Psychogeography of a Marathon Runner: An Exploratory EEG Approach

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Much research has been conducted on psychological states during exercise, over various levels of intensity and duration. Previous studies have explicated physical and mental benefits of endurance exercise, and psychological predictors of performance. This study contributes to that body of research using a novel approach of recording brainwave patterns through encephalography (EEG) during a marathon. Twelve runners (five female, seven male, Mean age = 31) wore portable EEG headsets for the entire race and post-hoc analyses illustrated changes in mental state attributable to distance, finish time, gender, age, experience, altitude gain, and restorative quality of the environment. Principal components regression confirmed retrospective research, asserting that a marathon consists of three psychological stages. Runners are more alert in stage one, then begin to shift toward a rhythm at mile 11 and demonstrate an inward mental shift from mile 18 to the finish. There was little variation in mental state attributable to the independent variables, though males demonstrated higher frontal theta (i.e.inward attention) in stage two, while females exhibited higher global alpha (i.e. relaxation). Results are discussed with regard for previous research and pragmatics of training, sport psychology, and course design.

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Following Roger Bannister's sub four-minute mile feat in 1954, he was quoted as saying, "Though physiology may indicate respiratory and circulatory limits to muscular effort, psychological and other factors beyond the ken of physiology set the razor's edge of defeat or victory..." (Bannister, 1956). The implications of this quote on the scientific study of running were profound in terms of greater awareness of the mind/body connection in human performance. In the latter half of the 20th century, research was devoted to developing a deeper understanding of how a runner's mental state interacted with their ability to cope with the myriad of physiological and psychological demands inherent in distance races like a marathon (c.f. Morgan, 1978; Schomer, 1986). Academics in this line of work have elucidated findings regarding association versus dissociation mental tactics (Zepp, 2016), inward attention approaches to managing stressors (Schomer, 1986), perceptions of "hitting the wall" (Buman, Omli, Giacobbi, & Brewer, 2008), and state anxiety and performance (Raglin & Hanin, 2000), to name a few. Meanwhile, sport psychologists have used this information to identify mental strategies that not only enhance performance, but improve enjoyment and satisfaction, as well (see Brady & Maynard, 2010).

To this end, literature is replete with research designed to educate marathon runners about cognitive processes and coping strategies that enhance performance and/or hedonics. However, there remains a dearth of literature measuring real-time mental states, illustrating personal ebbs and flows over the course of a race (Samson, Simpson, Kamphoff, & Langlier, 2017). Furthermore, a broader research focus may illuminate factors not directly associated with running, but that still affect competitors' mental states, such as environment aesthetics, social cues, atmospherics, and weather.

This study employs electroencephalography (EEG) in an effort to address methodological limitations present among previous psychological studies of marathoners. Much current research in this domain has relied predominately on survey instruments or interview questions requiring retrospective descriptions of mental states or coping strategies. Post hoc self-reporting of attitudes, mood states, emotions, or even pain, introduce complexities that limit the validity of findings (Stone, Shiffman, Atienza, & Nebeling, 2007). Even real-time self-report data could possess limitations, as respondents may attempt to provide meaningful answers that extend beyond the literal meaning of the question in the attempt to accommodate research interests. Bias may also occur in the event that feelings contradict a socially desirable response (DeMaio, 1984).

Use of EEG eliminates the need for information recall and presents a broader picture of competitors' mental states by tracking brain wave frequencies throughout the duration of a race. EEG devices measure a range of brain activity, potentially informing and confirming previous research on a runner's experience. For instance, many have described the psychological stages of a marathon, but no study, to the researchers' knowledge, has captured neurological data in real time to corroborate it. Several researchers have also attempted to examine runners' mental behavior in times of psychological crisis (c.f. McCormick, Meijen, & Morcora, 2018; Schuler & Langens, 2007), but few have studied the "hitting the wall" phenomenon using electrical signals in the cortex. Finally, new developments in mobile EEG technology have presented a valid opportunity to monitor runners' mental state variations real time. This method will not only permit an analysis of physiological effects, but will also demonstrate the impacts of aesthetics and environmental cues on mental states, creating immediate course design implications for practitioners. However, despite the research potential, minimal research exists incorporating EEG amidst athletic performance (c.f. Bailey, Johann, & Kang, 2017; Crabbe & Dishman, 2004; Doppelmayr, Sauseng, Doppelmayr, & Mausz, 2012). Even fewer studies have elected to study mental amplitude for periods longer than one hour. Thus, the purpose of this study was to explore the psychological experience of endurance athletes in action and determine the influence of race stages and course environment on that experience.

Literature Review

Psychological Impact of Exercise

Exercise may have varied impacts on mental functioning, depending on personal characteristics, frequency, longevity and training (Brown, 2015; Martinez, Kilpatrick, Salomon, Jung, & Little, 2015). Running, in particular, has been shown to increase cognitive performance, induce a relaxed mental state, enhance self-efficacy and resilience, reduce stress and improve subjective well-being (Brown, 2015; Martinez et al., 2015; Martinez & Scott, 2016). These psychological benefits may further enhance a runner's performance, creating a positive feedback loop that influences long-term enjoyment of the activity and general well-being (Cona et al., 2015). Distance runners experience these benefits in varying degrees throughout the training process and over the course of a single race. Positive affect and subjective well-being, for example, have been associated with shorter, lower intensity workouts, while distance running can push participants beyond the stage of enjoyment (Martinez et al., 2015; Martinez & Scott, 2016; Woo, Kim, Kim, Petruzzello, & Hatfield, 2009). Over the course of a marathon, a runner's mental state may be in constant flux, influenced by a host of internal (e.g., fatigue, pain, etc.) and external factors (e.g., course aesthetics, social support).

Runners employ cognitive strategies to combat physiological stressors and maximize environmental distractions, as explained by Morgan's (1978) association versus dissociation theory. According to that seminal work, runners employing association mental strategies are often identified as more competitive than those relying on dissociation, due to their acute sense of perceived exertion (Masters & Ogles, 1998). Utilizing inward attention strategies, such as self-talk, imagery, and rhythmic breathing, enables marathon runners to overcome pain, sustain pacing, and ultimately achieve greater physical performance. In contrast, those relying on dissociation tactics rely on non-race-related happenings in order to draw attention away from negative sensations, thereby improving their state of mind while running. Runners who cite dissociation cognitive approaches when enduring a long race have been classified as more casual, and thus, more susceptible to performance below expectations (Raglin & Wilson, 2000; Zepp, 2016). This is generally due to a lack of attention paid to race intensity, which is better achieved via associative strategies (Schomer, 1986; Schücker, Knopf, Strauss, & Hagemann, 2014).

In general, research confirms that runners respond quite individually to the various stressors experienced over 26.2 miles, making deductions based upon recall methodologies susceptible to error (Zepp, 2016). It is evident, however, that runners encounter varying degrees of emotion and utilize myriad cognitive techniques throughout the race to positively manage the experience (Lane et al., 2016; Raglin, 2007). Some techniques are exercised deliberately, while others are triggered by the subconscious. In an attempt to capture a comprehensive depiction of runners' mental states and their levels of intensity, emphasis was placed on five established EEG measures: anxiety, focus, motivation, relaxation, and inward attention. The following review of literature provides a brief summary of how each has been associated with running in previous studies.

