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A Mathematical Weibull Model to Unravel the Involvement of Acute Exercise on Serum Growth Hormone Response in Elite Male Water Polo Players

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ABSTRACT

An extreme value distribution, the Weibull distribution is frequently used to model reliability, wind speed, survival, and other data. One of the main reasons for this is its flexibility; Weibull distribution can mimic various distributions like the normal or exponential. The two-parameter Weibull has a shape (γ) and scale (β) parameter. Parameter estimation has been an ongoing research to find unbiased, efficient and minimal variance estimators. Hence, in the present study, we have investigated the effect of acute exercise on serum growth hormone (GH) levels in elite water polo players using Weibull distribution. Here, we have employed the two parameter Weibull distribution to analyse the life time data and to interpret the plot. However, it has also been used to find the survival function and hazard functions for corresponding values of serum growth hormone levels, respectively. The result clearly indicates that acute exercise significantly increases the serum GH levels in elite water polo players. Further, it should be noted that the water polo players showed the decreased levels of hazard functions and significantly increased levels of survival function as compared with sedentary subjects, suggesting that the regular exercise welfares the life span.

Keywords: Acute exercise, GH, Weibull distribution, hazard function, survival function.

1. INTRODUCTION

The Weibull distribution is a continuous probability distribution and it was introduced by the Swedish physicist, Waloddi Weibull. Initially, the author proposed the distribution as a model for material breaking strength, but the efficiency of Weibull distribution has been documented in his published work during 1951 on "A statistical distribution function of wide applicability"[1]. Since 1958, the Weibull distribution has been modified by many researchers to allow for non-monotonic hazard functions. It is well notorious that the Weibull distribution is the most popular and the most widely used distribution in reliability and in lifetime data analysis as well as to model failure times[2]. It has been demonstrated that the Weibull can also fit into a wide range of data from many different fields like material science, engineering, physics, chemistry, meteorology, medicine, pharmacy, economics and business, quality control, biology, geology, geography, engineering sciences and hydrology[3]. With is background, we were intended to analyse the life time data using Weibull distribution, the data has been engaged from the published work of Djelic M *et al*., 2014[4]. Hence, we have designated to study the effect of acute exercise on serum growth hormone (GH) levels in elite water polo players in comparison with the sedentary subjects.

Subsequently, Regular physical exercise is a path to lead healthy life. Physical exercise is termed as the movement or activity of the body that maintains the physical fitness which enhances the whole health system. The numerous health benefits are mainly accompanied with the habit of regular physical exercise[5]. Exercise is of various types such as aerobic exercise, anaerobic exercise and flexibility exercise. Physical exercise is a persuasive physiological stimulus for growth hormone (GH) secretion, and both aerobic and resistance exercise resulted in significant, acute increases in GH secretion[6]. Regular exercise gives substantial benefit and effects of numerous homeostatic mechanisms with which the endocrine system is almost immediately involved[7]. The adaptation to physical training results in a more efficient hormonal mechanism. Studies have shown that resting GH levels might be elevated in trained individuals[8-9]. In response to acute exercise, the growth hormone is stimulated in the blood and exhibits its potent physiological activity in metabolism. 10-15 min after the onset of exercise, the GH levels has initiated to increase and attain peak either at the end or shortly after exercise and following that the elevated GH levels remains for up to 2 hours (10). The need for energy supply is increased during exercise and is associated with adaptive hormonal changes in elite athletes, possible with GH[11]. It is very interesting to study GH response to acute endurance exercise sessions in athlete populations with high body fat percentage, as seen in water polo players. The aim of Djelic M. *et al*., was to investigate the effect of acute exercise on serum growth hormone levels in elite male water polo players, and to compare this response with sedentary. To our knowledge, the life time data was not yet analysed using two parameter Weibull distribution, so far. Moreover, we have analysed the Djelic M. *et al*., stated data using two parameter Weibull distribution with some modifications to acquire the clear interpretations on survival and hazards functions to express the data in well accepted as well as in understandable manner.

2. METHODOLOGY

2.1. Mathematical Model

2.1.1. Weibull Distribution

The Weibull distribution is one of the most popular distributions in analyzing the lifetime data. Two versions of the Weibull probability density function (pdf) are in common use: the two parameter pdf and the three parameter pdf. In this study we have used a two parameter Weibull distribution to analyse the GH levels in water polo players and controls. Much of the popularity of the Weibull distribution is due to the wide variety of shapes it can assume by varying its parameters[1-3].

