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A discrete-time hazard model of hitting the wall in recreational marathon runners☆

Matthew P. Buman [a,*], Britton W. Brewer [b], Allen E. Cornelius [b]

[a] Department of Applied Physiology and Kinesiology, University of Florida, USA
[b] Department of Psychology, Springfield College, USA

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ABSTRACT

Objective: Recent literature has begun to describe and identify predictors of hitting the wall among recreational marathon runners. Our purpose was to extend previous findings by exploring the relative probability of when runners of various risk profiles hit the wall and to describe the overall functional form of risk over the course of a marathon.

Method: Survival methods and discrete-time hazard modeling were used to model self-reported hitting the wall occurrence data among 324 recreational marathon runners from four Eastern Seaboard marathons.

Results: The combinative effects of male gender, running 20 miles or less in training, and expectancy, showed the greatest probability of hitting the wall at any timepoint of the marathon. The shape of hitting the wall risk appeared to most closely fit a cubic form with a dramatic incline of risk peaking at mile 21 followed by a precipitous decline.

Conclusion: These findings further clarify under what circumstances recreational marathon runners are most and least likely to hit the wall and contributes to the formation of a conceptual definition of the phenomenon.

There is a growing corpus of research that has sought to understand and describe periods of extreme physical duress during endurance sport performance. These episodes are commonly referred to by triathletes and cyclists as "bonking" and by marathon runners as "hitting *the Wall*" (HTW). The HTW phenomenon is an event distinguished by (a) a rather discrete and poignant onset and duration (Buman, Omli, Giacobbi, & Brewer, 2008; Stevinson & Biddle, 1998); (b) a multidimensional nature with physiological, cognitive, motivational, and affective characteristics (Buman, Omli, et al., 2008); and (c) typical onset around miles 18–21 of the marathon (Stevinson & Biddle, 1998; Summers, Sargent, Levey, & Murray, 1982). The frequency of HTW has varied in different studies from 43% (Buman, Brewer, Cornelius, Van Raalte, & Petitpas, 2008) to 53% (Stevinson & Biddle, 1998) of participants reporting the event in a given marathon.

Recent literature has also identified predictors of HTW. Elite runners are less likely to report HTW than nonelite runners (Morgan, 1978). Males are more likely to report HTW than females (Buman, Brewer, et al., 2008; Stevinson & Biddle, 1998). Training volume characteristics (e.g., distance of longest training run, miles run wk^{-1}) are inversely related to reports of HTW (Buman, Brewer, et al., 2008). Finally, even after controlling for these aforementioned associations, the prospective expectation of HTW is positively predictive of HTW (Buman, Brewer, et al., 2008).

Despite the recent attention to HTW in the sport psychology literature, consensus has yet to be reached on an acceptable conceptual definition of the HTW phenomenon. Among other methodological and theoretical challenges that must be addressed, this is partly due to research that has primarily focused on *if* an individual experienced HTW (i.e., descriptive analyses, predictors), in most cases failing to describe *when* the event was experienced for individuals with various risk profiles. The current investigation sought to extend previous work by addressing the question of *when* individuals experience HTW. The first aim of this paper was to examine HTW occurrence over the course of a marathon as a function of previously established predictors (gender, longest training run, and HTW expectancy). The second aim was to describe the overall functional form and shape of HTW risk across a marathon.

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* Corresponding author. Stanford Prevention Research Center, Stanford University School of Medicine, Medical School Office Building, 251 Campus Drive, Stanford, CA 94305-5411, USA. Tel.: +1 (650) 723 3342; fax: +1 (650) 725 6247.
E-mail address: mbuman@stanford.edu (M.P. Buman).

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These aims were addressed in a prospective sample of recreational marathon runners from four Eastern seaboard marathons using survival analyses and discrete-time hazard modeling (Singer & Willett, 2003). Understanding both *if* and *when* HTW is experienced will bring sport psychology researchers closer to establishing a conceptual definition of HTW and will set the stage for future work to delay onset and severity, and avoidance of HTW altogether.

Methods

Procedure

A prerace questionnaire, administered at the prerace expo, was used to obtain demographic data, marathon training history, and expectation of HTW in the upcoming marathon. A postrace questionnaire, administered by Internet or mail after marathon completion, was used to obtain marathon performance data and occurrence of HTW. Participants were asked whether they HTW, and if so, at which mile it occurred. This paper describes a secondary data analysis of previously published work. A full explanation of study procedures and participant characteristics is provided elsewhere (Buman, Brewer, et al., 2008).