Anxiety. Psychological stress can undermine performance by inhibiting sleep, inducing unnecessary calorie expenditure, and creating "tunnel vision" thus impeding racing strategy (Lane et al., 2016; Zepp, 2016). During training, runners rehearse coping strategies to manage stress, including self-talk, goal-making, social support structures, and race modifications (Schücker et al., 2014; Van Raalte, Morrey, Cornelius, & Brewer, 2015). Anxiety, associated with high-frequency brainwaves in the posterior cortex (Oathes et al., 2008), can effectively be reduced through relaxation or concentrative techniques (Stoll & Pithan, 2016). As noted in the previous discussion of association tactics, a runner sensing psychological stress might focus on breathing and movement, or they may repeat words or phrases that divert their attention from the source of the stress (e.g., pain, goal acquisition, etc.). The neurological effect of this technique would be to reduce the high-frequency activity to a lower, more sustainable level for long-term performance (Enders et al., 2016; Lane et al., 2016). A concentrative mental technique could be identifiable through EEG analysis, either as outward distraction (i.e., frontal beta) or inward attention (i.e., frontal theta).

Relaxation and motivation. Relaxation is perhaps the most commonly reported neurological response to exercise and distance running (Crabbe & Dishman, 2004; Gutman et al., 2015; Robertson & Marino, 2015). Signaled by a stronger intensity of alpha brainwave oscillations (i.e. frequency of 8-12 Hz), this resting state inhibits unnecessary or conflicting mental processing in the cortex, preparing the mind for loads imposed by arousal and attentiveness (Klimesch, 1999; Thut, Nietzel, & Pascual-Leone, 2006), motor learning (Jancke, Siegenthaler, Preis, & Steinmetz, 2006), and maintenance in working memory (Jensen & Tesche, 2002). Previous survey and EEG-based research has reported increases in perceived relaxation and alpha-power both during and immediately after a run (Crabbe & Dishman, 2004). These effects are consistent for runs lasting from 20 minutes to 45 minutes, but research on longer-distance events indicates that alpha power may decrease with continued physical effort (Doppelmayr et al., 2012). A relaxed mental state is desirable during physical exertion, as it both conserves energy and enhances positive affect during the activity (Lane et al., 2016). Positive affect, in turn, enhances interest, enjoyment, and motivation. EEG-based motivation, commonly measured as higher relative brain activity on the left frontal lobe (Coelli et al., 2015), differs from trait motivation as measured by psychological surveys. It is a much more malleable construct, changing constantly throughout the participant's experience. Higher motivation during a portion of the race would indicate a more enjoyable experience (i.e. positive valence) that enhances one's willingness to remain involved in the activity (Harmon-Jones, Gable, & Peterson, 2010).

Inward Attention. The final mental state assessed in this study was inward attention. Similar to mindfulness meditation practices, a runner may enter a phase where outward focus wanes and the activity seems to happen automatically. This state, associated with internal awareness, visualization, and "flow," is evidenced by the presence of theta waves in the anterior cortex (Cheron, 2016). Such a meditative state may be induced through mental practice, or it may occur as a result of environmental conditions or even nutrient deficiency (Stoll & Pithan, 2016). In separate studies of runners by Samson et al. (2017) and Nietfeld (2003), competitors reported that only 28% and 12% of their thoughts were non-internalized. In other words, an overwhelming majority of runners report internally-focused cognitive processes in comparison to thoughts external in nature. Sport psychologists differentiate internal thought processes which are task-related from those indicative of distraction from the task (Goode & Roth, 1993). Schomer (1986) notes that inward attentiveness designed to regulate efficiency (i.e., pace, self-talk, breathing) is in line with association tactics (e.g., focus), whereas attentiveness to external events reflects a distractive technique congruent with dissociation (e.g., crowds, ancillary events). According to Morgan, O'Conner, and Ellickson (1988), runners are likely to exhibit greater inward attention when the demands of the activity are heightened and internal attention is necessary to achieve optimal performance. Maintaining inward attention, whether it be a general awareness of one's physiological state or a rhythmic mantra-styled self-talk, would produce a "downshift" in prefrontal activity similar to that exhibited during meditation (Kaur & Singh, 2015; Stoll & Pithan, 2016). Much conceptual research has extolled the association of running with meditation, though a consensus of empirical support is lacking.

Given minimal EEG-based research during physical activity, little is known about the trajectory or direct antecedents of various mental states during a long-distance run. Pre-post and retrospective research designs have helped to elucidate the story of a marathon runner's experience (Benyo, Beverly, & Conover, 1998; Erdman & Lipinska, 2013). These studies provide a general trajectory of mental processes, broken into distinct stages.

Stages of Endurance Running

Preparing for a marathon involves a broad array of tasks, including lifestyle, nutritional, and psychological education, as well as physical training (Cona et al. 2015; Fulton, Richardson, & Griffith, 2017; Zepp, 2016). One key aspect of attaining a time goal is appropriate pacing, which requires adequate planning and the emotional aptitude to manage that plan during the event. To stay on strategy, runners typically divide the race into smaller stages, enabling them to regulate their pace and mental state accordingly. Runners commonly refer to the course by mile marker, though race strategists often divide the race into halves or thirds to accommodate physical and mental tactics appropriate to each phase. Erdman and Lipsinka (2013), for example, assert that the race can be generally perceived as two halves, and pacing should increase during the second half for optimal performance. Other researchers focus on historically troublesome areas, such as miles 18-20, where runners frequently experience the phenomenon of "hitting the wall" (Buman et al., 2008; Stevinson & Bittle, 1998). Benyo, et al. (1998) utilized the "wall" phenomenon to differentiate between the last two of their three-stage model. In their conceptualization, the first stage (start to mile seven) involves finding your pace, warming up the muscles and maintaining emotional stability. Miles seven through eighteen are typically the smoothest portion of the race, where runners find their rhythm and feel relatively positive about the experience. Mile 18 to the finish (the Death March) refers to the often-painful last portion, where glycol levels are low, physical pain is pronounced, and mental capacities are drained. Research has revealed that over 50% of marathon runners experience hitting the wall at some point during the final half of their race with the majority citing the phenomenon around mile 19 (Buman et al., 2008; Stevinson & Biddle, 1998; Smyth, 2018). While training regimens and pacing strategies can lessen the effects of hitting the wall, the phenomenon remains common among amateur runners in the final quarter of the race.

Although gender-based psychological disparities while running a marathon are less pronounced, it is in the demanding final stage that gender differences are most profound. Research over the past three decades has consistently reported that males are more susceptible to psychological stressors consistent with "hitting the wall" than their female counterparts (c.f. Buman et al., 2008; O'Deaner, Carter, Joyner, & Hunter, 2014). As a consequence, a male runner's pace is much more likely to decrease in the second half of a marathon, while females have a tendency to sustain their pace throughout the experience (Smyth, 2018). A variety of explanatory factors have been proposed, such as metabolic makeup, proneness to overheating, as well as competitiveness. With regard to the latter, Stevinson and Biddle (1998) hypothesized that men, more so than women, become more motivated to push the pace, or outperform their perceived expectations during a race, and these psychological characteristics make them more at risk of experiencing the wall phenomenon. Though previous research was conducted post hoc through surveys and interviews, it is feasible that unique stages would be observable through objective EEG measures.

Environmental Psychology

Race courses are often designed for the specific purpose of highlighting the unique aesthetic qualities of the host location (Chen, 2016). Indeed, runners may choose to participate in specific events because of the aesthetic location, in addition to other relevant factors, such as weather and elevation (Getz & Anderson, 2010). Aesthetic qualities throughout the course may prove helpful as runners strive to find the right balance of drive and relaxation, focus and flow, pacing and restraint. Much research indicates that natural environments restore mental energy by reducing attentional loads and inducing relaxed or meditative states (Bailey, Allen, Herndon, & Demastus, 2018; Berto, 2005; Kaplan, 1995). While urban environments usurp mental attention with lights, sounds, and obtrusive structures (i.e., disassociation or directed attention), natural landscapes facilitate inward attention by occupying the mind with objects of "soft-fascination" (e.g., trees, clouds, etc.) which attract attention without depleting it (Kaplan, 1995). Evidence of this effect has been measured through lower heart rate, higher heart rate interval, slower breathing, and relaxed and/or meditative EEG indicators (Berto, 2005; Bailey et al., 2018).

