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The Dynamics of Rowing

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The Dynamics of Rowing

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Table of Contents

Figures

Tables

Abstract

A phenomena experienced by many athletes, referred to as 'hitting the wall' lacks empirical evidence of occurrence. Data from eighteen collegiate female rowers (eight novice, ten varsity) revealed the dynamics of rowing emphasizing the dynamical pattern for the extreme physical duress period during a rowing task. The pattern identified displayed three distinct portions: the burst, the wall, and the recovery. Participants completed a 2000 meter task and 6000 meter task as a rowing ergometer recorded performance measured in watts during meter intervals. Results showed that the two training levels were significantly different in speed, though the distinct dynamical portions occurred at statistically similar meter intervals in each task for both training levels. Evidence suggests that the dynamical rowing pattern including 'hitting the wall' is dependent on teleanticipatory mechanisms (perceived task end), which occur in the rowing dynamical pattern proportional to the rowing distance regardless the training level or fatigue.

Keywords: hitting the wall, the recovery, the burst, dynamical pattern, teleanticipatory

The Dynamics of Rowing

Rowing history is extensive and is prominent in the sporting realm. *Rowing* refers to the boating competition between athletes on rivers placing oar blades in the water, which are used to pry the boat forward (Chandler, 1988). The earliest known image containing a boat with oars (powered by slaves) dates to 3000 B.C. on a stone wall relief found in Egypt. Virgil's *Aeneid* describes a boat race at the funeral games held in Aeneas's father honor establishing the earliest known rowing account in literature (Chandler, 1988). Rowing developed further on the Thames River in England around the eighteenth century; professional watermen operated ferry crafts along the river and Gentry members, for whom high stakes gambling was a popular past time, began wagering on the watermen (Chandler, 1988). In 1716, Thames watermen competed in a five-mile race from London Bridge to Chelsea. Known as the Doggett Coat and Badge Race: it is oldest documented race in the world and still occurs annually.

Yale started the first college boat club in 1843 and nine years later its team raced Harvard in America's first intercollegiate athletic event. The first regatta in the celebrated rivalry between Oxford and Cambridge Universities was held in 1896, a rowing event was adopted as an Olympic event that same year. Ten years later, the world's most prestigious amateur race, the Henley Royal Regatta, was founded and collegiate women's rowing teams have competed since the 1970's (Chandler, 1988). Today, there are an estimated 12,540 active coaches in the U.S. (doubled since 2004) and 220,000 rowers (+/- 9%), of which 44% are female according to a survey in 2008 (Derringer, 2009). In the 2002-03 school year, there were 1,712 male and 6,690 female collegiate rowers. The U.S. rowing market's annual value is $691 million, a 33% increase since 2004 (Derringer, 2009).

Illustrating 'Hitting the Wall'

Triathletes and cyclists commonly refer to physical duress episodes as "bonking" and marathon runners refer to it as "*hitting the wall* (HTW)". A recurring issue within the rowing sport is the HTW phenomenon. Characteristics are mostly physiological (Morgan, 1978) marking HTW as the sudden onset and rapid performance degradation. The phenomenon is a multi-faceted experience affecting behavior, physiology, and cognition in a complex manner (Buman, Omli, Giacobbi, & Brewer, 2007) emphasized by nonlinear dynamical systems theory stating the feedback loop generated by the interaction results in a circular causality (Kelso, 1995). Despite rowing's popularity and history, however, empirical work on the sport is lacking and especially on the HTW phenomenon.

No consensus on an acceptable conceptual definition for the HTW phenomenon is apparent in available literature (Buman, Brewer, & Cornelius, 2009), perhaps because the literature may be resulted from the need for an objective quantitative measure to replace self-reports dominating the phenomenon's research. These characteristics are well documented in marathon runners but there is no empirical evidence for the phenomena in rowing. The current work addresses this deficiency by investigating the dynamics of rowing including the behavioral, physiological, and cognitive factors for the extreme physical duress period's dynamical pattern. During the rowing tasks, the predicted dynamical pattern will contain the HTW phenomenon.

'Hitting the Wall' for Athletes

This phenomenon is widely explored in marathon running. The HTW phenomenon displays behavioral characteristics such as (a) loss of form, (b) pace disruption (maintained effort), (c) performance difficultly, and (d) tunnel vision (Buman et al., 2007). Marathon runners experience the wall after the 19-mile mark (~71% of task completion)—the runners' pace slows, legs feel leaden, feet feel numb and they lose muscle coordination. Earlier phenomenon encounter onset in the marathon is correlated with longer wall experience duration, but finishing times do not differ among participants who report HTW and participants who do not (Buman, Brewer, Cornelius, Van Raalte, & Petitpas, 2008), suggesting that participants who report HTW pushed to increase their pace at the marathon onset, subsequently slowed their pace and experienced a decrement in performance once they HTW. After understanding what rowing is, the phenomenon's behavioral characteristics are more specifically identified as it uniquely pertains to rowers.

