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ORIGINAL

OXYGEN UPTAKE KINETICS IN FEDERATED ATHLETES

CINÉTICA DE RECUPERACIÓN DEL CONSUMO DE OXÍGENO EN DEPORTISTAS FEDERADOS

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ABSTRACT

Oxygen uptake kinetics (VO2) is an indicator of functional capacity (CF). The objective of this study is to analyze the oxygen uptake kinetics in athletes of different disciplines, according to the predominant energy system in each one of them. A comparative, non-experimental and cross-sectional study was designed in 22 subjects of selected federated sports corresponding to futsal, weightlifting and triathlon through intentional non-probabilistic sampling. The following variables were assessed: weight, height, body mass index (BMI), blood pressure, waist circumference and oxygen uptake kinetics. The main results show that the oxygen uptake kinetics (VO2) showed that sportsmen who practice futsal, show a better recovery (p < 0.05) compared to athletes of triathlon and weightlifting.

KEY WORDS: Oxygen uptake kinetics, autonomic nervous system, heart rate variability, federated sport.

RESUMEN

La cinética de la recuperación del consumo de oxígeno (VO₂) es un indicador de la capacidad funcional (CF). El objetivo de este estudio es analizar el comportamiento de la cinética de recuperación del consumo de oxígeno en deportistas de diferentes disciplinas, de acuerdo al sistema energético predominante en cada uno de ellos. Se diseñó un estudio comparativo, no experimental y transversal en 22 sujetos de deportes federados seleccionados correspondientes a Futsal, Halterofilia y Triatlón mediante un muestreo no probabilístico intencionado. Se valoraron las siguientes variables: peso, talla, índice de masa corporal (IMC), presión arterial, perímetro de cintura y cinética del consumo de oxígeno. Los principales resultados muestran que la cinética de recuperación del (VO₂) demostró que los deportistas que practican futsal, evidencian una mejor recuperación (p<0,05) comparado con los deportistas de triatlón y halterofilia.

PALABRAS CLAVE: Consumo de oxígeno, cinética de recuperación, sistema nervioso autónomo, variabilidad del ritmo cardíaco, deporte federado.

INTRODUCTION

Cardiac stress tests with electrocardiographic registries are widely used for clinical purposes, due to their high predictive value in the diagnosis of coronary heart disease and to estimate the aerobic capacity of a person (Dávila, 2007; Fleisher & Beckman, 2007). In sports, cardiac stress tests including medical gas analyses (MGA) are a highly valued tool for the adaptation, tracking and optimization of training plans (Schouten & Poldermans, 2007). In addition, these tests provide a series of indexes for recovery assessment which are associated to Heart Rate (HR) records, one of the most important indicators for both performance control and workout intensity assessment (Mendo, 2012). The use of this parameter as an intensity regulator has several functions, such as maintaining a given work rate according to each sports discipline and maintaining a given training frequency to improve physiological threshold components (Montero & Peinado, 2002; Montero & González, 1997). In non-athlete patients, results tend to be submaximal (at least from the metabolic point of view) and there are usually no reference values to establish a comparison (Herrero & Machota, 1999). Those values do exist among athletes, regardless of their respective disciplines, and they are provided by those subjects who submit themselves to cardiac stress tests in order to learn about and improve their physical fitness (Calderon & Segovia, 1997). The link between recovery components and sports activity has been proven on several opportunities (Whipp & Wasserman, 1972; Jones & Burnley, 2009; Grassi & Wagner, 1996; Borghi & Costa, 2012). However, the link between higher (and faster) recovery and better physical fitness is not exclusive to athletes, as there may be some practical applications in patients under cardiovascular risk (Bentle & Bishop, 2007; Midgley & Marchant, 2007). Heart rate recovery after continuous effort presents a biphasic pattern, with

an initial sharp drop followed by a slow drop. Basically, the initial sharp drop does not depend upon the type of effort exerted since the drop bears greater influence on baroreflex sensitivity (Mezzani & Laethem, 2009). On the contrary, the slow drop phase does have a greater dependence on the type of exercise performed (Fletcher & Gulati, 2013). The relation established between the sharp and slow drops in the recovery heart rate is due to the link between cardiovascular system and the central nervous system through the baroreceptors, in particular baroreflex sensitivity. (Grassi, 2003). This link may become a relevant mechanism in cardiovascular regulation, apart from providing the organism with an adaptation mechanism to stressful environmental conditions (Nabkasorn & Miyashita 2006).