Natural environments have been self-reported to induce more tranquility and less anxiety than urban environments by recreational runners (Bodin & Hartig, 2003). Survey-based research on distance runners also found that natural environments are more conducive to the highly sought after "flow" state, associated with optimal performance and peak experience (Martinez & Scott, 2016). Most race courses will proceed through various segments of urban and green space, each with unique characteristics. To account for the influence of the environment on a runner's mental state, our study incorporated a restorative environment score for every half mile of the marathon route, based on an established psychometric instrument (Ke-Tsung, 2003).

Previous research has reported psychological changes over the course of a marathon and when traveling through natural and built environments. New technologies provide the opportunity to observe mental changes in real time, without the need for post-hoc recall of the entire experience. As such, the purpose of this study was to explore the psychological experience of endurance athletes in action and determine the influence of race stages and course environment on that experience.

Method

Participants

This initiative was largely an experiment of feasibility, given the technical challenges associated with collecting EEG data on active participants over the course of three to five hours. Researchers partnered with the planners for a city-sponsored marathon to solicit participants for the study. Announcements were sent out via social media and an email list of registered runners, to achieve a sample consisting of diversity in gender, age, marathon experience, and estimated pace. Participants were compensated with free race entry and a post-race readout of their mental performance. All agreed to wear an EEG headset the entire race, while streaming their brainwave data online in real time for spectators to observe. Each participant was provided with a unique website with their personal description, picture, and GPS tracking icon so spectators could observe their mental state as they progressed throughout the course. Runners were also permitted to conduct trial runs for the two weeks before the race, by "checking out" a headset from the university lab to determine how it might affect their performance.

Twelve participants were chosen from a pool of 18 applicants, to maximize diversity. This convenience sample included five females and seven males, ranging in age from 19 to 43 years ($M = 30.8$). Four participants were running their first marathon, two had run over 30 marathons, two were avid distance runners who used the opportunity to train for future events, and the rest had successfully completed between one and three marathons. While all runners hoped to perform well, they understood that their pace may be impacted by the research and were accepting of unforeseen delays. Participants were informally interviewed and surveyed to gauge marathon experience, race expectations, and pertinent history. None of the participants reported previous neuro-cognitive conditions or mental illness/injury that would complicate interpretation of EEG signals. All participants completed the marathon, and none reported any major incidents or practices (e.g., injuries, listening to music) that would have grossly affected mental measures during the race.

Procedures

Participants met researchers at the starting line a half-hour before race time to be fitted with the EEG headset. Emotiv Insight headsets were utilized for this study based upon previous successful implementation over an entire marathon (c.f. Fox, 2016) and the low-maintenance, universal-fitting design. Signals were collected using a custom iPhone application, which simultaneously recorded the data on the local device and streamed it to a server over cellular signals. The data were then translated into mental states on the participants' websites for observation and tracking. Data collection was completed successfully for all but two participants. One female participant had very thick braided hair, and the device quickly became disoriented when running. Her data were not used for analysis, as they were clearly contaminated with noise. Another female participant adjusted her headset at mile 16, thereby losing contact with the device's reference node and quickly dropping the recorded signal. Her data were included through mile 15, given its apparent quality upon visual inspection. This resulted in a complete data set for ten participants, and 60% data for one additional participant. Figure 1 illustrates the data for a single participate over every mile. Though much variance is evident throughout, a clear trend in mental focus appears when averaged over multiple time points.

Measurement

Efforts were made to account for major factors influencing a runner's experience, while accepting that many variables could not be predicted or practically measured. Objective measures used in the analyses included the participant's age, gender, finish time (i.e., total minutes running), overall change in elevation per mile of the race course, as well as the aesthetics of each portion of the race. Aesthetics were rated based on an instrument measuring the "mentally restorative" nature of visible scenery over each portion of the race. The Restorative Scale (Ke-Tsung, 2003) includes eight self-report, Likert-scaled items, measuring emotional (e.g., anxious or relaxed), cognitive (e.g., attentive and interested), and physiological (e.g., self-report breathing and tension) impacts of physical space. Prior to the race, researchers completed an assessment at each half-mile of the entire marathon course. Each section was rated by three independent researchers and the final scores were averaged into one composite rating for each half-mile section of the course. This composite number was incorporated into the analysis as the Restorative Environment Score (RES).

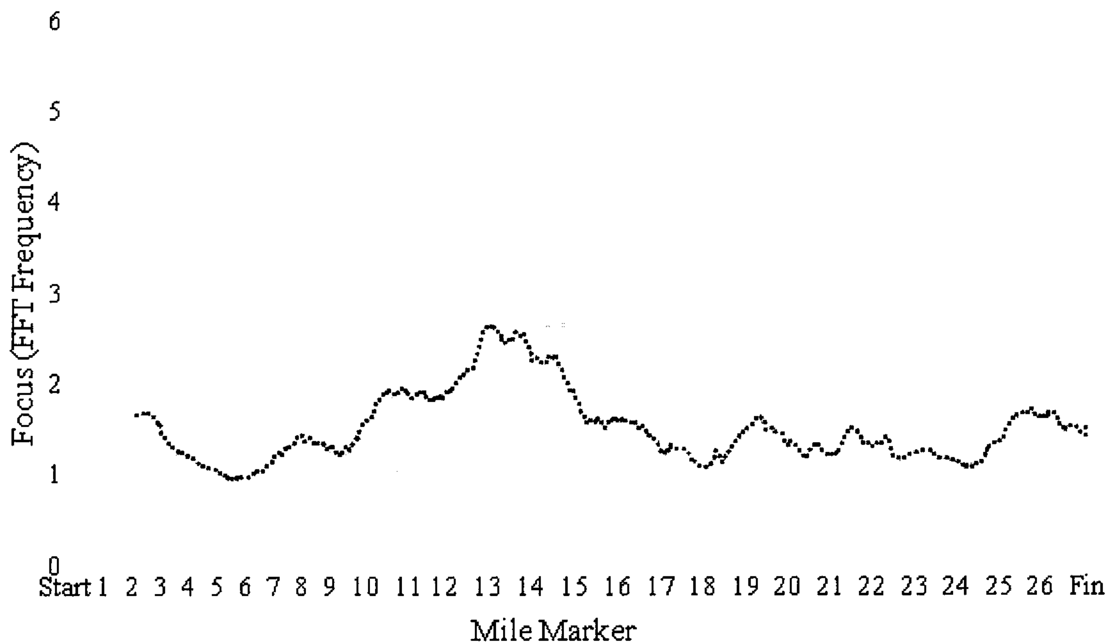

Figure 1. Data reflecting "focus" for a single individual at every mile. Trendline indicates a moving average of 50 time points (or 25 seconds)

Electroencephalogram (EEG). The EMOTIV headset is a brand of mobile EEG that has been utilized in various other studies (Aspinall, Mavros, Coyne, & Roe, 2015; Bailey, Johann, & Kang, 2017). The Insight® utilizes five sensors to measure electrical activity with dry contacts at separate cortical locations, including: right and left frontal lobe (AF4, AF3), temporal lobes (T7, T8), and the parietal lobe (PZ). Signals were collected at a rate of 128 Hz and transformed via Fast Fourier Transformation (FFT) to observe frequency band changes at a rate of twice per second.