An understanding of the physical nature of rowing is necessary to understand what HTW would look like in this sport. Rowing involves repetitive cyclic motions performed by oarsmen with different directions repeated approximately 220-240 times during a 2000 meter (m) task and 660-680 during the 6000 meter (m) task (Shimoda, Fukunaga, Higuchi, & Kawakami, 2007). The oarsmen use their body to give power to their oar by driving with the legs and sliding backwards on a seat gaining the most power followed by finishing the stroke by leaning back and bringing the hands to the chest. Each rower generates, in synchrony, around 450 Newtons of force over 200 strokes (Hagerman, Conners, Gault, Hagerman, & Polinski, 1978; Mahler, Andrea, & Anderson, 1984; Hartmann, Mader, Wasser, & Klauer, 1993; Schabort, Hawley, Hopkins, & Blum, 1999). The increased power comes from increased length leverage on the oar through athletes' longer limbs, aimed at moving the boat with the maximum speed. Body mass is compensated by the gliding as the body is supported by a sliding seat in the boat. This sliding seat results in the fat mass percentage having little effect on the oarsmen's power performance capability found in other sports (Drarnitsyn, Ivanova, & Sazonov, 2009), thus, body mass impact lack does not reduce the muscle inclusion or workload.

The major muscle groups exercised include quadriceps femoris, bicep brachial, triceps brachial, latissimus dorsi, gluteus and abdominal muscles. As the rower *catches*—the stroke position at which the oar blade enters the water and the drive begins; rowers conceptualize the oar blade as 'catching' or grabbing hold in the water—the machine "oars" and begins to pull forward, the pelvis and thighs are engaged; the rower pulls, involving the arms, shoulders, back, and abdomen, then the rower slides back, initiating the legs, hips, and torso to do the brunt of the work. The challenge in team and competitive rowing is synchrony with the other rowers, dropping the blades in the water together, pulling through the stroke together, lifting the blades cleanly from the water together, and swinging the oars back into place for another stroke together. Results in rowing also depend on environmental factors (i.e. wind force and direction, water density, currents, boat model, and so on) and, when conditions are not suitable for training, rowing ergometers are utilized.

Rowing ergometers conduce a comparable workout to waterborne training and provide a valid fitness measurement (Schabort et al., 1999). Most investigations into the relationship between physiological parameters and sports results are based on Concept II ergometer tests (Riechman, Zoeller, & Balasekaran, 2002; Ingham, Whyte, Jones, & Nevill, 2002). Ergometer test results are an objective quantitative fitness measure to assemble the fastest *crew*—rowers included in a single boat—possible. These machines are used to evaluate rowers and athlete selection for many senior and junior national rowing teams (Nevill, Beech, Holder & Wyon, 2010). During a test, athletes row a set distance (2000 m or 6000 m), trying to clock the fastest time possible: this results in the exhibition of a unique race pacing physiological pattern discernible through the ergometer data spreadsheets by coaches and competitors.

The Muscle Fibre Wall

Athletes begin rowing in a race with a vigorous sprint, followed by a severely high *aerobic steady state*—a state obtained in moderate exercise when the lactic acid removal by oxidation keeps pace with its production—and then an exhaustive sprint at the finish (Hagermann, 1984). The rower's metabolism is slow when compared to that of a runner. The slow twitch muscle fibres percentage in rowers is as high as 85%, while the remainder fibres are dominated by fast twitch fibres with high oxidative capacity (Roth, Schwanitz, Pas, & Bauer, 1993). A rower's large strength is reflected in *muscle hypertrophy*—the growth and increases in muscle cell size—in fast and slow twitch fibres. Uniquely in rowers is the slow twitch fibres are larger than the fast twitch fibres (Roth et al., 1993). Thus, the rowing sport is a multi-faceted experience unlike any other sport.

In contrast, runners often begin races at a fast pace, increasing their probability to HTW—due to physiological and metabolic exertion the heart cannot pump enough blood to ensure a steady oxygen supply to the muscles and burn glucose in oxygen absence. Cells can derive energy from carbohydrates either *aerobically*—in the presence of oxygen—or *anaerobically*—in the absence of oxygen (Volianitis et al., 2004). The anaerobic glucose metabolism becomes inefficient, yielding only about one-eighteenth the energy (in the adenosine triphosphate form) as aerobic metabolism. Among the anaerobic glucose metabolism by-products are the waste products lactic acid and hydrogen ions. Waste products accumulate in the blood and tissue making a burning sensation in muscles and inactivate the enzymes governing glucose metabolism (Williams, 2007). Blood becomes thicker causing the heart to pump harder and increases pace maintenance difficulty when slightly dehydrated (Johnsen, Ullum, Jensen, & Secher, 2001). Physical efforts in response to HTW include supplementation/hydration and reducing physical demands.

HTW characteristics are primarily physiological in nature and defined by the being of sudden onset and showing a rapid performance degradation (Morgan, 1978). Physiological characteristics often experienced include: (a) cardio-respiratory, (b) cramping, (c) dietary/hydration, (d) generalized fatigue, (e) illness, (f) leg-related fatigue, (g) pain and (h) sensory distortions. The earliest HTW descriptions included various extreme physical weakness manifestations suggesting HTW in a physiological effect and motor capabilities discretely and poignantly (Manuel, 2000) at a predictable time point between miles 18 and 21 (Masters & Lambert, 1989; Okwumabua, 1985; Summers, Sargent, Levey, & Murray, 1982). From the physiological standpoint, rowing is a mixed strength-endurance sport (Mäestu, Jürimäe, & Jürimäe, 2005). Rowing falls between both "sports phenotype spectrum" endpoints (power v. endurance) and a considerable aerobic and anaerobic performance components capability manifestation provision are encompassed in the sport (Winter, 2006). Competitive activity in 2000 m rowing tasks lasts for six to eight minutes, long enough to require endurance but short enough to feel like a sprint respectively placing rowing as a sport that is a multi-faceted experience.