Analytic approach

Survival analysis describes the probability, or hazard, of event occurrence (e.g., hitting the wall) by analyzing the event status of each observed case at each discrete timepoint (e.g., mile). Discrete-time hazard modeling extends these descriptive survival methods by fitting the hazard data to a statistical model that accounts for time and the predictors of interest. Descriptive life-table hazard and survival probabilities were obtained using the life-table function in SPSS 15.0 (SPSS, 2006). Next, the main effects of gender, longest training run, and HTW expectancy were estimated with a discrete-time hazards model (Singer & Willett, 2003). Potential interaction effects were also modeled. Finally, multiple polynomial specifications of time were modeled to determine the functional form that best fit the descriptive data. Deviance (−2 log likelihood), Akaike's Information Criterion (AIC), and Bayesian Information Criterion (BIC) were used to determine goodness-of-fit and model comparison.

Results

Descriptive statistics

Of the 324 participants, 138 (43%) did not report HTW during the marathon. Table 1 displays life-table estimates of hazard and survival probabilities. Because the earliest point in the marathon at which a participant reported HTW was mile 11, probabilities are not reported for previous mile intervals. The greatest risk of HTW was after mile 19, but before mile 23. Nearly 25% of the sample reported HTW by mile 21.

Hazard modeling

Results from the discrete-time hazards models showed that model-based estimates of hazard followed a similar pattern over time to those displayed in Table 1, with increasing probability of HTW occurrence up to mile 21 followed by decreasing probability from mile 21 to 26. The discrete-time hazards models also showed that all three predictors of HTW occurrence were significant. Table 2 compares parameter estimates and model-fit statistics to a no-predictor model, Model A, and stepwise models of gender, longest training run, and HTW expectancy, respectively (Models B–D). Model D, inclusive of all predictors, was a significantly improved model compared to the others. Combinations of interaction effects for all model predictors were tested and found not to yield significant beta estimates or model-fit improvements. The expectation of HTW appeared to be the strongest predictor of HTW occurrence, with gender displaying only a marginally significant effect in this final model. For interpretation, logit hazards used for modeling were converted to fitted odds and hazards (Singer & Willett, 2003). After controlling for other model predictors, females were 0.71 times *less* likely than males to hit the wall (fitted hazard = 0.41), runners whose longest training run was more than 20 miles were 0.67 times *less* likely than those whose longest training run was 20 miles or less to HTW (fitted hazard = 0.40), and runners who expected to hit the wall were 2.55 times *more* likely than those who did not expect to hit the wall (fitted hazard = 0.72).

Hazard and survival curves for eight combinations of model predictors are displayed in Fig. 1. The hazard curves in Panel A show that males whose longest training run was 20 miles or less and who

Table 1
Life-table estimates and standard errors of survival and hazard probabilities describing prospective occurrence of HTW in a sample of 324 marathon runners.

Mile Interval	Risk Set	Number HTW	Number censored	Hazard (SE)	Survival (SE)
[11, 12)	324	2	0	0.01 (0.00)	0.99 (0.00)
[12, 13)	322	2	0	0.01 (0.00)	0.99 (0.01)
[13, 14)	320	2	0	0.01 (0.00)	0.98 (0.01)
[14, 15)	318	1	0	0.00 (0.00)	0.98 (0.01)
[15, 16)	317	1	0	0.00 (0.00)	0.98 (0.01)
[16, 17)	316	5	0	0.02 (0.01)	0.96 (0.01)
[17, 18)	311	8	0	0.03 (0.01)	0.94 (0.01)
[18, 19)	303	21	0	0.07 (0.02)	0.87 (0.02)
[19, 20)	282	15	0	0.05 (0.01)	0.82 (0.02)
[20, 21)	267	21	0	0.08 (0.02)	0.76 (0.02)
[21, 22)	246	20	0	0.08 (0.02)	0.70 (0.03)
[22, 23)	226	16	0	0.07 (0.02)	0.65 (0.03)
[23, 24)	210	12	0	0.06 (0.02)	0.61 (0.03)
[24, 25)	198	9	0	0.05 (0.02)	0.58 (0.03)
[25,26)	189	4	0	0.02 (0.01)	0.57 (0.03)
[26, 26.2)	185	1	138	0.01 (0.01)	0.57 (0.03)

Note. Mile interval notation uses [brackets] to denote inclusion and (parentheses) to denote exclusion. Censored individuals in the final interval represent those who did not report the occurrence of HTW.

