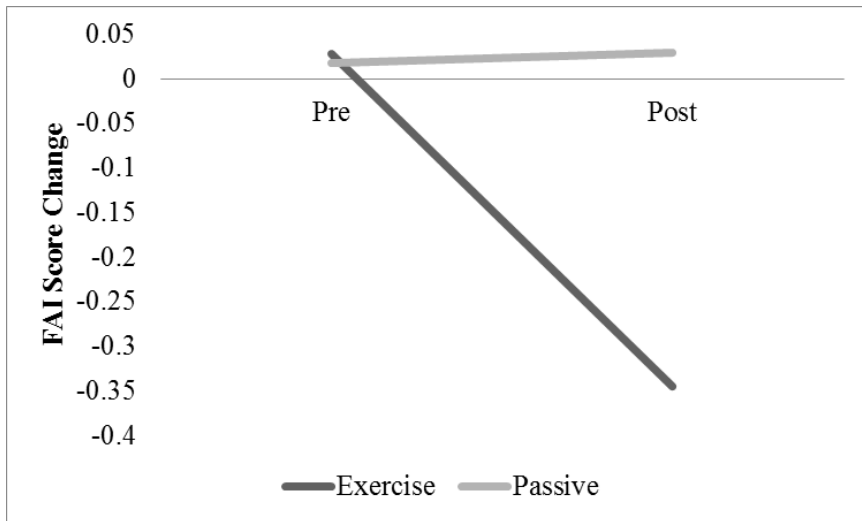


Figure 2. Pre- and post-trial mean FAI score change due to beverage exposure in the avoidant group.

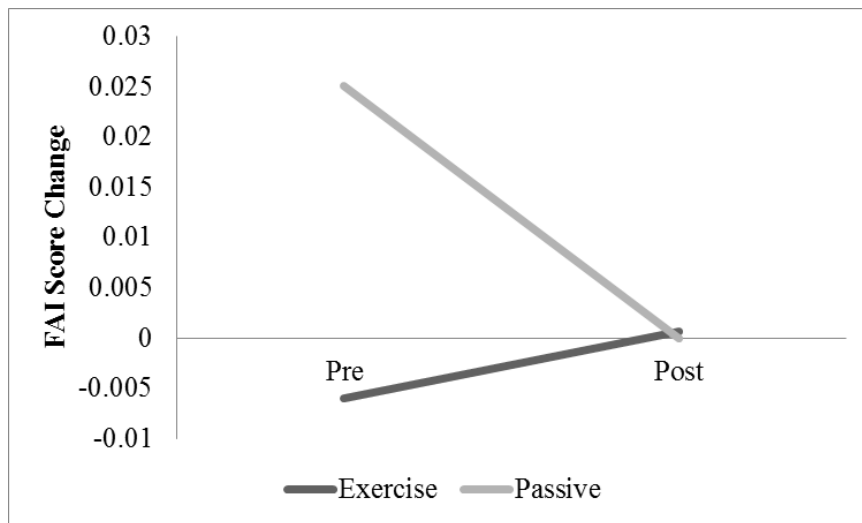


Figure 3. Pre- and post-trial mean FAI score change due to beverage exposure in the approach group.

No correlation was found between resting FAI score and the fluid replacement status during the exercise trials for either pre-exercise ($r = -0.064$;

$p = 0.85$) or post-exercise ($r = 0.16$; $p = 0.65$) FAI scores within all the subjects.

However, only in the approach group, a moderate correlation was observed between mean difference in pre- and post-exercise FAI score change and fluid replacement status ($r = 0.72$; $p < 0.05$) (Figure 4).

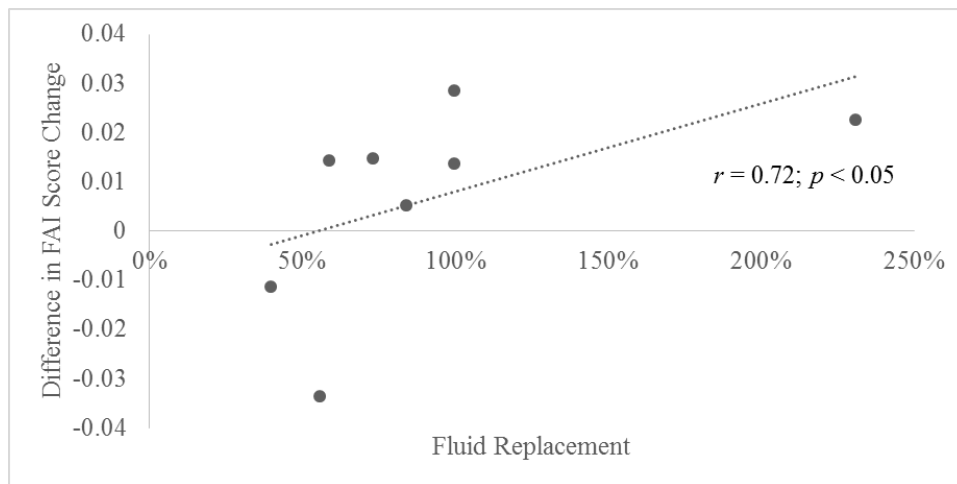


Figure 4. Difference in FAI score change due to beverage exposure between pre- and post-exercise trial in the approach group.