The Metabolism Wall

Physical activity in rowing is approximately 70% aerobic, with the anaerobic component accounting for 21—30% (Secher, 1993; Shephard, 1998). Rowers' aerobic component is the largest among endurance athletes (~6.9 l min^{-1}). The demand for a large stroke volume in addition to overcoming the high blood pressure at each stroke beginning (Clifford, Hanel, &

Secher, 1994), in response to a Valsalva-like maneuver, is manifested in a heart output comparable with the largest hearts among elite athletes. Athletes' cardiac output ranges from 30 to 40 l min^{-1} during exercise. Anaerobic metabolism, indicated by blood lactate, may reach 32 *millimolar* (mM)—a solute concentration measure in a solution—during rowing and plasma bicarbonate is eliminated, while pH decreases to 6.74 (Nielsen, 1999; Mattern, Gutilla, Kirby, & Devor, 2007). Thus, the oxygen deficit, representing the metabolism part that is not covered by oxygen uptake is 90 ml kg^{-1}, or ~30% larger in comparison with running (Medbo et al., 1988). Central blood volume is higher during seated rowing compared to running and allows for lower heart rate and larger *VO_2max*—maximum capacity an individual's body can transport and use oxygen during incremental exercise, which reflects physical fitness (Yoshiga & Higuchi, 2002). Despite the cramped body position during the initial rowing stroke phase, 270 l min^{-1} ventilation is developed (Jensen, Johnsen, & Secher, 2001). The elite rowers' physiological parameters relationship and sport performance results from 2000 m and 6000 m competitions with rowing ergometers display the *cardiorespiratory parameters dynamics*—forces and motions that characterize a system's limit or boundary related to the heart and the respiratory system—illustrated here (Drarnitsyn et al., 2009). The motion involved in rowing compresses the athletes' lungs; it limits the oxygen amount available and creates cardiorespiratory parameters (Vogelsang et al., 2006).

The cardiorespiratory parameter dynamics require rowers to tailor breathing to the stroke inhaling and exhaling twice per stroke, unlike most other sports such as cycling and running where competitors can breathe freely (Mäestu et al., 2005). The aerobic contribution to the total energy production during competition represents ~70% (Shephard, 1998) and yet muscle's ability to produce high power (400—500 watts/ stroke) at high velocities is important (Ivanova & Sazonov, 2009). Rowers have the highest power outputs in any sport (Mäestu et al., 2005). Rowing over a 2000 m course, accomplished in about five to six minutes, requires ~590 watts and represents a maximum for humans, while the oxygen transport system from atmospheric air to the working muscles is challenged.

Runners' primary fuel sources are carbohydrates in the blood glucose form, glycogen and fats—free fatty acids. Fat would be a logical first fuel choice for endurance events, but the fatty acid metabolism requires plentiful circulating oxygen, whereas carbohydrate metabolism requires less oxygen with glucose staying in a muscle until metabolized; nonworking muscles cannot transfer glycogen to working muscles. Sex differences in fuel metabolism have led some scientists to speculate men of depleting glycogen stores more rapidly than women (Loftin et al., 2009). HTW is defined as the point "where glycogen supplies have been exhausted and energy has to be converted from fat" (Stevinson & Biddle, 1998, p. 229), operational definition for exhausting energy (Midgley, McNaughton, & Jones, 2007). Once the glycogen supplies are exhausted, athletes' bodies and minds become fatigued increasing cognitive difficulties (Williams, 2007).

The Cognitive Wall

Runners experiencing HTW report cognitive difficulties, including confusion and self-doubt (Midgley et al., 2007). Other cognitive factors impacted by HTW include: (a) anxiety, (b) changing goals, (c) confusion, (d) mental battle, and (e) trouble focusing, as well as decreased motivation and the desire to quit are also identified in the literature. As success in sports is 60 to 90 percent attributed to "mental factors and psychological mastery" (Raglin, 2007), HTW is obliviously a major concern in performance. Central nervous system (CNS) fatigue results from neurochemical changes in the brain and is involved in HTW during a marathon. Elevated serotonin levels have been implicated in lethargic feelings, which increase during prolonged exercise due to increased tryptophan delivery to the brain (Williams, 2007). The brain's *dopamine production*—the neurotransmitter responsible for generating feelings expressed as excitement, reward, motivation, and pleasure—begins to drop as serotonin levels rise (Williams, 2007). *Stress elements*—events occurring in the environment or in the body making an emotional or task demand on the person (Hobfoll, 1988)—are triggered by disturbances or changes in either: affective; cognitive; motor behavior; or physiological systems (Lazarus, 1999). HTW can, therefore, be studied as a distinct construct conceptualized as a stress form beyond normal fatigue.

Ultimately, the brain limits performance and central fatigue described by central limitation in slow twitch recruitment rather than fast twitch fibres since the contraction maintains tension rise rate while losing endurance (Secher, Seifert, & Van Lieshout, 2008). Longer races during training are the foundation for the Spring season, building the rower's endurance and mental toughness over a competition year (Chung-Jung, Nesser, & Edwards, 2007). HTW occurrence appears more prevalent among men than among women influenced by expectancy (Buman et al., 2008). In response to mental stress, circulating *eosinophils*—white blood cells containing granules stained by eosin or other acid dyes—decrease by 80% before and are almost eliminated after a rowing race (Renold, Quigley, Kennard, & Thorn, 1951). Thus, rowing is a stressful experience beyond normal fatigue in which the body reacts intensely and recovers quickly.