Emotiv headsets have been verified as comparable to high-end research EEG systems (Badcock et al., 2015). Additionally, they have been successfully implemented in other research during physical activity, including walking (Aspinall, et al., 2015), climbing/ rappelling (Bailey et al., 2017), and, in feasibility testing, during a full marathon (c.f. Fox, 2016). EEG tracking during exercise is difficult, though becoming relatively common in laboratory settings (Bailey et al., 2008; Enders et al., 2016). Generally speaking, lower frequency oscillations (Delta = .5-3Hz, Theta = 4-7 Hz) indicate lower intensity brain functions such as sleep, meditation, and daydreaming (Clarke et al., 2008). Alpha waves (8-15 Hz) are often associated with a relaxed brain that is ready for action. This is generally due to an inverse relationship between alpha power and cortical activity. Higher frequency waves (Beta = 16-31 Hz, Gamma = 32-100 Hz) are associated with outward focus and higher levels of mental engagement (i.e., concentration, stress, etc.). Complete datasets for marathon runners ranged from just over 21,000 points for the fastest runner (3-hour finish) to over 40,000 for the last finisher.

Data Preparation

Given the high level of physical activity during a marathon, low and high pass filters were utilized to remove all Delta frequencies (< 3 Hz) and Gamma frequencies above 43 Hz. This filter was employed by the hardware before converting the raw data into distinct wavelengths via Fast Fourier Transformation (FFT). Filters reduce unwanted artifacts in the data, produced by ambient electrical signals in the atmosphere or muscle movements. Data were then manually prepared using an iterative process, by first removing all obvious artifacts. Next individual data points more than 3 standard deviations from the participant's average were removed from the analysis, due to the likelihood that it was produced by noise from the participant knocking or adjusting the headset, or any number of incidents that may occur during a marathon. This reduction removed less than 5% of the data. Raw FFT data were then transformed into mental states, based on formulas established in previous research (see below). During this conversion, data were smoothed with a running-Mean over 10 time points (5 seconds). Data were then marked by mile and further reduced for analysis. A sampling of every 5th data point (20% of total data) for each participant was used for analysis. Data reduction is common with high-dimensional analyses, particularly when they will be averaged over time-bound epochs (Ayabe, Kumahara, Morimura, & Tanaka, 2013). Data were median filtered for each epoch, thus removing any common signals across all sensors. Finally, data were standardized to normalize the variance for the entire group, as well as clarify interpretation of changes in mental states, which included variant scaling.

Data were transformed into five empirically-based mental states for longitudinal analysis. High frequency waves across the frontal lobe were used as an indication of mental focus (i.e., concentration) while frontal asymmetry provided an indication of participant interest and enjoyment (Coelli et al., 2015). Higher relative activity on the left frontal cortex is associated with a more enjoyable or interesting experience (i.e., Approach Motivation; AM), while right frontal activity indicates a desire to withdraw from the situation. Anxiety, or high arousal, was measured through relative gamma waves in the posterior cortex (Oathes et al. 2008). Global alpha power across all sensors served as a measure of relaxation (Harmon-Jones et al., 2010). Finally, inward attention was measured as the presence of more powerful lower frequency waves in the frontal cortex (theta) and stronger alpha waves in the posterior, a measure consistent with various forms of meditation in previous research (Kaur & Singh, 2015).

Data Analyses

Given the high-dimensional nature of the EEG data (> 21,000 points per participant), a 26-mile course, and multiple mental states, a factor analysis was initially conducted to reduce the data into discernable components. Principal components analysis (PCA) is a common method of reducing complex, high-dimensional EEG data for further analyses (Costa, Da-Silva, Almeida, & Infantosi, 2014). To determine the progression of mental states throughout the marathon, regression coefficients produced through PCA were plotted for each mile. This provided information regarding psychological "stages" of a marathon for comparison with previous research.

Once the stages had been assessed, data were analyzed for differences in mental states by gender, age, finish time, and marathon experience for each of three marathon stages. In order to compensate for small sample size, non-parametric Mann-Whitney U tests were utilized for analysis of gender and experience variables. Experience was divided into a binary variable to differentiate those who had run a full marathon previous to this experience ($n = 7$) and those who had not ($n = 4$). This was done to strengthen the test and to account for psychological differences when knowing what to expect from the race. Age and finish time were analyzed as covariates in a repeated-measures analysis of covariance (RM ANCOVA) with race stages serving as repeated measurements.

Results

Principal components analysis (PCA) resulted in two factors, predicting 60.97% of the variance (Tables 1 and 2). Factor 1 was labeled "Inward Attention", as it was driven by a high level of inward attention (0.802) and high RES score (0.601), with negative loadings for focus (-0.792), anxiety (-0.687), and relaxation (-0.563). The second factor was labeled "Stress", characterized by a high loading for anxiety (0.543) and focus (0.490), with negative loadings for motivation (-0.529) and relaxation (-0.432). A third factor (loading on elevation change and relaxation) was just below the Eigenvalue threshold of 1.0, but was included in the discussion given its significant contribution to the model (Table 2).

Principal components regression (PCR) was then conducted with mental states as the independent variables and marathon miles as the dependent variable. The resulting biplot is presented in Figure 2, accounting for an adjusted 82.2% of the variance in mile. The psychological experience of a marathon is broken into discrete categories similar to that described by previous research. The initial two miles and the final mile of the race are the most relaxing and motivating. Miles three through 10 induce focus and stress, likely a sign of attentiveness to pacing. Miles 11 through 17 are transitional, not associated with any single mental state. This portion of the race was also influenced by higher elevation gain and higher RES ratings for the Chattanooga course. Finally, the most difficult portion of the race is evident at mile 18 through 25, as inward attention reaches its height.

In accordance with the findings from PCR, data were recoded into three race stages: Stage 1 (miles 1-10), Stage 2 (miles 11-17), and Stage 3 (miles 18-finish). Mann-Whitney U tests were then conducted on mental states for the entire race and each stage by gender and experience, and RM ANCOVA was used to investigate the influence of age and finish time on mental states. Non-parametric tests revealed significant differences for inward attention ($p = .038$) and relaxation ($p = .010$) due to gender, during stage two of the race. Males had higher inward attention during stage two, and women, higher relaxation. There were no significant differences for experienced and novice runners over the course of the race. RM ANCOVA revealed no influence for age ($p = .550$) nor for finish time ($p = .169$) on mental states during any stages of the race.

Discussion

The purpose of this study was to explore the psychological experience of endurance athletes in action and determine the influence of race stages and course environment on that experience. The following is a discussion of the study's most salient findings, implications, and research limitations.

Table 1.
Descriptive statistics for variables included in the Principal Components Regression

Variable	Observations	Minimum	Maximum	*Mean*	*Std. Dev.*
Mile	26	1.000	26.000	13.500	7.649
RES	26	3.920	8.840	6.431	1.211
Elevation	26	6.000	145.000	54.731	43.470
Focus	26	-0.307	0.115	-0.090	0.105
Motivation	26	-0.353	0.368	-0.051	0.138
Anxiety	26	-0.253	0.008	-0.141	0.074
Inward Attention	26	-0.453	0.559	0.071	0.292
Relaxation	26	-0.265	1.868	0.038	0.461

Table 2
Factor loadings and comparative influence on the final model.