Table 2
Beta estimates, standard errors, Wald test, and goodness-of-fit statistics of four stepwise discrete-time hazard models to the occurrence of HTW (n = 324, n *events* = 186).

	Model A	Model B	Model C	Model D
Female				
β (SE)		−0.42 (0.20)*	−0.45 (−0.20)*	−0.35 (0.20)~
Wald test		4.34*	5.09*	2.93~
Long Run > 20				
β (SE)			−0.51 (0.18)**	−0.40 (0.19)*
Wald test			7.82**	4.61*
Expect HTW				
β (SE)				0.94 (0.19)***
Wald test				24.28***
Goodness-of-fit				
Deviance	1046.82	1042.22	1034.26	1011.58
n parameters	16	17	18	19
AIC	1078.82	1076.22	1070.26	1049.58
BIC	1086.99	1084.90	1079.45	1059.28
Δ Deviance from previous model	–	4.60*	7.96**	22.68***

Note. ~$p < .10$; *$p < .05$; **$p < .01$; ***$p < .001$; Model A represents the general model with no predictors; Deviance = −2 Log Likelihood; AIC = Akaike's Information Criterion; BIC = Bayesian Information Criterion.

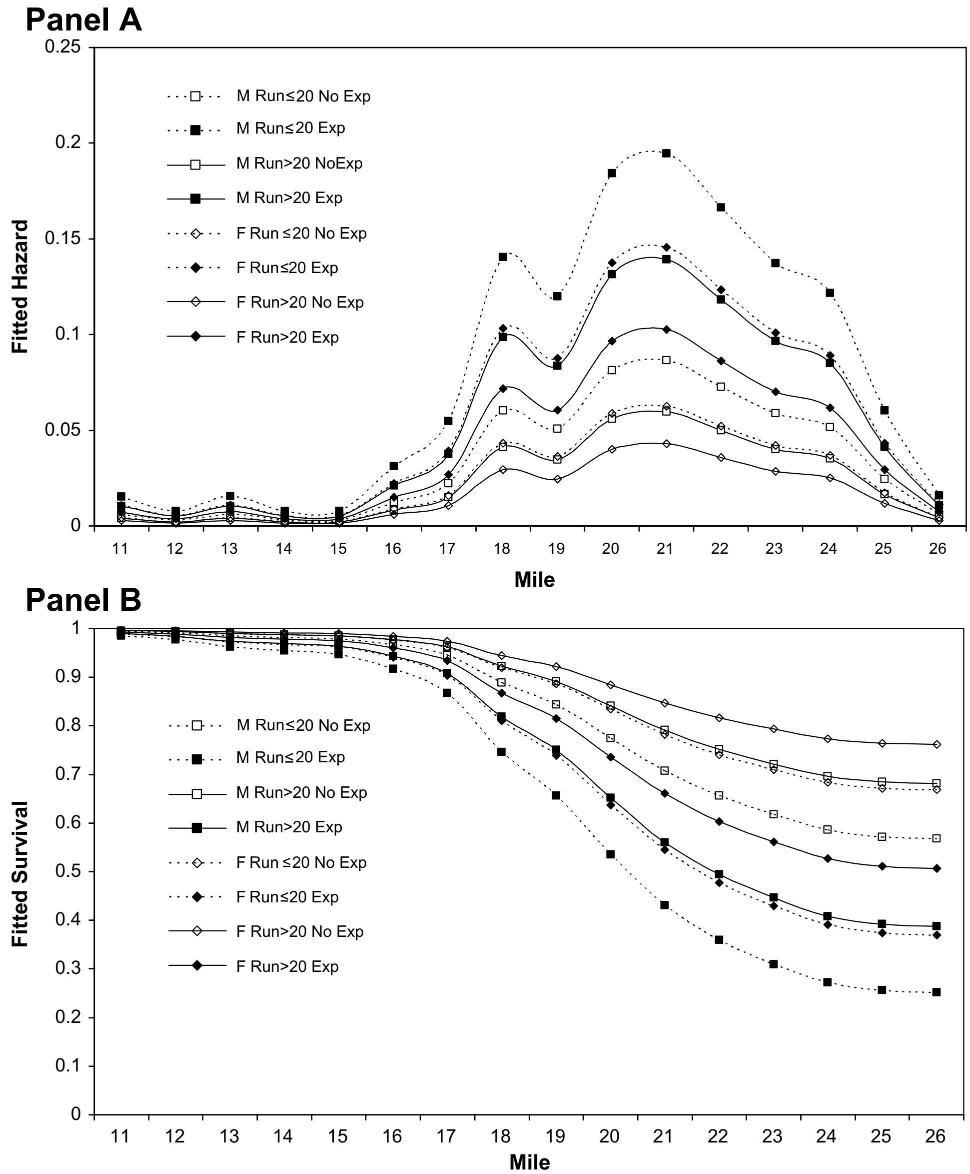

Fig. 1. Model-based hazard (Panel A) and survival (Panel B) curves for eight combinations of gender, length of longest training run, and HTW expectancy. Note. M = Male, F = Female, Run>20 = Longest training run > 20 miles, Run≤20 = Longest training run ≤ 20 miles, Exp = Expected to HTW, No Exp = Did not expect to HTW. Legend: M (square) vs. F (triangle); Run>20 (solid line) vs. Run≤20 (dotted line); Exp (filled marker) vs. No Exp (clear marker).

indicated an expectation of HTW were most likely to report experiencing the event. In contrast, females whose longest training run was more than 20 miles and who did not indicate an expectation of HTW were least likely to report experiencing the event. The survival curves in Panel B highlight the wide range of cumulative survival probabilities across groups. Females whose longest training run was more than 20 miles long and who did not indicate an expectation of HTW had almost an 80% chance of not HTW, whereas males whose longest training run was 20 miles or less and who indicated an expectation of HTW had only a 25% probability of not HTW.