Adaptations to endurance sport stress and stress appraisals are constantly in flux given the duration and intense situational or person-centered stress and can be predicted by the relational meaning between the person and her environment (Buman et al., 2007). Nonlinear dynamical systems theory avoids the causality fallacy by emphasizing the functional interaction between variables (Kelso, 1995). Perceived exertion is dependent upon *teleanticipatory mechanisms*—the finishing point perception—that may be mediated by associative/ dissociative strategies (Baden, Warwick-Evans, & Lakomy, 2004). Perceived exertion is reduced by psychological states that reduce fatigue by occupying fewer attentional resources (i.e. dissociation; Rejeski, 1985).

The most commonly observed cognitive strategies are mental reframing and performance justification in response to HTW (Buman et al., 2007). Elite runners tend to use associative thinking strategies—thinking about physical sensations, such as breathing, muscle soreness, or blisters, and other race-related issues such as pacing and competitive strategy—during competition (Masters & Ogles, 1998). Therefore, HTW can occur in any task including rowing competitions.

Finding the Wall

The purpose of this study was to investigate the dynamics of rowing among collegiate female rowers and assess the dynamical pattern for the extreme physical duress period during rowing tasks, in an attempt to provide empirical evidence for three distinct portions in the dynamic pattern: the burst, the wall, and the recovery. *The burst* is the point in the rowing task in which the rower has a steady decline in performance and suddenly increases in performance. *The wall* occurs after the burst when a sudden onset and rapid degradation in performance until decline peak. Once performance reaches the peak in decline (the end of the wall) *the recovery* begins at which point performance increases until the rowing task end where performance peaks. As perceived exertion is dependent upon teleanticipatory mechanisms during any task (Baden et al., 2004), the dynamical pattern is expected to be similar within different rowing tasks varying in distance and training level. The more familiarity with the task, the more consistent portions in the dynamical pattern should occur. Thus, novice should have more variability within their dynamical pattern and varsity's dynamical pattern should exhibit distinctive portions. Knowledge about the dynamical pattern of extreme physical duress will set the stage for future work to delay onset, decrease severity, and avoid the phenomenon.

Method

Participants

Participants included eight novice rowers and ten varsity rowers from a university women's rowing team. Participants had no previous rowing experience before team affiliation. *Novice* participants were untrained, obtained basic knowledge of rowing and had no prior experience with the tasks. *Varsity* participants were trained, varied with rowing experience (1 to 3 years of training), and had experience with the tasks. Participants varied in weight (110-225 lbs), height (5'2" to 6'4"), age (18-23 years old), and athletic background. To join the team, the females met all National Collegiate Athletic Association (NCAA) guidelines, including completed a physical each Fall semester to participate in college sports and hold a 2.5 grade point average (GPA) or higher to qualify for the collegiate team.

Apparatus

The protocols for testing rowing performance recommend the Concept 2 rowing ergometer machine that stimulates the rowing action providing a means of training on land and measuring rowing fitness when waterborne training is restricted (Schabort et al., 1999). The Concept 2 ergometers operate on air resistance generated by wind caught in the spinning flywheel (Diameter=6; Schabort et al., 1999). The Concept 2 Model D rowing ergometer has a resistance when pulled between 4 and 5. The Concept 2 model D rowing ergometer is 7’11” in length and 24” in width (Schabort et al., 1999). The seat sits at a height of 14” and the apparatus consumes 9’ x 4’ area. A spiral damper creates the restraints that allow variability in the rowing workout intensity. The aluminum rail capped with a stainless-steel track for smooth seat movement. Ergometers do not simulate the lateral balance challenges, the exact water resistance, or the exact rowing motions, including the oar handle sweep. However, this action allows a comparable workout to waterborne training and provides a valid measurement of fitness (Schabort et al., 1999).

Figure 1. Photograph of collegiate female rowers training on rowing ergometers.

The rowing ergometer monitor (PM3) measures the *drag factor*—a numerical value for the rate at which the flywheel decelerates—on each stroke recovery phase and calculates performance measurement using the power equation (power = force x distance /time; power: watts, force: drag factor, distance: meters, time: split; Schabort et al., 1999). This number changes with air volume that passes through the flywheel housing. This "self-calibration" method compensates for local conditions and damper settings, making scores on different indoor rowers comparable (Schabort et al., 1999). For consistency and comparability it is vital the ergometer test is completed in an identical manner each time. The measured power output is within plus or minus two percent of the true value according to the manufacturer, but it is not possible at the present time to dynamically calibrate rowing ergometers (Winter, 2006).

To calibrate the ergometers for the current study, a volunteer elite rower performed an adequate warm up and completed three strokes at maximal effort with fifteen-second breaks between machines. The ergometers did not significantly differ in split $t(24)= 281.788$, $SD=.01$, $p>.05$. The PM3 included an outlet for a log card to record performance below the screen (Schabort et al., 1999). The log cards record the rower's name, workout, total time, total meters, average strokes per minute, time to row split length, split length, strokes per minute for split length, split, possible calories burned per hour for split length, and watts per split length (Schabort et al., 1999). All of the measurements above inform participants during rowing tasks and are recorded for performance tracking. Appendix A contains photographs of these materials.

Procedure

Participants received an informed consent form and read along silently as the form was read aloud to them. Once the participants signed the consent form, the form was folded in half and placed in behind the participant's ergometer by the participant where other participants, coaches, and researchers could not see participation agreement decision.