	Inward Attention	Stress	Relax
Eigenvalue	2.969	1.299	0.910
Variability (%)	42.418	18.554	13.005
Cumulative %	42.418	60.973	73.978
RES	0.601	0.305	0.009
Elevation	0.454	0.407	0.714
Focus	-0.792	0.490	-0.011
Motivation	-0.585	-0.529	0.000
Anxiety	-0.687	0.543	-0.271
Inward Attention	0.802	-0.199	-0.320

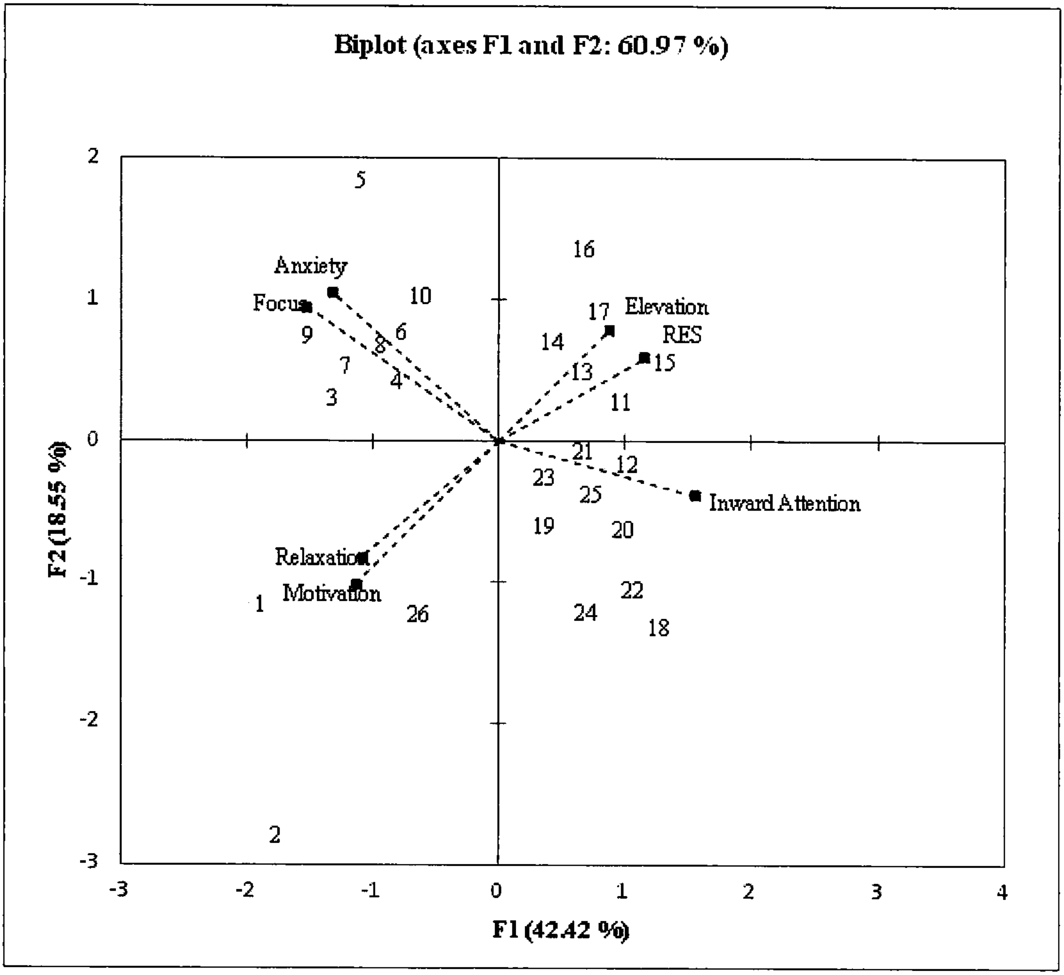

Figure 2. Biplot illustrating loadings for mile on PCA factors:F1 (Inward attention) and F2 (Stress).

Stages of a Marathon

The results generally agree with the previous research on the psychological stages of a marathon, though the specific time of transition differs. For example, Erdmann and Lipinska (2013) were largely concerned with the correct approach to maximizing race performance, dividing a marathon roughly into two halves. Benyo et al. (1998) provided a more in depth analysis of psychological stages, with miles one through seven focused on pacing, miles eight through 17 settling into a rhythm, and miles 18 through the finish being a survival death march. Our results largely confirm those three stages with minor variation. The first two miles and last mile of the marathon appear to be the most pleasant, motivating, and relaxing. The first two miles likely induce enjoyment and relaxation through a release of anticipatory energy and a sense of relief from finally beginning the journey. In our study, miles three through ten reflect the Stage 1 as described by Benyo et al. (1998). Runners demonstrated a heightened level of focus and anxiety, indicative of attention required to find their pace and navigate distractions from others and the environment.

The anomaly of the first two miles may have implications for research on physical activity. For instance, a wide amount of previous research was conducted on participants involved in activity of short duration (20-30 minutes) (Crabbe & Dishman, 2004; Martinez et al. 2015). Given the average daily recommended activity level of 20 minutes a day from the Office of Disease Prevention and Health Promotion (ODPHP, 2018), this duration is not unfounded. However, it is feasible that the benefit of relaxation so often ascribed to running may be duration-dependent. Previous research indicates that relaxation follows a u-shaped trajectory during exercise, reaching a peak at 30 minutes and then dropping to pre-test levels at 45 minutes (Woo et al., 2009). An average runner on an average pace would be somewhere between mile two and three at the 20-minute mark. That is precisely where the mental shift in this study moved from relaxation to "stress." This is not to say that running more than 3 miles is detrimental, but that we do not have a true understanding of what happens psychologically beyond that stage. Cognitive performance temporarily increases as a result of short-term physical activity (Winter et al., 2007), with activity in an outdoor setting reaping greater rewards (Bailey et al., 2018). Routine exposure to physical activity has been shown to have long-term effects, as well (Ploughman, 2008). However, in regards to exercise prescription protocols, more research is needed to understand proper doses of physical activity for specific outcomes, both physical and psychological.

Unlike previous research (Benyo et al., 1998; Erdmann & Lipinska, 2013), our results pinpoint the second stage beginning between mile 10 and 11. Past literature identified above was retrospective and intended to provide general guidance for discrete psychological phases of a marathon. Conceivably, the threshold for stage two could vary based on a myriad of factors, including: physical and mental training, fatigue, weather, venue, ancillary events, and elevation. Elevation is a likely influencer in this study, given change in elevation beginning at mile ten of the race course. This section of the course included steep hills over aesthetic terrain, weaving through trendy upscale neighborhoods, a large park space, and pedestrian bridge crossing the Tennessee River. The change in mental status from outward focus toward inward attention could have been induced by the distance (i.e., entering stage two), challenging terrain, aesthetic location, or a combination of these elements. A post hoc PCR was conducted without elevation and RES in the model, with the initiation of stage two remaining the same. While variance likely exists due to internal and external factors, the general window for a psychological shift during a marathon is the eleventh mile.

In transitioning, then, to the final stage of a marathon, the study's most revealing findings came following the mile 18 point. The pronounced drop in focus after the seventeenth mile reveals a mental shift consistent with previous survey and interview-based research (see Buman et al., 2008; Stevinson & Biddle, 1998). Whether it is due to lower energy reserves or internal coping strategies, all runners demonstrated this shift regardless of gender, experience and finish time. This stretch of the course, often characterized by pain, fatigue, and lack of motivation, has been named "The Death March" (Benyo et al., 1998). While these findings are not novel, they confirm the existence of this phenomenon across gender, experience, age, and pace. It would seem difficult to avoid this experience without drastically changing the race strategy. Training and pacing may delay or minimize the effects (Smyth, 2018), but no amount of pleasantries, aesthetics, course design features or ancillary events can remove that experience once encountered. However, it may provide solace for runners to know that others are experiencing the same thing, and motivation can be garnered from seeing others push through that discomfort. Appropriate expectations may facilitate coping through this stage, and potentially reframe it as a moving meditation (Stoll & Pithan, 2016)

The only noted differences for gender occurred during the second stage of the race, whereby men demonstrated a more meditative state and women exhibited greater relaxation. While it is unclear what the cause of those differences might be, a hypothesis can be drawn from previous research. First, it has become clear that men more frequently stretch their racing capabilities during the middle stages of the race, thereby making them more susceptible to feelings of fatigue and a shift in focus to survival tactics (Buman et al., 2008). Our results indicate a shift toward inward attention at mile 18, though a distinction between dissociative or associative techniques cannot be determined. Stevinson and Biddle (1998) suggest that non-elite marathon runners who report hitting the wall-like symptoms have a much greater disposition towards inward dissociation (i.e., imagination, imagery, meditation) cognitive approaches. As referenced prior, this is in contrast to those in a relaxed and readied state of mind, one characterized by enjoyment and attentiveness. Because women, in comparison to men, have historically shown greater discipline in pacing throughout beginning and middle stages of a race, they are less inclined to demonstrate signs of fatigue, distress, slowing, and pain. Thus, one could posit that because men have a tendency to outpace their abilities early on in the marathon, they may experience meditative states consistent with those found by Stevinson and Biddle (1998) during the middle to latter stages of a run.