The weibull distribution has the distribution function;

$F(x;\alpha,\beta) = 1 - e^{-\beta x^{\alpha}} \qquad x > 0 \;\; , \alpha, \beta > 0$

Therefore, the weibull distribution has the density function,

$f(x;\alpha,\beta) = \alpha\beta x^{\alpha-1}\, e^{-\beta x^{\alpha}} \qquad x > 0.$

The survival function,

$S(x;\alpha,\beta) = 1 - \left(1 - e^{-\beta x^{\alpha}}\right) \qquad x > 0.$

And the hazard function,

$h(x;\alpha,\beta) = \frac{\alpha\beta x^{\alpha-1} e^{-\beta x^{\alpha}}}{e^{-\beta x^{\alpha}}}$

Here α and β are the shape and the scale parameters, respectively. It is known that the density function of the Weibull distribution (PDF) can be decreasing or unimodal, and the hazard function (HF) can be either decreasing or increasing depending on the shape parameter[1-3].

3. RESULTS

3.1. Application

3.1.1. Participants

Twelve elite male water polo players and eleven nonathletic male subjects participated in Djelic *et al*., 2014[4] study. The non-athletes were recruited from the student population of the University of Belgrade. They exercised less than 3 h/week. The subjects were healthy, non-smokers, normotensive, did not take any drugs or medication and had no history of any endocrine disorders before or during this study. None of them had any family history of diabetes or obesity. All participants in this study were fully familiarized with the procedures before providing written informed consent to participate in the experiment as approved by the Ethics Committee of the School of Medicine, University of Belgrade.

3.1.2. Experimental design

All participants in Djelic *et al*., 2014[4] study has completed a questionnaire about their training history and a body composition test before exercise testing. The pre-exercise blood

samples (Pre-Ex) for both athletes and non athletes were taken at 9 AM. All participants had eaten a high-carbohydrate meal about two hours before the exercise testing. Exercise tests were performed on a treadmill following an incremental protocol targeting duration between 8 and 12 min. The treadmill protocol used for the VO2 max test began at a speed of 4 km/h at 0.0% incline. The speed of the treadmill was increased by 1 km/h each minute. A maximal level of effort was considered to have been attained if there was a plateau in VO2 despite increased exercise intensity and a RER value > 1.10. VO2 was monitored continuously, and the average of the three highest 10-s consecutive values was defined as the VO2max. Post-exercise blood samples were taken immediately after (Post-Ex) and 30 min (30 min rec) during recovery after the treadmill running test.

There were no significant differences in the ages of the water polo players and controls. Furthermore, whole lean body mass significantly higher in the water polo players. The GH response of the maximum exercise test is shown in fig 1. All pre and post exercise GH concentrations were in the population reference range. In water polo players, the concentration of GH was significantly higher immediately after and after the 30-min of recovery compared to baseline levels (+84.2 %; +107.0 %, respectively; $p<0.05$; Fig. 1). In the controls, the concentration of GH was significantly increased (+22.9%; $p<0.05$; Fig. 1) immediately after the exercise and remained high 30 min after the exercise.

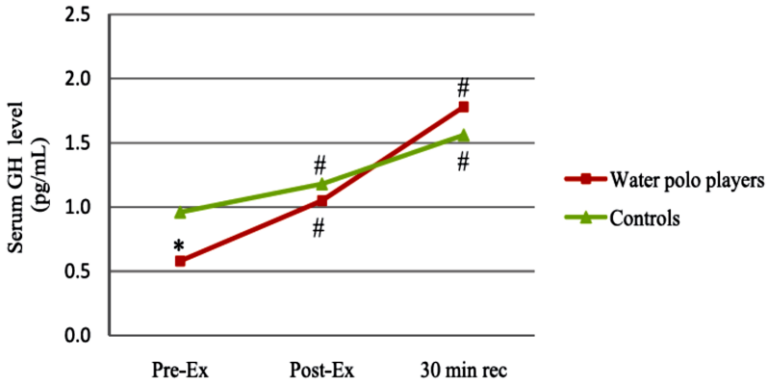


Fig. 1. Serum growth hormone (GH) concentrations before (Pre-Ex), immediately after (Post-Ex), and after 30 min of recovery (30 min rec) in water polo players and controls. * Significantly different from Controls; # significantly different from Pre-Ex.

3.2. MATHEMATICAL RESULTS

3.2.1. Two parameter Weibull probability distribution function (PDF) on GH levels of water polo players and sedentary controls

Fig.1 depicts the comparative analysis of GH levels in water polo players and sedentary controls using two parameter Weibull distributions. In contrast to Djelic *et al.*,[4] the two parameter Weibull distributions f(x) plot shows the increased level of GH in water polo players as compared to non-athletic subjects in Pre-Ex condition. It should be noted that, in

Post-Ex state, the GH levels were decreased from Pre-Ex level and gradually increased in after 30min recovery state from Post-Ex level in water polo payers. In similar with Djelic *et al.*, the level of GH was significantly increased in water polo players as compared to non-athletic subjects in after 30min recovery state. In addition, the GH levels in non-athletic control subjects were increased from Pre-Ex state and decreased after Post-Ex state.