Participants were tested for speed with a 2000 m rowing distance (sprint) and a 6000 m rowing distance (endurance) on a Concept 2 model D rowing ergometer. The 6000 m task was completed first followed by the 2000 m on a separate day. Participants completed both rowing tests after an adequate warm up, including a quarter-mile jog, static stretching with shoulders, lower back, hamstrings, quadriceps, and calves, followed by a steady state row on the ergometers for eight minutes with an increase in intensity for the last 30 seconds of the middle four minutes. Rowers chose an aligned ergometer facing the field house wall with varsity at one end and novice at the other. Participants were able view other participants' monitor on either side. After the eight-minute rowing warm up, participants got water and stretched for three minutes. Varsity received a goal, set by the head coach, based on previous performance. Novice participants lacked a previous performance, therefore received an estimated goal instead. These tests were explained as an all out rowing test and if the rower felt as if she could row faster than the set goal, she should do so to get the best time possible.

Participants obtained a memory card that was inserted in each PM3. After the memory cards were in place, participants programmed the monitors for the set distance (2000 m or 6000 m). The coach verbally went through the steps to program the monitor, in order for the rowers to complete together. Participants sat at the catch to indicate readiness. After all participants were in the position, the coach gave the command “row”. This command instructed the participants to begin the test. The *coxswains*—team members that do not row, instead steer the boat while giving informative feedback and encouragement to rowing individuals—and coaches encouraged the rowers throughout the test. Once rowers finished the task and cooled down, they encouraged the other team members not yet finished with the task. The research procedure was approved by the Institutional Review Board of the University of Central Oklahoma.

Data Analysis

The inputs to the data analysis were the performance (in watts) during meter intervals (MI). MI amounted to 100 m during the 2000 m task and 200 m during the 6000 m task. Two way mixed factorial Analysis of Variance (ANOVA) were conducted separately by distance rowed to determine dynamical portions’ occurrences through pairwise comparisons. Next, the MI, in which a dynamical portion occurred, was divided by the total number of MIs in that rowing task for each participant producing ratio data used in primary analysis. For the primary analysis, a two (Distance Rowed: 2000 m, 6000 m) within participants by two (Training Level: novice, varsity) between participants mixed ANOVA was employed to test the effects of training level on rowing performance during rowing tasks. Appendix B contains raw data for 2000 m task and Appendix C contains raw data for 6000 m data.

Results

Raw data inspection showed that training levels are significantly different independent groups, such that varsity was faster in the 2000 m rowing distance, $F(3.5,55)=17.295$, $p=.000$, $\eta_p^2=.519$, observed power of 1.00, and the 6000 m rowing distance, $F(3.5,58)=15.296$, $p=.000$, $\eta_p^2=.459$, observed power of 1.00. Distance rowed was separately subjected to two way mixed factorial ANOVA, with training level as the between participant factor and meter interval (MI) as the repeated measures factor.

According to the study hypothesis, a dynamical pattern for the extreme physical duress period during the rowing tasks was expected with three distinct portions: the burst, the wall, and the recovery. In particular, the burst should display a sudden increase in performance after a steady performance decline, followed by the wall, which should produce a sudden and rapid degradation in performance until performance decline peak. The recovery should begin at the end of the wall, increasing performance until the end of the rowing task at which point performance should peak. As Figure 2 reveals, there is a dynamical pattern for the extreme physical duress period in the 2000 m rowing distance with the three distinct dynamical portions in both training levels. Figure 3 reveals the same dynamical pattern for the 6000 m rowing distance. The MI in which each dynamical portion occurs in both distances rowed is presented in Table 1. Appendix D contains raw ratio data.

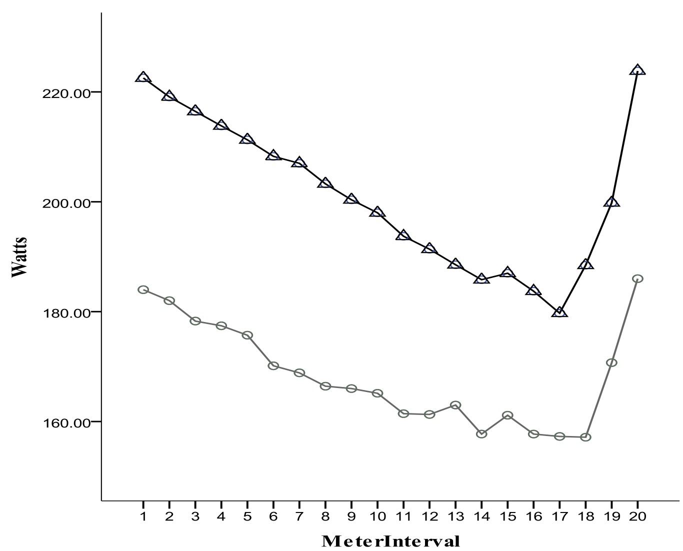

Figure 2. Dynamical patterns for the 2000 m rowing distance. Triangles indicate varsity and circles indicate novice.