In addition to the central nervous system, the autonomic nervous system (ANS) also plays an important role in HR regulation through the parasympathetic nervous system (PNS), specifically through the vagus nerve, influencing its functioning in the form of HR modifications, causing an effect called chronotropism. It is thus that the innervation of the PNS causes a reduction of the HR (the negative chronotropic effect). (Chicharro & Vaquero, 2006).

The negative chronotropic effect reflects the parasympathetic activity that slows down the HR until it reaches basal levels, ceasing sympathetic influence on the HR through the prevalence of the former. In most physiological situations, sympathetic and parasympathetic activity go through reciprocal regulation, which finally points towards the classical idea of sympathetic vagal balance (Cardinali, 2007). The available research on post-stress cardiac recovery relates HR normalization to postexercise oxygen consumption behavior (Brandenburg & Regensteiner, 1999; Franco & Evans, 2014; Koppo & Jones, 2004).

The study of VO₂ offers relevant information about the use of metabolic pathways, particularly the oxidative pathway, that are involved in obtaining the energy needed to perform almost every daily activity (Whipp & Ward, 2002; Neunhaeuserer & Ermolao, 2017), VO₂ max, the VO₂ required to perform submaximal exercise, and the rate to which VO₂ rises during aerobic-anaerobic transition (from a lower to a higher energy requirement until reaching the steady state), are factors that affect individual tolerance to physical activity (Van Dyck & Salvo, 2015; Goto & Isonuma, 2015). It is in this regard that the study of VO₂ kinetics enables the analysis of the physiological mechanisms responsible for dynamic VO₂ response to exercise and its subsequent recovery. VO₂ kinetics are derived from this analysis, defined as the study of the physiological mechanisms, such as the heart and tissues, that are responsible for dynamic VO₂ response, that is, from oxygen intake through the respiratory system to its consumption by the muscles, applied to physical exercise and their subsequent recovery (Espinoza, 2016). Within VO₂ kinetics, we find two kinds of curves in on and off modes. The first is the stretch that appears as a product of the increase in physiological requirements as exercise starts, to which organism adaptations, mainly bioenergetic and cardiometabolic, are the response. These changes take place in a succession of three phases, which are "phase 1, or cardiodynamic phase; phase 2, or fast phase; and phase 3, or slow component (Burnley & Jones, 2007), whereas the second curve, off kinetics, comprises three phases, phase 1 or fast phase; phase 2 or slow phase (Bertuzzi, 2010) and an additional ultra-slow phase which lasts 24 hours (Castinheiras y Farinatti, 2009).

From a mathematical perspective, we can see that both curves possess a monoexponential, biexponential o triexponential feature given the number of their components. (Lima, 2009; Stirling & Zakynthinaki, 2009; Gurd et al, 2009). These curves will be analyzed using tau kinetics. The concept deals with a time constant which is defined as the time needed for oxygen consumption to reach the steady state during the *on* phase or, on the other hand, reach basal levels once exercise is over or in the *off* phase, known also as the recovery phase. This is obtained quantifying the time elapsed between propagation delay and final time (Espinoza, 2016).

The objective of the following study is to analyze the behavior of oxygen uptake kinetics in athletes from different disciplines according to the prevailing energy system in each one of them.

MATERIAL AND METHOD USED

Design

Exploratory, comparative, non-experimental and longitudinal study in three groups of outstanding federated athletes in Chile, analyzing both the fast and slow components of oxygen uptake kinetics comparing the data provided the 3 sport disciplines involved in relation to their corresponding prevailing energy systems.

Participants

The study considered 22 subjects who are federated athletes, ranging between the ages of 16 and 31, from the Olympic Training Center. The athletes were then sorted in three disciplines: weight-lifting (n=7), futsal (n=7) y triathlon (n=8). The study used a non-probability sampling method. Those participants whose highest training frequency was lower than three times a week; those with a previous history of cardiopulmonary disease; whose exercise routines were higher than three times a week; with an active smoking habit; with a history of hypertension or with a recent or current cardiopulmonary disease; and those taking medication bearing an effect on the autonomic function were excluded from the study. Prior to the evaluation, all subjects had to sign an informed consent form.