Parameterization of time

A series of polynomial time parameters (constant, linear, quadratic, cubic, and fourth order) were fitted to the discrete-time hazard model. Higher-order functions were compared to lower-order functions (e.g., linear to constant, quadratic to linear) and a general model that represented an unspecified, best-fitting model of time (see Model A in Table 2). Results indicated that the cubic function of time was the best fit to the data, $\beta\,(SE) = -0.007\,(0.002)$, $\chi^2\,(4) = 1103.95$, AIC = 1113.95, BIC = 1116.50, $p < .001$. Chi-square difference tests revealed the cubic function was a significantly improved model compared to the quadratic function, $\chi^2\,(1) = 12.64$, $p < .001$, but not significantly different from the fourth order function, $\chi^2\,(1) = 2.37$, $p > .05$. The general, unspecified model was a significantly improved model compared to the cubic model, $\chi^2\,(12) = 57.13$, $p < .001$. Graphical displays of these parameterizations are pictured in Fig. 2. The presence of a negative logit hazard estimate for the cubic function indicates that hazard started with a "trough" followed by a "peak." The peak in the cubic function appears more prominent and leptokurtic compared to the quadratic function, yet still occurs around mile 21. This appears to correspond most closely with the general model.

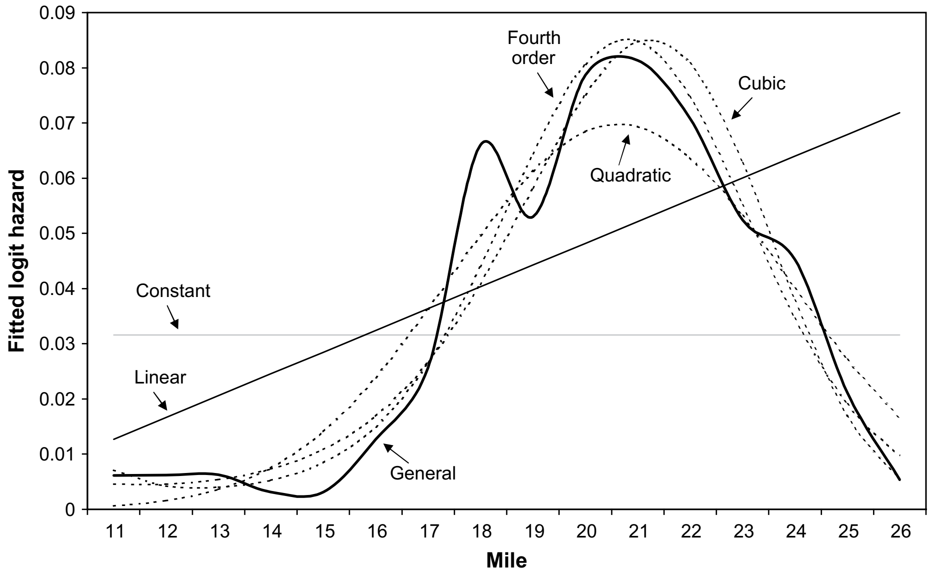

Fig. 2. Polynomial functions of fitted logit hazard compared to a general, best-fitting model of HTW occurrence.

