The Journal of the International Association for Taekwondo Research 2015;2(1):1-5

SPECIAL TOPIC

Maximizing Performance of Taekwondo Athletes: Insights from Animal Athletes

James H. Jones*

Department of Surgical & Radiological Sciences, School of Veterinary Medicine, University of California, USA

Abstract

This paper discusses the physiological factors that affect the performance of Taekwondo athletes. It may seem odd to have these issues being raised by a faculty member from a school of veterinary medicine, in which the patients and the research are primarily directed toward animals, whereas the Taekwondo athletes being discussed are clearly humans. However, an important point to keep in mind is that humans *are* mammalian animals and the same principles that govern the functioning of other mammals apply to humans as well. In the discipline of comparative physiology, we utilize differences that exist between different animals as a tool for understanding the broad principles that govern the design of animals and dictate why they perform the way they do. By utilizing very large differences that exist between variables of interest in different types of animals we can increase the magnitude of differences that exist and better understand the underlying principles of the relationships responsible for the observed differences. These analyses also provide insights into the factors that limit animals' functional performances. In this paper, I will apply these principles of the comparative physiological approach toward better understanding the aspects of a Taekwondo competitor's performance.

***Keywords*:** temperature, speed, body size, scaling, physiological time, Q_{10} effect

Introduction

When we use a comparative physiological approach to understand animal function by comparing how different kinds of animals are affected by a given variable, we have a huge advantage over studying only a single species (e.g., humans). That advantage is that the diversity among animals in many aspects of their structure and function is much greater than is found within a single species. Hence, it is possible to have much larger differences occur between different species or classes of vertebrates, and these large differences maximize our ability to determine the quantity of functional information from the available information on a topic when identifying important effects of the variable of interest.

When Taekwondo competitors spar (*kyorugi*), a critical factor that influences which contestant wins or loses is speed; whether a kick, strike or block occurs even a few milliseconds faster or slower can determine the difference in winning or losing at the most elite levels of competition. A key factor that influences the speed at which competitors can move their muscles is the amount of practice they undertake, which will develop their neural motor pathways and the speed at which those impulses are delivered to the peripheral motor units that will perform the intended movement. However, there are other factors that determine the speed at which a contestant's body functions that may, or may not, be as directly amenable to alteration as practice that can increase speed by tuning the neuromuscular system. In this paper, I will explore two of those factors using the tools of comparative physiology. Those factors are the effects of temperature and body size on speed and performance.

Temperature

When it comes to evaluating temperature effects on animal

* Corresponding author: James H. Jones, Department of Surgical & Radiological Sciences, School of Veterinary Medicine, University of California, One Shields Avenue, Davis, CA, USA 95618. Email: jhjones@ucdavis.edu
ISSN 2383-5958 online

function, a valuable tool is to compare differences between animals that are *homeothermic*, or animals that maintain a relatively constant body temperature around a carefully regulated set point, to animals that are *poikilothermic*, or animals that maintain a body temperature that is usually close to being at equilibrium with their surrounding environment. Homeotherms consist of the two classes of vertebrates, mammals and birds, and are sometimes referred to as 'warm-blooded.' The other vertebrate classes–fish, amphibians, and reptiles–constitute the poikilotherms. A key factor that distinguishes homeotherms from poikilotherms is that homeotherms have higher mass-specific (per kg) metabolic rates than poikilotherms, so they can generate more heat to warm their bodies and maintain a higher than ambient body temperature. They also have external insulation in the form of fur or feathers to trap air, a good insulator, next to their skin to prevent heat loss to the environment. When discussing the term *body temperature*, it is important to keep in mind that the different parts of any animal's body are at different temperatures depending on the temperature of the surrounding environment and rates of heat loss through the body surface as well as other factors (e.g., such as how much muscle activity is occurring) given that the majority of energy used in muscular contractions is released in the form of heat.