CHAPTER 5

Discussion and Conclusion

The purpose of this study was to examine FAI score in eu-hydrated, hypo-hydrated, and exercise and investigate the relationship between FAI scores (approach or avoidance) and individual fluid consumption behavior during exercise in a hot environment. In frontal EEG studies, it is known that relatively large left frontal EEG activities are associated with behavioral approach systems, and relatively large right frontal EEG activities are associated with behavioral avoidance systems (9, 14, 31). Faries et al. (14) found that there was the relationship between dietary choice (desert/sweets consumption) and individual frontal EEG asymmetry index. According to this study, while the approach group did not change their normal dietary habits, the avoidance group consumed greater amount of desert/sweets and showed significant change in their normal dietary pattern after seeing their own body image. Therefore, it was hypothesized that behavioral approach and avoidance systems are associated with proper dietary choice so that this

present study examined if there was a relationship between individual EEG characteristics (initially approach or avoidance) and fluid consumption behavior during exercise.

Change in FAI Score

Within the dehydration (passive) trial, there was no significant change in FAI score before and after the trials in the approach group. An increase in the FAI score was observed in the avoidance group although perceptual scores were not significantly changed between pre- and post-exercise and dehydration trials within both the approach and avoidant groups. In this study, although insufficient samples in the avoidance group limited our comparisons across groups, in the dehydration trial, FAI score in the avoidant group (n = 3) changed from minus score (avoidance) to plus score (approach) (mean -0.345 to 0.229) between pre- and post-trials, while the approach group did not show a significant change (0.0436 to 0.0437). A large response to brain activity caused by the exercise stimulation and the dehydration was observed in the avoidance group compared to the approach group. These results seem to suggest that the avoidance group may be more susceptible to

environmental stimulations. Faries et al. (14) also indicated that the avoidant group tends to be sensitive to stimulus. Based on these data, we are uncertain to how these greater variations in FAI scores amongst varying environmental settings and exercise or work might affect other behaviors and consumptive tendencies. Mean FAI score was not significantly altered by beverage exposure throughout all the trials both in the approach ($n = 8$) and the avoidant ($n = 3$) groups. However, only in the avoidant group, resting FAI score greatly increased after the dehydration trial, and post-exercise FAI score greatly decreased with beverage exposure with no significance. Due to small sample size within the present study that may inaccurately portray correlations found, relationship between resting FAI and fluid consumption behavior was not found.

Fluid Consumption during the Exercise

For all subjects, there was a moderate positive correlation between pre-trial 100 mm score and actual fluid consumption behavior (percent fluid replacement) during exercise in the heat with no significance ($r = 0.58$; $p = 0.06$). The correlation between 100 mm scale and fluid consumption at

post-trial was weak ($r = 0.3$; $p = 0.37$) compared to pre-trial. There was also no correlation between 100 mm score and fluid replacement in the dehydration trials. However, relatively greater FAI change (more approach) to beverage exposure after exercise compared baseline and higher level of fluid replacement were moderately correlated in the approach group. Also, in the approach group, a correlation was greater between desire for fluid consumption and level of fluid replacement status after exercise. Therefore, these results may be able to suggest that individuals who do not perceive a desire for fluid intake may have the possibility of developing dehydration and/or heat illness during prolonged exercise and/or in a hot environment.

Impact of Exercise and Thermal Stress on Perception

In the present study, no significant relationship was observed between neither FS nor FAS and FAI score. Hall et al. (17) indicated that acute high-intensity exercise activates brain function and increases FAS score, and it was revealed that there is a positive correlation between exercise fatigue and calmness (associated to greater frontal EEG activity). In addition, it was reported that highly trained individuals tend to be categorized in initially

approach group, and exercise shows further increases in FAI score within those individuals. On the other hand, effects on EEG and arousal level differ depending on intensity of exercise, duration, type of exercise, and individual fitness level. Hall et al. (17) also suggested that light intensity of exercise may not significantly affect FAS score. In addition, it was reported that prolonged exercise and/or a hot environment affect cognitive function due to elevated body temperature and voluntary dehydration, especially thermal stress reduces FAS (25). In the present study, well-trained subjects performed low-intensity treadmill exercise for a long time (2 hours) in a hot environment (mean $34.88 \pm 0.87^{\circ}\text{C}$). There was no significant change in FAI score before and after exercise. However, the approach group consistently showed positive scores, and the avoidance group showed negative scores in the exercise trials. These results could indicate that prolonged exercise and hyperthermia possibly inhibited increase of relatively greater left frontal EEG activity. Moreover, thermal stress and exercise might affect subjects' perceptual desire for fluid consumption compared to normal conditions. In the present study, one subject replaced 231% of sweat loss during the exercise

trial, and it caused increase of mean fluid replacement status; other subjects replaced mean of $84 \pm 32\%$ of sweat loss. However, even after removal of this subject data, there was no significant difference between pre- and post-100 mm score (changed from 36 ± 22 to 40 ± 19 ; $p = 0.62$). Although this result was in range of normal fluid regulation in majority of people, half of subjects were hypo-hydrated but did not report great desire for fluid consumption. These results may support that exercise in a hot environment impact individual perception and also frontal EEG activity.