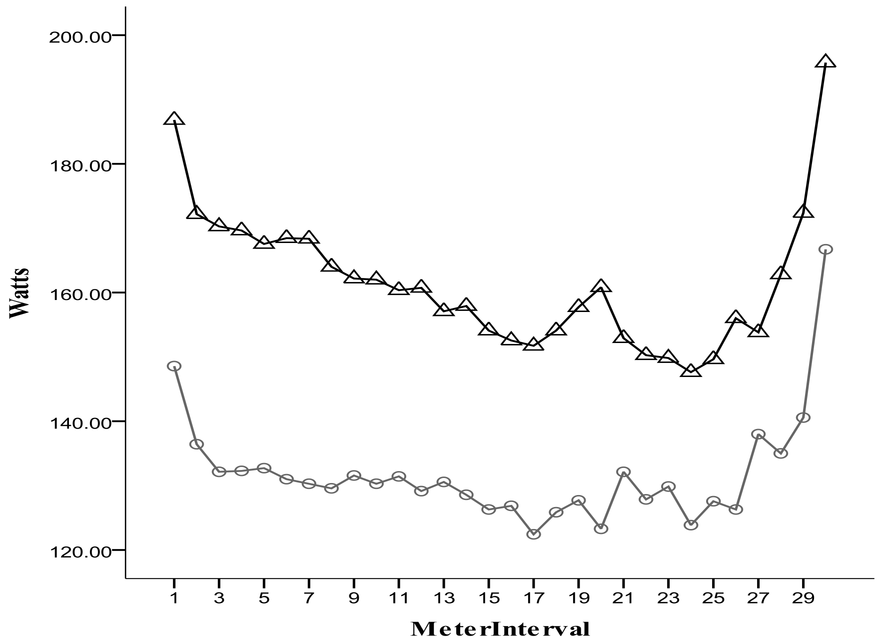

Figure 3. Dynamical patterns for the 6000 m rowing distance. Triangles indicate varsity and circles indicate novice.

Table 1: 2000 m MI and 6000 m MI (in parentheses) for dynamical portions' occurrence (burst, wall, recovery).

	Burst	Wall	Recovery
Novice	15(21)	16(22)	19(27)
Varsity	15(18)	16(21)	18(25)

A two way mixed ANOVA was performed on the MI occurrence: MI total ratio with distanced rowed as the within participant variable and training level as the between participant variable. Mauchly's test checked the sphericity assumption, which was not violated, showing that the matrix had approximately equal variance and covariance. There was no significant training level by distance rowed interaction, $F(1,16)=2.823$, $p=.112$, $\eta_p^2=.15$, observed power of .352, indicating the dynamical portions' occurrence in each distance rowed did not significantly differ in varsity and novice.

A significant main effect of distance rowed, $F(1,16)=46.780$, $p=.000$, $\eta_p^2=.745$, observed power of 1.00, was found, however. This identified a statistically significant difference in the dynamical portions' occurrence in the 2000 m and 6000 m rowing distance. Pairwise comparisons revealed the dynamical portions occurred 5% earlier in the 6000 m distance (*M*=.76, *SD*=.007) than the 2000 m distance (*M*=.71, *SD*=.005). In training level, varsity performed both rowing distances faster than novice, but the dynamical portions occurred at statistically similar MIs in each task for both training levels illustrated in Figure 4. Thus, the dynamical pattern is dependent on teleanticipatory mechanisms with distinctive portions occurring in the same pattern proportional to the rowing distance regardless the training level.

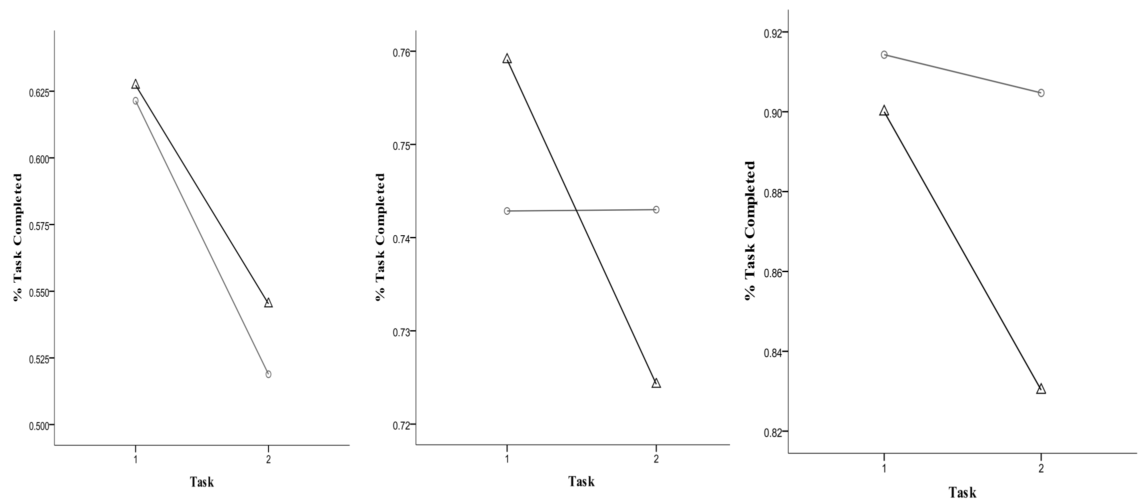

Figure 4. 2000 m MI and 6000 m MI for dynamical portions' occurrence (in order: burst, wall, recovery). Triangles indicate varsity and circles indicate novice.

Discussion

The dynamics of rowing among collegiate female rowers in both training groups display statistically similar dynamic patterns for the extreme physical duress period in both tasks. All participants outperformed the beginning of the task, indicating physiological characteristics lack dependency and the physical duress period has cognitive components. A specific behavior is the product of interactions between variables emphasized by nonlinear dynamical systems theory. Each variable influencing all other variables with each variable being influenced revealing the impact feedback has during interactions and the need for skepticism when assuming a single variable caused an outcome. Sources and stress appraisals are constantly in flux given the duration and intensity situational or person-centered in nature, but adaptations are predicted by the relational meaning between the person and her environment (Buman et al., 2007). This directionality issue eschewed by nonlinear dynamical systems theory stating a typical self-organizing structure's characteristic is the feedback loop generated by the interaction result in a circular causality (Kelso, 1995). Thus, the Gestalt idealism is more appropriate with every part of the whole being important and narrowing one factor as causing the outcome is erroneous and misleading limiting potential knowledge gain. The findings suggest that the dynamical pattern is dependent on teleanticipatory mechanisms with the distinctive portions occurring in the pattern regardless of training level and proportional to the rowing distance.