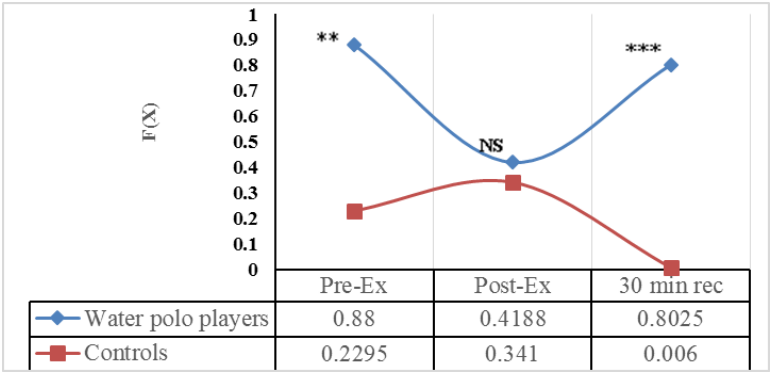


Fig.1. Effect of two parameter Weibull probability distribution function (PDF) on serum growth hormone (GH) concentrations before (Pre-Ex), immediately after (Post-Ex), and after 30 min of recovery (30 min rec) in water polo players and controls. Where, ** p<0.01, control vs pre-Ex; *** p<0.001, control vs 30min rec; NS, control vs post-Ex.

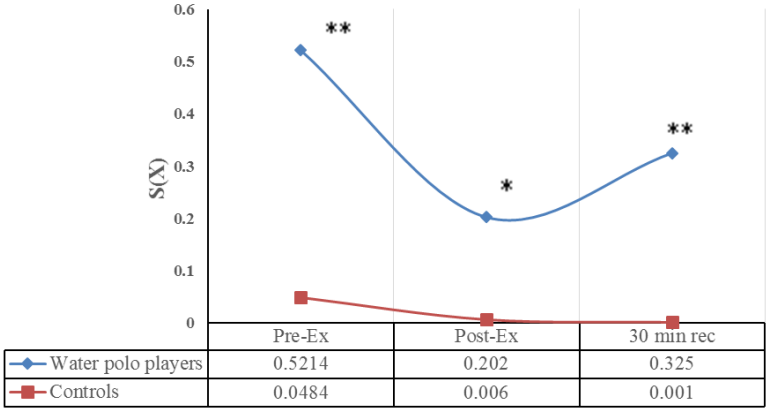


Fig.2. Effect of two parameter Weibull survival function on serum growth hormone (GH) concentrations before (Pre-Ex), immediately after (Post-Ex), and after 30 min of recovery (30 min rec) in water polo players and controls. Where, ** p<0.01, control vs pre-Ex; ** p<0.01, control vs 30min rec; * p<0.05, control vs post-Ex.

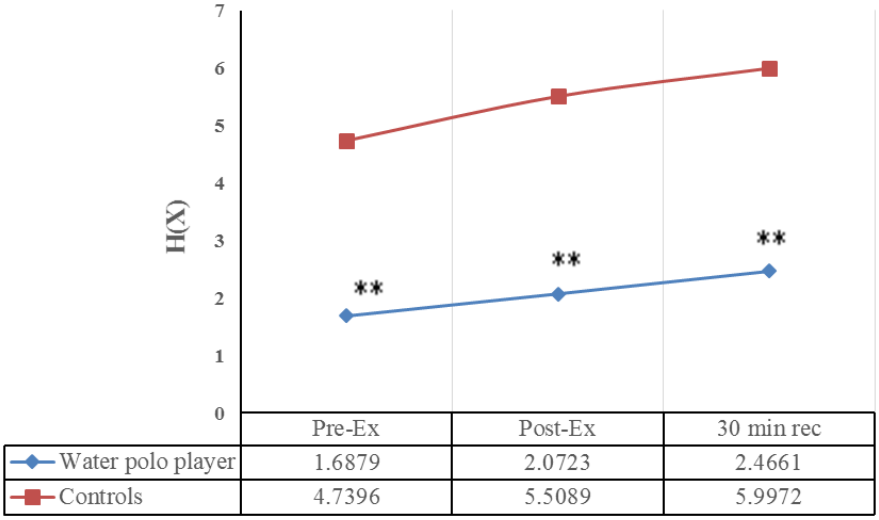
3.2.2. Two parameter Weibull survival function on GH levels of water polo players and sedentary controls

The survival function of Weibull distribution analysis on GH levels in water polo players and non-athletic controls are shown in Fig.2. The two parameter Weibull distributions survival function s(x) plot reveals that the elevated survival rate in water polo players as compared to non-athletic subjects in Pre-Ex state. In Post-Ex state, the s(x) was significantly

decreased from Pre-Ex level and gradually increased in after 30min recovery state from Post-Ex level in water polo payers. The survival function was notably increased in water polo players as compared to non-athletic subjects in after 30min recovery state. Subsequently, the survival function in non-athletic control subjects were declined to the zero from Pre-Ex state.