Methodological Analysis

The ergospirometry test lasted 22 minutes and it was executed in the following manner: the subject was asked to remain on the cycloergometer in a state of absolute resting, breathing calmly for six minutes to obtain resting VO₂ data and Borg scale perceived exertion. This was followed by a two-minute warm-up in which the subject had to cycle at 50 revolutions per minute (rpm) load-free, retrieving breathing to breathing and perceived exertion data in the last 15 seconds. Afterwards, a modified Astrand & Rhyming submaximal protocol was applied on the cycloergometer for six minutes. During this time, the subjects had to cycle steadily at 50 rpm, with an adjusted load for detrained subjects (50 to 100 Watts), obtaining their perceived exertion and their heart rate (HR) in the last 15 seconds of each minute through the use of a cardiotachometer (Polar RS800 CX). Finally, a two-

minute return to resting phase took place, with a gradual load reduction, but asking the subject keep cycling at 50 rpm, obtaining the perceived exertion in the last 15 seconds. Once this was finished, the subject had to get off from the cycloergometer and take a sitting position on a chair with both arms and back-rest in order to breathe calmly for the following six minutes. Breathing to breathing and perceived exertion data were retrieved at the end of this period. The protocol was evaluated and authorized by the Ethics Committee at Santo Tomas University.

STATISTICAL ANALYSIS

Data Capture and Registry

The VO₂ v/s Time data obtained using Metasoft software was cleansed by averaging ten second intervals and adjusting them to a bi-exponential model to develop an illustration chart of VO₂ uptake kinetics and its components. The use of a nonlinear regression bi-exponential model (two phase decay) proved essential, since it allows to divide the recovery curve in one fast and one slow component, apart from providing the extraction of relevant parameters, such as time constants (tau) and velocity, amplitude and resting VO₂.

All statistical tests were developed using SPSS v20 (IBM 2011) software. The type of analysis proposed to compare the differences between disciplines is a covariance analysis (ANCOVA), to observe the different dependent variables used in this study. To run a posteriori tests, the HSD TUKEY (Sokal & Rolf 1995) test was used. For the correct application of ANCOVAS, data was adjusted to a linear regression model of the y=a+bx type, in order to assess the link between time and VO₂ variables, Heart Rate (HR), and Respiratory Rate (RR).

RESULTS

The sampling took place during two months on 22 male Federated Athletes of Futsal, Weightlifting and Triathlon, all of whom were included in the study as volunteers using the inclusion/exclusion criteria that can be seen in **Table 1**.

	Futsal Mean (±) SD	Weightlifting Mean (±) SD	TriathIon Mean (±) SD
N Males	7	7	8
Age (years)	20.8 ± 1.7 (18-24)	18.5±2.6 (16-23)	27.5±3.6 (21-31)
Weight (kg)	69.5 ±9.0 (57-85)	73.8±13.3 (60-99)	68.2±7.7 (55-79)
Height (cm)	169±4.6(160-174)	168.7 ±5.9 (160- 178)	175.8±6.0 (168- 189)
BMI (kg/m²)	24.4±2.4 (21-28)	25.2±3.2 (21-31)	21.8±2.4 (19-26)
Waist Circumference (cm)	79.28±4.8 (73-85)	77.25±9.1 (61-94)	77.5± 5.8 (67-84)

Table 1. Average values and standard deviations of the anthropometric measurements of the individuals.

SD: Standard Deviation; cm: Centimeters; kg: Kilograms; m: Meters; BMI: Body Mass Index.

The results show that relative VO₂ uptake kinetics (see figure 1) from the three disciplines present a similar pattern in terms of oxygen consumption during the evaluation period. However, the data shows significant statistical differences among the sport disciplines included in the study (F: 106.532; g.I.=2; 899, p<0.001). The oxygen consumption curve registered in Futsal is higher than in Triathlon and Weightlifting (p<0.05), but there are no statistical differences between Triathlon and Weightlifting (p>0.05).

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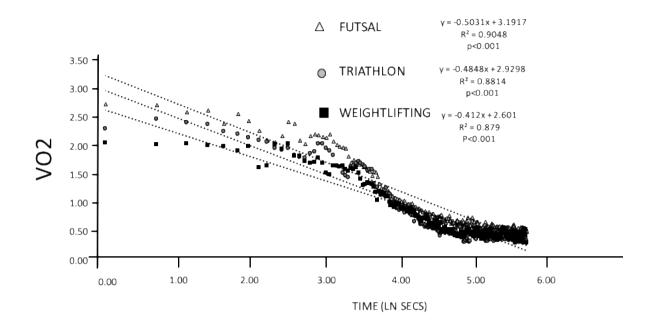


Figure 1: Comparative graph of VO₂ uptake kinetics in relation to the three chosen sports disciplines, Futsal, Weightlifting and Triathlon.