Environmental Influence

Unanticipated by the research team, course sections which scored favorably on RES also corresponded with those exhibiting the greatest gain in elevation. While it was hypothesized that course aesthetics, such as green space, affluent neighborhoods, and routes adjacent to the river would trigger positive effects, such as motivation or relaxation, findings proved inconclusive. In reality, elevation gains likely negated any dissociation benefit that may have possibly existed from environmental aesthetics. Reasons for this rest in the psychological tactics runners generally apply when attacking a hill. For instance, running experts often suggest navigating hills by focusing on stride length, posture, rhythm, and reducing sections into manageable segments by mentally ticking off seconds (Zepp, 2016). These are all examples of associative inward attention, enabling competitors to cope with difficult aspects of the course.

Results from the principal components regression affirmed this, as inward attention, elevation, and RES all loaded positively on the same factor. Thus, it appears that momentary physiological stress will provoke inward attention, perhaps being conflated with environmental characteristics. It should be noted that the third factor in the PCA (relaxation; $r^2 = 13\%$) was driven by a positive relationship between relaxation and elevation change, perhaps indicative of aesthetics and downhill sections. Previous research has demonstrated that natural environments induce relaxation and inward attention (Bailey et al., 2018; Bodin & Hartig, 2003), but this relationship was likely confounded by other factors in this study (i.e., distance, stage, elevation). Future research will help determine the influence of natural environments during sustained physical activity.

Conclusions

Marathons push participants through the gamut of emotional, physical, and psychological states. Although irregular conditions, such as elevation, aesthetics, weather, and nutrition may impact individuals uniquely, this study reveals a series of mental states that are invariant over the course of a challenging endurance competition like a marathon. Through real-time, neurological data capturing, this study corroborates previous research, suggesting a psychological sequence of excitement, transitioning to relaxation and focus, then seguing to internal thought processes, and ultimately ending in re-found pleasure. Mental preparation for this cycle prior to a marathon will improve expectations and mental response to shifts in each stage. Educating runners on effective coping approaches to marathon stressors will not only benefit athletes' performance, but their race satisfaction as well. Pre-marathon trainings while wearing a portable EEG device may aid with prescriptive strategies catered to a specific runner and create detailed runner profiles to enhance coaching. Future research may also account for participant motivations, as those hoping to score a personal best would approach those running for pleasure.

In addition to making a contribution to the sport psychology literature, research into runners' mental states may also aid practitioners wishing to augment their course design, accentuate sponsor relations, and improve runners' level of satisfaction. To provide an example, race organizers utilizing a marathon for destination marketing purposes must be cognizant of runners' decreasing awareness of environmental cues as their bodies tire and mental capacities enter a state of depletion. Thus, architectural features or natural environments being showcased to highlight a city's tourism benefits may be best realized during the initial stages of a marathon. One's cognitive focus on external stimuli will also affect sponsorship recall, so vendor placement and sponsorship activation tactics should then be integrated early in the race rather than late. Further research using EEG methodologies is needed to further support these findings, but results from this study provide a foundation by which to compare and contrast future research. In summary, implications derived from this study are not merely theoretical, but certainly have the means to increase participation via improved alertness and race enjoyment.

Limitations

The study provides novel, first-person insight into the psychology of a marathon runner that should be interpreted with regard for study limitations. This is the first known study implementing EEG recordings while running an entire marathon. Though novel and surprisingly successful, skepticism is warranted and the findings require repetition and confirmation to verify the conclusions. It should also be noted that, while the method was novel, the findings were not. Confirmation of previous research cited above lends credit to the results and demonstrates promise for future replication. Small sample size complicates external validity, as well, though comparable samples are common in EEG research. The small sample did preclude thorough examination of certain predictor variables (pace, gender, age, etc.) due to a lack of power. Though participants were permitted to run with a headset before the race, not all runners completed trials. Wearing a headset during the marathon could influence one's mental state through annoyance, discomfort, or the publicizing of emotions. Finally, a lack of randomization (i.e., convenience sampling) diminishes the rigor of the study's design. Given appropriate caution, these results provide an unprecedented glimpse into the first-hand experience of marathon runners.

References

Aspinall, P., Mavros, P., Coyne, R., & Roe, J. (2015). The urban brain: Analyzing outdoor physical activity with mobile EEG. *British Journal of Sports Medicine, 49*, 272-276.

Ayabe, M., Kumahara, H., Morimura, K., & Tanaka, H. (2013). Epoch length and the physical activity bout analysis: An accelerometry research issue. *BMC Research Notes, 6*, 20. https://doi.org/10.1186/1756-0500-6-20

Badcock, N. A., Preece, K. A., de Wit, B., Glenn, K., Fieder, N., Thie, J., & McArthur, G. (2015). Validation of the Emotiv EPOC EEG system for research quality auditory event-related potentials in children. *PeerJ, 3*, e907. https://doi.org/10.7717/peerj.907

Bailey, A.W., Allen, G., Herndon, J., & Demastus, C. (2018). Cognitive benefits of walking in natural versus built environments. *World Leisure Journal, 0*(0), 1–13. https://doi.org/10.1080/16078055.2018.1445025

Bailey, A. W., Johann, J., & Kang, H.-K. (2017). Cognitive and Physiological Impacts of Adventure Activities: Beyond Self-Report Data. *Journal of Experiential Education, 40*(2), 153–169. https://doi.org/10.1177/1053825917701250

Bailey, S.P., Hall, E.E., Folger, S. E., & Miller, P. C. (2008). Changes in EEG During Graded Exercise on a Recumbent Cycle Ergometer. *Journal of Sports Science & Medicine, 7*(4), 505–511.

Bannister, R.G. (1956). Muscular effort. *British Medicine Bulletin*, 12, 222-225.

Benyo, R., Beverly, J., & Conover, M. (1998). The three stages of the marathon: Like a multi-staged rocket, the marathon easily breaks down into three distinct segments. *Marathon & Beyond, 2*(5), 10–29.

Berto, R. (2005). Exposure to restorative environments helps restore attentional capacity. *Journal of Environmental Psychology, 25*(3), 249–259. https://doi.org/10.1016/j.jenvp.2005.07.001

Bodin, M., & Hartig, T. (2003). Does the outdoor environment matter for psychological restoration gained through running? *Psychology of Sport and Exercise, 4*(2), 141–153. https://doi.org/10.1016/S1469-0292(01)00038-3

Brady, A. & Maynard, I. (2010). At an elite level the role of a sport psychologist is entirely about performance enhancement: A debate article. *International Review of Sport and Exercise Psychology, 6*(1), 59-66.