3.2.2. Two parameter Weibull survival function on GH levels of water polo players and sedentary controls

The hazard function of Weibull distribution analysis on GH levels in water polo players and non-athletic controls are shown in Fig.3. The two parameter Weibull distributions hazard function h(x) plot reveals that the decreased level of hazard rate in water polo players as compared to non-athletic subjects in Pre-Ex state and the h(x) was gradually increased from Pre-Ex level to after 30min recovery state in water polo payers. The hazard function was markedly decreased in water polo players as compared to non-athletic subjects. Subsequently, the hazard function in non-athletic control subjects were markedly increased zero from Pre-Ex state to after 30min recovery state.



	Pre-Ex	Post-Ex	30 min rec
Water polo player	1.6879	2.0723	2.4661
Controls	4.7396	5.5089	5.9972

Fig. 3. Effect of two parameter Weibull hazard function on serum growth hormone (GH) concentrations before (Pre-Ex), immediately after (Post-Ex), and after 30 min of recovery (30 min rec) in water polo players and controls. Where, ** p<0.01, control vs pre-Ex; ** p<0.01, control vs 30min rec; ** p<0.01, control vs post-Ex.

4. DISCUSSION

The results of the present study clearly demonstrated that the water polo players showed the decreased levels of hazard functions and significantly increased levels of survival function as compared with sedentary subjects, suggesting that the regular exercise welfares the life span.

There are many applications for the Weibull distribution in statistics. It is used to plot the data and interpret the plot. This distribution evaluating the corrective action plans and to

test substantiation for new designs with minimum cost also maintains planning and cost effective replacement strategies. In the present study, we have applied the two parameter Weibull distribution to analyse the life time data (GH levels) of Djelic *et al*., 2014. The results reveals that, the GH levels in Post-Ex state were decreased from Pre-Ex level and gradually increased in after 30min recovery state from Post-Ex level in water polo payers. In similar with Djelic *et al*., the level of GH was significantly increased in water polo players as compared to non-athletic subjects in after 30min recovery state. In addition, the GH levels in non-athletic control subjects were increased from Pre-Ex state and decreased after Post-Ex state. In contrast to Djelic *et al*., the two parameter Weibull distributions f(x) plot shows the increased level of GH in water polo players as compared to non-athletic subjects in Pre-Ex condition, signifying that acute exercise showed impact on GH levels. Mejri *et al*.2005[12] confirmed this statement, showing that GH levels were highest at the beginning of the season and then reduced. There are several explanations for this decrease in GH response. First, an adaptive response to continuous physical activity is an increased sensitivity of target tissues to GH, which despite lower levels of GH increases the release of energy substrates in the liver and adipose tissue[13].

Statistical derivations are in the appendices to keep the main body of the Handbook more readable. The ability to provide reasonably accurate failure forecasts and failure analysis with extremely small samples is the primary advantage of Weibull analysis. Solutions are possible at the earliest indications of a problem without having to "crash a few more." Another advantage of Weibull analysis is that it provides a simple and useful graphical plot of the failure data. The two parameter Weibull distributions survival function s(x) plot reveals that the elevated survival rate in water polo players as compared to non-athletic subjects in Pre-Ex state. Conversely, the hazard function was markedly decreased in water polo players as compared to non-athletic subjects and the hazard function in non-athletic control subjects were markedly increased zero from Pre-Ex state to after 30min recovery state, suggesting that acute exercises increases survival rate, in other hand decreases the hazard function. Hence, the practice of Weibull distribution in the present study gives an adequate interpretation in the results of Deljic *et al*., with appropriate understandings.

5. CONCLUSION

In the present study, we have explored a two parameter Weibull distribution for alternative approaches to analysis a life time data. The results confirm the outcomes of Djelic *et al*., 2014 that acute exercise have impact on the GH levels. In addition, the two parameter Weibull distributions predicts the survival function s(x) and hazard function of the serum growth hormone levels which reveals that the elevated survival rate in water polo players as compared to non-athletic subjects in Pre-Ex state. Conversely, the hazard function was markedly decreased in water polo players as compared to non-athletic subjects. These finding could be an additional contribution to a better understanding of human endocrine and metabolic physiology in acute exercise conditions with clear note.

6. ACKNOWLEDGMENT

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