The HTW phenomenon in rowing can now be conceptually defined as the occurrence after the burst when a sudden onset and rapid degradation in performance is seen until the decline peak occurring approximately at 73% of task completion dependent on teleanticipatory mechanisms. The findings have practical implications for professional practice and future research. Recall marathon runners experience the wall between mile 18 and 21, ~71% of task completion (Master & Lambert, 1989; Okwumabua, 1985; Summers et al., 1982). Limiting HTW understanding to a single-faceted experience in a single context eliminates practical application progression.

Nonlinear dynamical systems theory avoids the causality fallacy by emphasizing the functional interaction between variables. Self-similar, iterative, and dependent on initial conditions patterns are consistencies in structures and behavior. The variability and linearity are equally important within a system (Kelso, 1995). Understanding the extreme physical duress period's dynamical pattern may bring sport psychology researchers closer to establishing a conceptual definition for the HTW phenomenon and set the stage for future work. This study could form the basis for how intervention research might be formulated, and at which point in the task strategies might be most effectively applied, but because this research is new, care should be taken in how psychological skills training is applied.

Finally, there is a need to denote some study limitations, with which further research will have to deal. The literature identifies females as less likely to experience HTW, therefore in efforts to produce a more conservative study only females were included but males' performance may differ. Novice had no experience with the rowing tasks, thus a learning curve was not accounted for. The land measurement was supported by literature, but is still not true to the rowing dynamics occurring waterborne. The meter interval size did not allow for sufficient dynamical pattern descriptions. Nevertheless, understanding the factors associated with the dynamical pattern may help coaches and sport psychology consultants better prepare athletes with psychological skills necessary to cope with extreme physical duress during competitive tasks.

Aside from these limitations, an inmportant challenge in future studies is to systematically study strategies that delay the onset and prevent extreme physical duress. Another data collection method using measurement of each stroke will provide adequate data points for a time series analysis, which will sufficiently describe the dynamical pattern. Nevertheless, the results from this study could form the basis for how intervention research might be formulated, including how to select appropriate psychological and physiological mechanisms, and at which point in a competition they are most effectively applied. Although HTW characteristics are majority physiological in nature (Morgan, 1978), further investigation involving other factors would provide a more comprehensive phenomenon understanding.

Rowers deserve as much attention as runners. HTW reports include cognitive difficulties (e.g., confusion and self doubt) characterized by (a) anxiety, (b) changing goals, (c) confusion, (d) mental battle, and (e) trouble focusing (Midgley et al., 2007) also important in rowing. Research into these factors may help coaches and sport psychology consultants better prepare athletes with the psychological skills necessary to cope with extreme physical duress periods. The investigation into what adaptive psychological skills might be has begun (Buman et al., 2008), but care should be taken in how psychological skills training is applied and additional research is needed to determine how effective the strategies are at overcoming the phenomenon. Another reason to study the dynamical pattern is the potential utility this information could provide about human adaptation responses under extreme physical duress.

A comprehensive understanding about the salient psychological and physiological characteristics attributed to the extreme physical duress period's dynamical pattern, as well as understanding how athletes interpret and cope with the experiences provide researchers with a conceptual and theoretical framework to guide future work. Limiting HTW understanding to a single-faceted experience in a single context eliminates practical application progression. Behavior consists in self-similar, iterative, and dependent on initial conditions pattern with which variability is equally important as linearity (Kelso, 1995). As progress is made in understanding the dynamical pattern of extreme physical duress, sport psychologists will be creative in designing corresponding strategies reducing the debilitating effects of extreme physical duress, enhance performance, and produce more positive outcomes.

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Appendix A

Materials

Concept 2 Model D Rowing Ergometer

Rowing Ergometer Performance Monitor with Log Card

Appendix B

2000 Meter Raw Data

	Training	MI1	MI2	MI3	MI4	MI5	MI6	MI7	MI8	MI9	MI10	MI11	MI12	MI13	MI14	MI15	MI16	MI17	MI18	MI19	MI20
1	Novice	147	128	126	128	125	124	125	122	124	125	121	121	122	118	118	116	114	115	125	135
2	Novice	203	205	205	198	198	193	186	181	181	169	161	165	165	171	167	167	167	175	198	221
3	Novice	184	181	167	161	175	163	171	167	167	173	169	175	171	167	175	171	167	169	200	213
4	Novice	161	177	175	179	173	165	163	154	156	150	149	139	161	129	141	133	130	116	135	152
6	Novice	175	173	177	173	165	159	157	154	156	150	145	142	135	141	133	126	124	125	138	169
7	Novice	230	210	208	208	208	208	205	208	205	208	208	210	208	205	208	210	213	210	213	224
8	Novice	188	200	190	195	186	179	175	179	173	181	177	177	179	173	186	181	186	190	186	188
5	Varsity	233	208	205	208	213	203	210	195	198	208	195	200	195	200	193	188	208	205	195	224
9	Varsity	249	243	243	246	243	236	233	224	216	203	210	198	198	205	216	179	157	219	219	263
10	Varsity	216	213	203	203	200	198	198	198	198	203	195	198	198	198	198	193	198	198	210	249
11	Varsity	227	216	210	208	208	213	210	208	208	205	205	203	200	195	190	195	190	200	210	216
12	Varsity	249	256	256	243	246	236	243	243	249	246	246	239	230	213	239	243	210	239	233	236
13	Varsity	227	216	213	213	208	208	203	203	190	190	177	173	177	167	163	161	157	154	171	177
14	Varsity	233	236	233	233	224	219	210	210	208	208	203	198	203	200	198	195	198	193	198	205
15	Varsity	216	216	213	205	203	200	193	188	177	167	169	167	163	163	161	159	163	169	216	230
16	Varsity	286	274	274	270	259	259	259	252	243	239	236	236	233	227	221	224	224	224	233	320
17	Varsity	173	175	177	173	171	169	169	165	163	152	139	141	125	126	129	135	128	128	157	169
18	Varsity	139	157	154	150	149	150	149	150	154	157	156	152	152	150	149	149	144	144	156	173