With these principles in mind, we can consider that metabolism is, in essence, a series of chemical reactions, and changes in body temperature will inevitably alter the amount of energy activating those chemical reactions and their rates, including enzyme activities. Among those enzyme activities affected by temperature is that of myosin-ATPase, the enzyme that catalyzes the interaction of actin and myosin myofilaments in skeletal muscle sarcomeres and dictates the speed at which cross-bridges form and break, and ultimately, the speed of muscle contraction. The metabolic rate of an animal and the various functions that contribute to determining it (e.g., muscle shortening velocity) all increase with increased temperature and decrease with decreased temperature. This relationship of the effect of temperature on chemical reaction, and metabolic rate is quantified as a variable called Q_{10}. Q_{10} is described by the equation:

[1]

$$Q_{10} = \left(\frac{\mathrm{R}_2}{\mathrm{R}_1}\right)^{\frac{10}{\mathrm{T}_2 - \mathrm{T}_1}}$$

where Q_{10} is the quantitative value of the effect of temperature

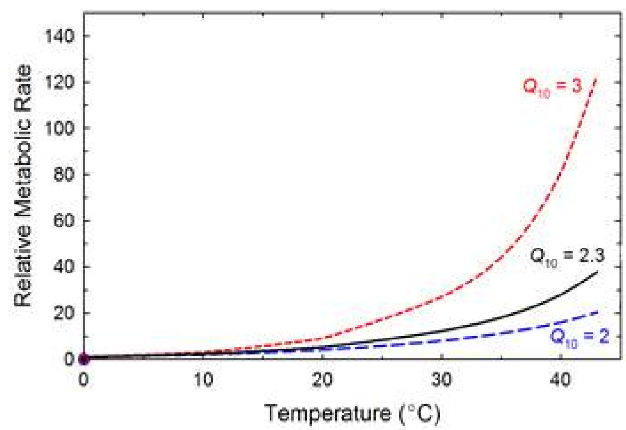

Figure 1. Relationship between temperature (°C) and chemical reaction rates that determine metabolic rate. The short dashed curve in red is the relationship when Q_{10} = 3; the long dashed curve in blue is the relationship when Q_{10} = 2; the solid black curve is the relationship when Q_{10} = 2.3, which is the average value for most vertebrates. Metabolic rates are standardized, so the value is 1 at 0 °C.

on reaction rate (R_1 is the rate of reaction at the initial temperature in °C, and R_2 is the reaction rate after a temperature change), and T_1 and T_2 are respectfully the initial and final temperatures in °C that are causing the changes in reaction rates. The relationship between temperature and reaction rate is shown in Figure 1.

The relationship between temperature and reaction rate can be made easier to interpret by rearranging the equation and logarithmically transforming it to express log R_2 as a function of log R_1, log Q_{10}, and the inverse of the temperature relationship:

[2]

$$\log \mathrm{R}_2 = \log \mathrm{R}_1 + (\log Q_{10} \bullet \frac{\mathrm{T}_2 - \mathrm{T}_1}{10})$$

with the symbols having the same meanings as they did for equation [1]. If this relationship is plotted as log R_2 *vs.* $\frac{-T_1}{10}$) (linear abscissa and logarithmic ordinate), it yields a line with a slope equal to log Q_{10} and an intercept of log R_1.

For most vertebrate animals, regardless of whether they are homeothermic or poikilothermic, their change in metabolic rate, a function of the rates of chemical reactions throughout the body, averages about 2.3 for every 10 °C change in body temperature with higher temperatures yielding higher rates. As a result, when animals increase body temperature, they increase the speed of reactions, including the rate of actin-myosin cross-bridge cycling that causes skeletal muscles to shorten. An increase in temperature therefore increases the speed at which muscles contract. Given that vertebrate animals exist with body temperatures of slightly below 0 °C (poikilothermic Antarctic ice fish) to approximately 43 °C (homeothermic Passerine song birds), this indicates that due to the Q_{10} effect vertebrates can vary the rates of chemical reactions and speed of muscle shortening by a factor of nearly 40-fold.

The key factor relating this issue to Taekwondo athletes is that warming up sufficiently before a contest enables them to capitalize on the Q_{10} effect that can ultimately provide slightly more speed to their movements than without an adequate warmup. Even though the differences in muscle temperature are slight, the Q_{10} effect will increase speed in a situation in which milliseconds can make the difference between winning and losing. An excellent summary of these relationships is given by Schmidt-Nielsen (2) in the chapter entitled "Temperature Effects."