Brown, K. P. (2015). *Marathon training improves perceived stress, self-efficacy, and aerobic fitness in adolescents* (Thesis). https://doi.org/10.15781/T2WG7M

Buman, M. P., Omli, J. W., Giacobbi Jr., P.R., & Brewer, B. W. (2008). Experiences and Coping Responses of "Hitting the Wall" for Recreational Marathon Runners. *Journal of Applied Sport Psychology, 20*(3), 282–300. https://doi.org/10.1080/10413200802078267

Chen, C.-K. (2016). *Staging Mass Participation Marathons in Heritage Tourism Destinations: Seeing Through the Eyes of Distance Runners* (SSRN Scholarly Paper No. ID 2900094). Rochester, NY: Social Science Research Network. Retrieved from https://papers.ssrn.com/abstract=2900094

Cheron, G. (2016). How to Measure the Psychological "Flow"? A Neuroscience Perspective. *Frontiers in Psychology*, *7*, 1823. https://doi.org/10.3389/fpsyg.2016.01823

Clarke, A. R., Barry, R. J., Heaven, P. C. L., McCarthy, R., Selikowitz, M., & Byrne, M. K. (2008). EEG in adults with attention-deficit/hyperactivity disorder. *International Journal of Psychophysiology, 70*, 176-183.

Coelli, S., Sclocco, R., Barbieri, R., Reni, G., Zucca, C., & Bianchi, A. M. (2015). EEG-based index for engagement level monitoring during sustained attention. In *Proceedings of the Annual International Conference of the IEEE Engineering in Medicine and Biology Society, EMBS* (Vol. 2015-November, pp. 1512-1515). [7318658] Institute of Electrical and Electronics Engineers Inc.. https://doi.org/10.1109/EMBC.2015.7318658

Cona, G., Cavazzana, A., Paoli, A., Marcolin, G., Grainer, A., & Bisiacchi, P. S. (2015). It's a Matter of Mind! Cognitive Functioning Predicts the Athletic Performance in Ultra-Marathon Runners. *PLOS ONE, 10*(7), e0132943. https://doi.org/10.1371/journal.pone.0132943

Connick, M. J., Beckman, E. M., & Tweedy, S. M. (2015). Relative Age Affects Marathon Performance in Male and Female Athletes. *Journal of Sports Science & Medicine, 14*(3), 669–674.

Costa, J. C., Da-Silva, P. G., Almeida, R. M., & Infantosi, A. F. (2014). Validtion in Principal Components Analysis applied to EEG data. *Computational and Mathematical Methods in Medicine, 2014*, 1–10. https://doi.org/10.1155/2014/413801

Crabbe, J., & Dishman, R. K. (2004). Brain electrocortical activity during and after exercise: A quantitative synthesis. *Psychophysiology*, *41*, 563–574. https://doi.org/10.1111/j.1469-8986, 2001.00176.x

Deaner, R. O., Carter, R. E., Joyner, M. J., & Hunter, S. K. (2015). Men are More Likely than Women to Slow in the Marathon. *Medicine and Science in Sports and Exercise*, *47*(3), 607–616. https://doi.org/10.1249/MSS.0000000000000432

DeMaio, T. J. (1984). Social desirability and survey measurement: A review (Vol 2.). In C. G. Turner and E. (Eds.), *Martia Surveying Subjective Phenomena*(pp. 257–281). New York: Russell Sage Foundation.

Doppelmayr, M., Sauseng, P., Doppelmayr, H., & Mausz, I. (2012). Changes in EEG during Ultralong Running. *Journal of Human Performance in Extreme Environments*, *10*(1), Article. 4. https://doi.org/10.7771/2327-2937.1047

Enders, H., Cortese, F., Maurer, C., Baltich, J., Protzner, A. B., & Nigg, B. M. (2016). Changes in cortical activity measured with EEG during a high-intensity cycling exercise. *Journal of Neurophysiology*, *115*(1), 379–388. https://doi.org/10.1152/jn.00497.2015

Erdmann, W. S., & Lipinska, P. (2013). Kinematics of marathon running tactics. *Human Movement Science*, *32*(6), 1379–1392. https://doi.org/10.1016/j.humov.2013.07.006

Fox, K. (2016, March 11). Researchers Can Now Look Inside Your Brain During a Marathon. Retrieved May 30, 2018, from https://www.runnersworld.com/news/a20862018/researchers-can-now-look-inside-your-brain-during-a-marathon/

Fulton, A., Richardson, J., & Griffith, K. (2017). Goal Setting and Goal Achievement in Marathon and Half-Marathon Runners. *FHSS Mentored Research Conference*. Retrieved from https://scholarsarchive.byu.edu/fhssconference_studentpub/298

Getz, D., & Anderson, T. D. (2010). The Event-Tourist Career Trajectory: A Study of High-Involvement Amateur Distance Runners. *Scandinavian Journal of Hospitality and Tourism*, *10*(4), 468–491. https://doi.org/10.1080/15022250.2010.524981

Goode, H., & Roth, D. (1993). Factor analysis of cognitions during running: Association with mood change. *Journal of Sport & Exercise Psychology, 15*, 375-389.

Gutmann, B., Mierau, A., Hülsdünker, T., Hildebrand, C., Przyklenk, A., Hollmann, W., & Strüder, H. K. (2015). Effects of Physical Exercise on Individual Resting State EEG Alpha Peak Frequency [Research article]. https://doi.org/10.1155/2015/717312

Harmon-Jones, E., Gable, P.A., & Peterson, C.K. (2010). The role of asymmetric frontal cortical activity in emotion-related phenomena: A review and update. *Biological Psychology, 84*(3), 451-462.

Hubble, C., & Zhao, J. (2016). Gender differences in marathon pacing and performance prediction. *Journal of Sports Analytics*, *2*(1), 19–36. https://doi.org/10.3233/JSA-150008

Jancke, L., Siegenthaler, S., Preis, S., & Steinmetz, H. (2006). Decreased white-matter density in a left-sided front-temporal network in children with developmental language disorder: Evidence for anamotimical anomalies in a motor-language network. *Brain and Language, 102*, 91-98.

Jensen, O., & Tesche, C. (2002). Frontal theta activity in humans increases with memory load in a working memory task. *European Journal of Neuroscience, 15*(8), 1395-1399.

Jiang, N., Gizzi, L., Mrachacz-Kersting, N., Dremstrup, K., & Farina, D. (2015). A brain–computer interface for single-trial detection of gait initiation from movement related cortical potentials. *Clinical Neurophysiology, 126*(1), 154–159. https://doi.org/10.1016/j.clinph.2014.05.003

Kaplan, S. (1995). The restorative benefits of nature: Toward an integrative framework. *Journal of Environmental Psychology, 15*(3), 169–182. https://doi.org/10.1016/0272-4944(95)90001-2

Kaur, C., & Singh, P. (2015). EEG Derived Neuronal Dynamics during Meditation: Progress and Challenges. *Advances in Preventive Medicine, 2015*. https://doi.org/10.1155/2015/614723

Ke-Tsung, H. (2003). A reliable and valid self-rating measure of the restorative quality of natural environments. *Landscape and Urban Planning, 64*(4), 209–232. https://doi.org/10.1016/S0169-2046(02)00241-4

Klimesch, W. (1999). EEG alpha and theta oscillations reflect cognitive and memory performance: A
review and analysis. *Brain Research Reviews, 29*, 169–195.

Lagopoulos, J., Xu, J., Rasmussen, I., Vik, A., Malhi, G. S., Eliassen, C. F., … Ellingsen, Ø. (2009). Increased theta and alpha EEG activity during nondirective meditation. *Journal of Alternative and Complementary Medicine (New York, N.Y.), 15*(11), 1187–1192. https://doi.org/10.1089/acm.2009.0113

Lane, A. M., Devonport, T. J., Friesen, A. P., Beedie, C. J., Fullerton, C. L., & Stanley, D. M. (2016). How should I regulate my emotions if I want to run faster? *European Journal of Sport Science, 16*(4), 465–472. https://doi.org/10.1080/17461391.2015.1080305

Larumbe, E., Perez-Llantada, M. C., Llave, A. L. de la, & Buceta, J. M. (2015). Development and preliminary psychometric characteristics of the PODIUM questionnaire for recreational marathon runners. *Cuadernos de Psicologia Del Deporte, 15*(3), 41–52.