Limitations

In the present study, insufficient sample size seemed to affect the data analysis, especially in the avoidance group. Faries et al. (14) suggested that majority of people could be categorized in the approach group; more samples should have been recruited to get more initially avoidant individuals. In addition, some variation in FAI score within subjects was seen in resting EEG measurements before the first and second trials, although approach or avoidance tendencies did not change. To help ensure more reliable measures, EEG recording time could be extended and greater control utilized in

providing space that is appropriate for such measurements. Also, data for individual fluid consumption behavior in free-living condition should be examined to assess how exercise and/or a hot environment impact individual ad libitum fluid consumption.

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Appendix A

AHA/ACSM Health Questionnaire

AHA/ACSM Health/Fitness Facility Preparticipation Screening Questionnaire

Assess your health status by marking all *true* statements

History

You have had:

- a heart attack
- heart surgery
- cardiac catheterization
- coronary angioplasty (PTCA)
- pacemaker/implantable cardiac
- defibrillator/rhythm disturbance
- heart valve disease
- heart failure
- heart transplantation
- congenital heart disease

Symptoms

- You experience chest discomfort with exertion.
- You experience unreasonable breathlessness.
- You experience dizziness, fainting, or blackouts.
- You take heart medications.

Other Health Issues

- You have diabetes.
- You have asthma or other lung disease.
- You have burning or cramping sensation in your lower legs when walking short distances.
- You have musculoskeletal problems that limit your physical activity.

You have concerns about the safety of exercise.

You take prescription medication(s).

You are pregnant.

If you marked any of these statements in this section, consult your physician or other appropriate health care provider before engaging in exercise. You may need to use a facility with a medically qualified staff.

Cardiovascular risk factors

You are a man older than 45 years.

You are a woman older than 55 years, have had a hysterectomy, or are postmenopausal.

You smoke, or quit smoking within the previous 6 months.

Your blood pressure is >140/90 mm Hg.

You do not know your blood pressure.

You take blood pressure medication.

Your blood cholesterol level is > 200 mg/dL.

You do not know your cholesterol level.

You are > 20 pounds overweight.

You have a close blood relative who had a heart attack or heart surgery before age 55 (father or brother) or age 65 (mother or sister).

You are physically inactive

(i.e., you get <30 minutes of physical activity on at least 3 days per week).

If you marked two or more of the statements in this section you should consult your physician or other appropriate health care provider before engaging in exercise. You might benefit from using a facility with a professionally qualified exercise staff to guide your exercise program.

None of the above

You should be able to exercise safely without consulting your physician or other appropriate health care provider in a self-guided program or almost any facility that meets your exercise program needs.

Appendix B

Feeling Scale

Feeling Scale (FS)

(Hardy & Rejeski, 1989)

While participating in exercise, it is common to experience changes in mood. Some individuals find exercise pleasurable, whereas others find it to be unpleasant. Additionally, feeling may fluctuate across time. That is, one might feel good and bad a number of times during exercise. Scientists have developed this scale to measure such responses.

+5 Very good

+4

+3 Good

+2

+1 Fairly good

0 Neutral

-1 Fairly bad

-2

-3 Bad

-4

-5 Very bad

Appendix C

Felt Arousal Scale

FELT AROUSAL SCALE (FAS)

(Svebak & Murgatroyd, 1985)

Estimate here how aroused you actually feel. Do this by circling the appropriate number. By "arousal" we meant how "worked-up" you feel. You might experience high arousal in one of a variety of ways, for example as excitement or anxiety or anger. Low arousal might also be experienced by you in one of a number of different ways, for example as relaxation or boredom or calmness.

1 LOW AROUSAL

2

3

4

5

6 HIGH AROUSAL

Appendix D

100 millimeter Scale

Draw a vertical mark across the horizontal line below to indicate how great your desire to consume these fluids is.

I do not want to consume these fluids at all.

I really want to consume these fluid right now.

VITA

After graduating from Okayama Hosen High School, Okayama, Japan, Ayano Katayama entered Women's Junior College of Nippon Sport Science University, Tokyo, Japan. Following the transfer to Nippon Sport Science University, Tokyo, Japan, she received the degree of Bachelor of Physical Education in March 2013. Passing through one year at Merced College, Merced, California, she entered the Graduate School of Stephen F. Austin State University, and received the degree of Master of Science in August 2019.

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