Discussion

In summary, being female and training greater than 20 miles in preparation for a given marathon were protective of HTW. Having the prospective expectation of HTW was the most robust and positive predictor of HTW occurrence. The combinative effects of these predictors show divergent probabilities of HTW over the course of a marathon. The overall functional form of HTW occurrence appears to most closely fit a cubic form with a center point at mile 21, with a dramatic incline of HTW probability followed by precipitous decline.

The unique running profiles that predict if, and when, runners may HTW suggest a number of hypotheses about how these predictors influence running outcomes. First, psychological (e.g., competitiveness, pace perception) and physiological (e.g., fat storage, glycogen supply) hypotheses have been posited to explain why men are more likely to HTW (and HTW earlier) than women (American Academy of Orthopaedic Surgeons, 1991; Blue, 1988; Buman, Brewer, et al., 2008; Stevinson & Biddle, 1998). Although each of these explanations is plausible, the current study did not collect adequate data to formally test any of these hypotheses. Second, the finding that runners whose longest training run was less than 20 miles are more likely to HTW would suggest training preparation is an important predictor of the HTW outcome. It should be noted that amongst a host of training volume characteristics that were collected (e.g., maximum miles run wk^{-1}, weeks of training, number of marathons previously run), longest training run was found to be the most robust predictor of HTW. Because of strong multicollinearity, we chose to include longest training run as the single proxy measure of overall training volume. This suggests that runners may be able to mitigate the effects of HTW by increasing any or all aspects of training volume in preparation for a marathon. Finally, HTW expectancy was the most robust predictor of HTW fitted in the models. This was true even after accounting for gender and training volume. This unique, and rather pronounced effect, suggests that expectancy may reflect more than just the level of preparation for the race. The expectancy effect suggests other psychological determinants of performance such as self-confidence (Vealey, 2001) and self-efficacy (Bandura, 1997) that may have contributed to this expectation. The relationship between these theoretical constructs and HTW expectancy, along with the sources of self-confidence and self-efficacy relevant to endurance sport performance (e.g., previous performance accomplishments, social climate, self-regulatory skills, vicarious experience, etc.), should be investigated in future research.

The overall shape of HTW probability indicates HTW onset is slightly later, and less variable, than the mile 18–21 range previously reported (Stevinson & Biddle, 1998; Summers et al., 1982). The leptokurtic peak that emerged in the data around mile 21 would indicate that HTW occurrence clusters dramatically around this timepoint. This finding, along with the indication that runners whose longest training run was 20 miles or less are more likely to hit the wall at *any* mile, would indicate that runners should be encouraged to train beyond this distance to avoid HTW. Close examination of the general model in Fig. 2 shows a small, but steady HTW probability during miles 11–13 followed by declining probability during miles 14–15. This may be indicative of those ill-prepared to run the marathon distance, followed by a decreased probability of HTW among the larger group of runners who were prepared. The overall cubic form that follows to the leptokurtic peak would then describe runners who have adequately prepared for the race.

The findings from this study have practical implications for professional practice and future research. Understanding the factors associated with increased probability of HTW (and HTW earlier) may help coaches and sport psychology consultants to identify particularly at risk individuals, and to better prepare these runners with the psychological skills necessary to cope with HTW. Because research of the HTW phenomenon is still in its formative stages, care should be taken in how psychological skills training is applied. Although one study has begun to examine what these adaptive psychological skills might be (Buman, Omli, et al., 2008), additional research is needed to determine how effective these strategies are at overcoming HTW. Nevertheless, the results from this study could form the basis for how intervention research might be formulated, including how to target high-risk and low-risk runners, how to select appropriate psychological and physiological mechanisms, and at which point in the race these strategies might be most effectively applied.

A few limitations to this research bear mention. First, because this was a secondary data analysis of previously published data, care should be taken to not overstate these findings. Data from this study should not be used to compute effect sizes for meta-analysis or be characterized as an independent dataset. Second, more reliable assessments of HTW occurrence are needed. This measurement issue remains difficult to address until a thorough understanding of the HTW phenomenon is reached. Related to this, the accuracy of the reports of when individuals hit the wall is unknown. Although retrospective reports were limited to 10 days post-marathon, more concurrent assessments are needed for reports of HTW.

In conclusion, characterizing *when* individuals with different profiles of risk hit the wall is important in establishing a conceptual definition of the phenomenon. Researchers with this knowledge, along what is already known about the HTW phenomenon, can begin to systematically study strategies that delay onset and prevent HTW altogether.

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