Martinez, C. T., & Scott, C. (2016). Trail and Ultrarunning: The Impact of Distance, Nature, and Personality on Flow and Well-Being. *Psy Chi Journal of Psychological Research, 21*(1), 6–15.

Martinez, N., Kilpatrick, M. W., Salomon, K., Jung, M. E., & Little, J. P. (2015). Affective and Enjoyment Responses to High-Intensity Interval Training in Overweight-to-Obese and Insufficiently Active Adults. *Journal of Sport and Exercise Psychology*, *37*(2), 138–149. https://doi.org/10.1123/jsep.2014-0212

Masters, K.S., & Ogles, B.M. (1998). Associative and dissociative cognitive strategies in exercise and running: 20 years later, what do we know. *The Sport Psychologist, 12*(3), 253-270.

McCormick, A., Meijen, C., & Marcora, S. (2018). Psychological demands experienced by recreational endurance athletes. *International Journal of Sport and Exercise Psychology, 16*(4), 415–430. https://doi.org/10.1080/1612197X.2016.1256341

Meijen, C., Day, C., & Hays, K. F. (2017). Running a psyching team: Providing mental support at long-distance running events. *Journal of Sport Psychology in Action*, *8*(1), 12–22. https://doi.org/10.1080/21520704.2016.1205697

Morgan, W.P. (1978). The mind of the marathoner. *Psychology Today, 11*, 38-49.

Morgan, W.P., O'Conner, P.J., & Ellickson, K.A. (1988) Personality structure, mood states, and performance in elite male distance runners. *International Journal of Sport Psychology, 19*, 247-263.

Nietfeld, J.S. (2003). An examination of metacognitive strategy use and monitoring skills by competitive middle distance runners. *Journal of Applied Sport Psychology, 15*, 307, 320.

Oathes, D. J., Ray, W. J., Yamasaki, A. S., Borkovec, T. D., Castonguay, L. G., Newman, M. G., & Nitschke, J. (2008). Worry, generalized anxiety disorder, and emotion: Evidence from the EEG gamma band. *Bilogical Psychology*, *79*, 165–170.

O'Deaner, R.O., Carter, R.E., Joyner, M.J., & Hunter, S.K. (2014). Men are more likely than women to slow in the marathon. *Medicine and Science in Sports and Exercise, 47*(3), 607-616.

ODPHP. (2018). Scientific Report - 2018 Physical Activity Guidelines - health.gov. Retrieved May 21, 2019, from https://health.gov/paguidelines/second-edition/report/

Pasini, M., Berto, R., Brondino, M., Hall, R., & Ortner, C. (2014). How to Measure the Restorative Quality of Environments: The PRS-11. *Procedia - Social and Behavioral Sciences*, *159*, 293–297. https://doi.org/10.1016/j.sbspro.2014.12.375

Ploughman, M. (2008). Exercise is brain food: The effects of physical activity on cognitive function. *Developmental Neurorehabilitation*, *11*(3), 236–240. https://doi.org/10.1080/17518420801997007

Raglin, J. S. (2007). The psychology of the marathoner. *Sports Medicine, 37*, 404–407.

Raglin, J.S., & Hanin, Y.L. (2000). Competitive anxiety and athletic performance. In Y.L. Hanin (Ed.),*Emotions in sport* (pp. 93-112). Champaigne, IL: Human Kinetics.

Raglin, J.S., & Wilson, G.S. (2000). Psycholgy in endurance performance. In R.J. Sheppard & P.O. Astrand (Eds.), *Olympic encyclopedia of sports medicine and science: Endurance in sport* (pp. 211-219). Oxford: Blackwell Science.

Robertson, C. V., & Marino, F. E. (2015). Prefrontal and motor cortex EEG responses and their relationship to ventilatory thresholds during exhaustive incremental exercise. *European Journal of Applied Physiology, 115*(9), 1939–1948. https://doi.org/10.1007/s00421-015-3177-x

Samson, A., Simpson, D., Kamphoff, C., & Langlier, A. (2017) Think aloud: An examination of distance runners' thought processes, *International Journal of Sport and Exercise Psychology, 15*(2), 176-189.

Santos-Lozano, A., Angulo, A. M., Collado, P. S., Sanchis-Gomar, F., Pareja-Galeano, H., Fiuza-Luces, C., Lucia, A., Garatachea, N. (2015). Aging's Effects on Marathon Performance: Insights From the New York City Race. *International Journal of Sports Physiology and Performance, 10*(7), 840–847. https://doi.org/10.1123/ijspp.2014-0366

Schomer, H. (1986). Mental strategies and the perception of effort of marathon runners. *International Journal of Sport Psychology, 17*(1), 41-59.

Schücker, L., Knopf, C., Strauss, B., & Hagemann, N. (2014). An Internal Focus of Attention Is Not Always as Bad as Its Reputation: How Specific Aspects of Internally Focused Attention Do Not Hinder Running Efficiency. *Journal of Sport and Exercise Psychology, 36*(3), 233–243. https://doi.org/10.1123/jsep.2013-0200

Schuler, J., & Langens, T.A. (2007). Psycological crisis in a marathon and the buffering effects of self-verbalizations. *Journal of Applied Social Psychology, 37*(10), 2319-2344.

Smyth, B. (2018). Fast starters and slow finishers: A large-scale data analysis of pacing at the beginning and end of the marathon for recreational runners. *Journal of Sports Analytics, 4*(3), 229–242. https://doi.org/10.3233/JSA-170205

Stevinson, C. D., & Biddle, S. J. (1998). Cognitive orientations in marathon running and "hitting the wall". *British Journal of Sports Medicine, 32*(3), 229–234. https://doi.org/10.1136/bjsm.32.3.229

Stoll, O., & Pithan, J. M. (2016). Running and Flow: Does Controlled Running Lead to Flow-States? Testing the Transient Hypofontality Theory. In *Flow Experience* (pp. 65–75). Springer, Cham. https://doi.org/10.1007/978-3-319-28634-1_5

Stone, A., Shiffman, S., Atienza, A. & Nebeling, L. (2007). *The science of real-time data capture: Self-reports in health research.* New York, NY: Oxford.

Thut G., Nietzel A., Pascual-Leone A. (2006). Differential distribution of alpha-band electroencephalographic (EEG) activity over occipital cortex indexes visuo-spatial attention bias and predicts visual target detection. *Journal of Neuroscience, 26*, 9494–9502.

Van Raalte, J. L., Morrey, R. B., Cornelius, A. E., & Brewer, B. W. (2015). Self-Talk of Marathon Runners. *The Sport Psychologist*, *29*(3), 258–260. https://doi.org/10.1123/tsp.2014-0159

Winter, B., Breitenstein, C., Mooren, F. C., Voelker, K., Fobker, M., Lechtermann, A., Krueger, K., Fromme, A., Korsukewitz, C., Floel, A., & Knecht, S. (2007). High impact running improves learning. *Neurobiology of Learning and Memory*, *87*(4), 597–609. https://doi.org/10.1016/j.nlm.2006.11.003

Woo, M., Kim, S., Kim, J., Petruzzello, S. J., & Hatfield, B. D. (2009). Examining the exercise-affect dose-response relationship: does duration influence frontal EEG asymmetry? *International Journal of Psychophysiology: Official Journal of the International Organization of Psychophysiology*, *72*(2), 166–172. https://doi.org/10.1016/j.ijpsycho.2008.12.003

Zepp, C. (2016). Coping with Stress During a Marathon. In *Marathon Running: Physiology, Psychology, Nutrition and Training Aspects* (pp. 83–105). Springer, Cham. https://doi.org/10.1007/978-3-319-29728-6_5