Body Size

A second factor that can affect speed of movement is the size of the contestant's body. In comparative physiology, the study of the effects of differences in body size is the field of *allometry* or *scaling*. The term allometry stems from Greek origins where *alloios* means 'different' and *metros* means 'measure', and when combined the word means 'by a different measure.' The term indicates that because dimensions of an animal change size heterogeneously as body size changes based on different exponential relationships, small and large animals cannot be built the same as animal size changes.

Allometric relationships are in the form of power functions, e.g.:

[3]

$$Y = a\ M^{b}$$

where Y is a variable, a is a constant dictated by the shape of the animal, M is the animal's body mass, and b is an exponent that describes how the variable Y changes with size. This relationship, when plotted on linear axes, usually yields a curvilinear relationship that can be difficult to interpret visually (Figure 2A and Figure 2B). The relationship can be simplified for visual analysis by transforming both sides of the equation logarithmically as:

[4]

$$\log Y = \log a + (b \bullet \log M)$$

This transformation allows the relationship to be plotted on logarithmic axes, where the slope of the resulting line indicates the value of the mass exponent b (Figure 2C). Although the shape factor, a, influences the final value of the relationship, it is the mass-exponent b that describes the effect of body size on the variable.

If we consider a part of an animal's body that has a given length (L) of 1 cm, then $L = L^1 = 1$ cm. We can now calculate

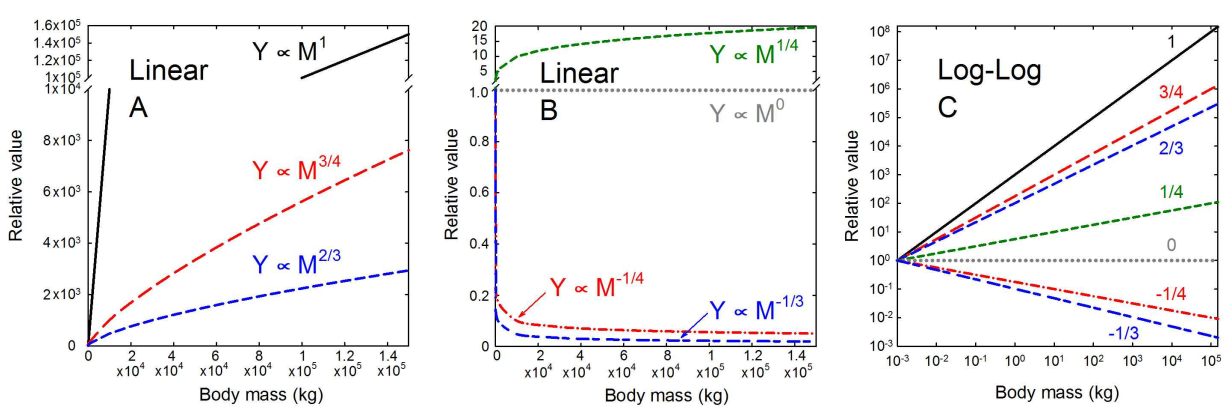

Figure 2. Allometric relationships as a function of body mass (abscissa) when the ordinate is plotted with a linear scale (A and B) or with a log-log scale (C). Curvilinear relationships, when data are plotted on linear scale, reflect the magnitude of the mass-exponent in the power function ($Y = a\ M^{b}$) where b is the mass-exponent. Note that when data are plotted on log-log axes the curvilinear power function relationships transform into straight lines with slopes equal to the mass-exponent of the original power function.

that the area (A) of a square of this unit length will be $L^2 = 1\ cm^2$, and the volume (V) of a cube with 1 cm edges will be $L^3 = 1\ cm^3$. This will be the volume of the animal's body when multiplied by the appropriate shape factor a. The exponents of these different geometrical elements of the animal's body are different, which means inherently that lengths, areas, and volumes of an animal change disproportionately as body size changes. For instance, we can consider how area and volume are related, $A \propto L^2$ and $V \propto L^3$, which can be rearranged to show that $A \propto V^{2/3}$. Because all vertebrates have bodies of nearly identical density, we can substitute body mass (M) for V and can state that:

[5]

$$A \propto M^{2/3}$$

This relationship shows that areas of an animal's body increase at a slower rate as body size increases ($\propto M^{2/3}$) than does body mass ($\propto M^{3/3} = M^1$). The areas that increase are not just surface areas, but also cross-sectional areas (e.g., the cross-sectional area of skeletal muscles). Because the peak stress (force/area) that skeletal muscle can generate is dictated by the number of actin-myosin cross-bridges within a given cross-sectional area of muscle and the packing of myofilaments in sarcomeres is relatively constant, the maximal force that can be generated by a muscle is directly related to its cross-sectional area. As shown in equation [5], this means that smaller animals can generate a greater amount of force relative to their body mass than can larger animals. Hence, smaller and relatively stronger animals are capable of performing feats such as exerting sufficient force to raise their body mass vertically against gravity when climbing a tree, whereas a size limit exists beyond which larger animals are incapable of generating sufficient muscular force to raise their body mass against gravity.

Among the allometric relationships shown in Figure 2 is one with a mass exponent of 0.25 or ¼. This relationship is pertinent, because it expresses a relationship called *physiological time*. Physiological time refers to the amount of time required for a certain event to occur in mammals of different sizes. For instance, given that mammals span a size range of 10^8 or 100-million-fold from the smallest mammal, the Etruscan shrew at 0.0015 kg (1.5 g), to the blue whale at 150,000 kg, every time that body mass increases by 10^4, the time it takes for a similar event to occur in an animal's body will increase by a factor of 10^1 (i.e., it will take 10-times longer), because of the exponent of ¼ indicating the ratio of time in the numerator to body mass in the denominator. A simple example of this is how heart rates of mammals change with body size given that the time it takes for a heartbeat to occur is governed by physiological time. The 1.5 g Etruscan shrew has a resting heart rate of approximately 600 beats/min, whereas the 150-ton blue whale has a heart rate of about 6 beats/min. This reduction in heart rate with size is due to the initial increase in body mass of 10^4 resulting in a 10-fold reduction in heart rate, but the second increase of an additional 10^4 in body mass causes the total reduction in heart rate to be $10 \times 10 = 100$-fold. This change in the scale of physiological time affects nearly all processes that occur within an animal's body.

Conclusion

Because Taekwondo competitors are separated into weight classes of limited size range, this minimizes the effects of the physiological time scale affecting their performance. Nevertheless, because the effects of physiological time that are so clearly demonstrated by comparing animals with large differences in body size, it is important to realize that inevitably these same principles apply to humans as well, as shown in Figure 3.

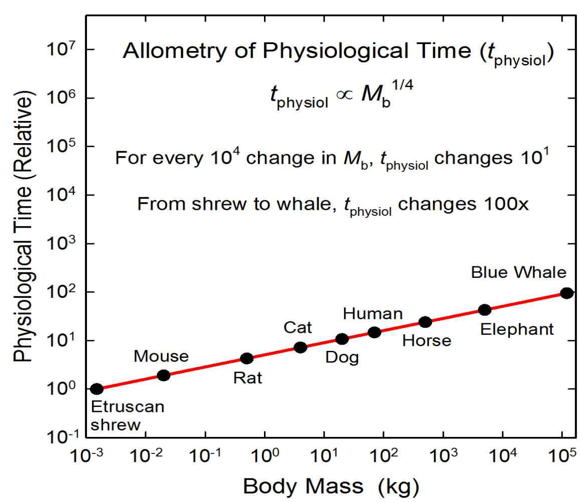

Figure 3. The relationship between body mass and physiological time. For each species shown with its body mass, a relative duration (on a log scale) is shown for an identical event occurring in mammals of different sizes. Across the size range of mammals, there is a 100-fold difference in the time required for a similar event to occur in the smallest and largest mammals, hence a 100-fold difference in rate (e.g., heart rate and rate at which skeletal muscles shorten).

In conclusion, all other factors being equal, smaller competitors will inherently be slightly faster in terms of their muscle contractions than larger competitors. An excellent and extremely understandable introduction to the effects of allometry and scaling on animal function is in Schmidt-Nielsen (1).

References

(1) Schmidt-Nielsen K. Scaling, why is animal size so important? Cambridge (NY): Cambridge University Press; 1984.

(2) Schmidt-Nielsen K. Animal physiology: adaptation and environment. 5th ed. Cambridge (NY): Cambridge University Press; 1997.