Appendix C

6000 Meter Raw Data

ID	Training	MI1	MI2	MI3	MI4	MI5	MI6	MI7	MI8	MI9	MI10	MI11	MI12	MI13	MI14	MI15	MI16	MI17	MI18	MI19	MI20	MI21	MI22	MI23	MI24	MI25	MI26	MI27	MI28	MI29
1	Novice	118	111	108	96	98	89	99	102	98	105	99	103	105	106	103	89	75	95	94	78	83	82	86	85	85	79	106	98	112
2	Novice	145	145	144	145	147	145	147	146	145	147	150	147	150	148	143	147	148	148	149	149	156	152	155	150	148	151	149	161	162
3	Novice	147	128	118	125	122	109	111	104	109	107	109	106	102	105	102	105	103	97	100	90	109	98	122	88	112	111	115	106	113
4	Novice	177	176	162	158	154	155	143	144	136	133	134	135	137	130	126	135	122	125	122	120	125	130	128	125	126	61	130	114	122
6	Novice	143	124	118	123	124	123	128	128	132	132	130	125	128	129	127	128	128	129	132	137	145	134	129	126	130	153	141	141	139
7	Novice	121	117	121	116	114	120	121	126	139	126	126	123	130	124	126	130	125	123	130	132	144	135	132	130	135	161	150	157	156
8	Novice	189	154	154	163	170	176	163	157	162	162	172	165	162	158	157	154	156	164	167	157	163	164	157	163	157	168	175	168	180
5	Varsity	120	124	121	115	108	107	100	99	95	101	97	95	97	98	97	93	95	96	89	93	93	94	89	85	85	88	87	95	101
9	Varsity	201	177	176	173	169	176	174	169	172	171	174	171	168	176	164	161	164	173	168	163	172	166	170	167	168	177	168	176	195
10	Varsity	188	170	167	167	169	168	167	167	163	167	160	162	161	163	162	155	151	156	157	158	160	157	152	151	157	152	152	153	161
11	Varsity	192	171	170	168	165	166	168	161	166	163	166	164	160	161	157	153	154	153	159	155	157	153	152	156	158	160	157	165	167
12	Varsity	223	190	194	194	196	201	200	195	195	196	198	204	196	201	198	203	192	200	205	212	205	200	203	196	200	204	204	192	210
13	Varsity	150	141	139	147	139	139	145	141	141	141	141	142	137	137	133	136	138	136	135	135	134	126	130	135	135	142	148	163	144
14	Varsity	217	205	201	195	189	187	188	177	178	180	178	176	166	166	156	154	155	155	148	158	135	140	138	125	133	143	150	171	181
15	Varsity	216	216	213	205	203	200	193	188	177	167	169	167	163	163	161	159	163	169	216	230	158	157	158	154	155	161	154	193	226
16	Varsity	243	209	214	217	216	217	220	214	214	217	213	212	208	204	208	208	205	204	208	206	206	201	206	204	204	209	210	219	223
17	Varsity	175	156	146	146	150	154	152	151	139	134	127	130	130	126	118	115	111	114	114	121	124	122	116	119	117	130	117	123	143
18	Varsity	130	135	132	139	139	138	145	142	144	145	141	145	142	142	141	141	141	139	136	138	138	137	134	132	134	150	145	141	145

Appendix D

Ratio Raw Data

ID	Training	2k_Burst	6k_Burst	2k_Wall	6k_Wall	2k_Recovery	6k_Recovery
1	Novice	0.7	0.5	0.8	0.77	0.9	0.93
2	Novice	0.55	0.5	0.7	0.77	0.9	0.93
3	Novice	0.65	0.53	0.75	0.77	0.9	0.93
4	Novice	0.6	0.53	0.75	0.73	0.95	0.93
6	Novice	0.65	0.5	0.75	0.77	0.9	0.87
7	Novice	0.65	0.53	0.7	0.67	0.95	0.87
8	Novice	0.55	0.53	0.75	0.73	0.9	0.87
5	Varsity	0.65	0.53	0.75	0.73	0.85	0.8
9	Varsity	0.55	0.53	0.75	0.77	0.9	0.8
10	Varsity	0.6	0.53	0.75	0.73	0.95	0.83
11	Varsity	0.55	0.53	0.7	0.7	0.9	0.8
12	Varsity	0.65	0.53	0.8	0.7	0.9	0.8
13	Varsity	0.65	0.53	0.75	0.7	0.95	0.87
14	Varsity	0.6	0.57	0.75	0.7	0.85	0.83
15	Varsity	0.65	0.53	0.75	0.7	0.9	0.83
16	Varsity	0.65	0.57	0.75	0.7	0.8	0.87
17	Varsity	0.65	0.53	0.85	0.78	0.95	0.83
18	Varsity	0.7	0.6	0.75	0.78	0.95	0.87