Upon analyzing the temporal change pattern between the respiratory rate and time, the data shows statistical differences between disciplines (F: 1290.582; g.l.=2; 899, p<0.001; see figure 2). Respiratory rate data shows that the rate of change or calculated slope is different for each of the disciplines analyzed in the study (p<0.05). In this case, Futsal displayed a high slope, Weightlifting an intermediate slope, and Triathlon a smaller slope.

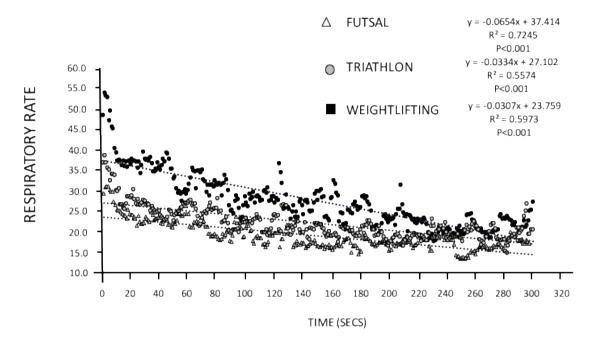


Figure 2: Comparison between the Respiratory Rate (RR) of all three sport disciplines, Futsal, Weightlifting and Triathlon.

Regarding the case of Heart Rate (HR), the data shows a pattern similar to that of Respiratory Rate, with some statistical differences between the three disciplines. (F: 1386.740; g.l.=2; 899, p<0.001; see figure 3). Heart rate data shows that the rate of change or calculated slope is different for each of the disciplines analyzed in the study (p<0.05). Once again there were higher values in Futsal, intermediate values in Weightlifting and lower values in Triathlon.

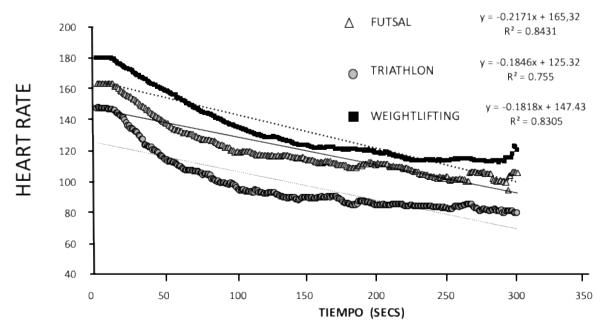
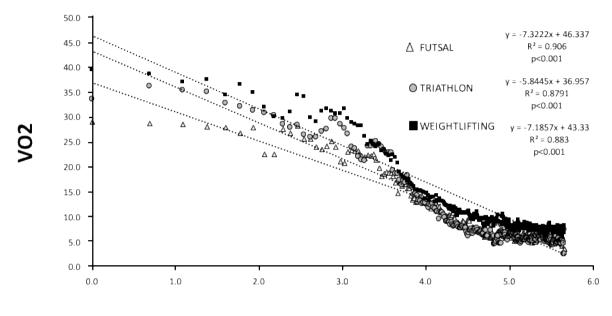


Figure 3: HR comparison between the three disciplines, Futsal, Weightlifting and Triathlon.

Finally, the results show that upon evaluating absolute oxygen consumption (see figure 4), once again the three disciplines present different levels of consumption (F: 99.382; g.l.=2; 899, p<0.001). The slope for the registered oxygen consumption in Futsal is higher than in Triathlon and Weightlifting (p<0.05) and there are no meaningful statistical differences between Triathlon and Weightlifting (p>0.05).



TIME (SECS) Figure 4: Results for inter-subjects' protocol in the Absolute VO₂ dependent variable.

DISCUSSION

Upon analyzing the behavior of oxygen uptake kinetics in athletes from different disciplines, and in association with the prevailing energy system in each type of training, VO₂ uptake kinetics was valued through the use of ergospirometry. The group comprising Futsal athletes presented a faster tau than the athletes from the Weightlifting and Triathlon groups. HR and RR showed a behavior pattern similar to that of VO₂, where the Futsal group presenting the greatest recovery slope in these variables. Nevertheless, and unlike what is found in VO₂ uptake kinetics, the Weightlifting group showed a steeper recovery than the group of triathletes in both parameters.

The literature on the subject shows that the behavior of VO₂ in exercise and recovery is mediated by different factors and mechanisms, both central and peripheral (Espinoza & Zafra, 2018; Skinner & Mclellan,1980). Central elements are mediated from the motor areas of the cerebral cortex, producing a quick "anticipatory" response that is reflected on an increased HR, as a product of a vagal withdrawal and later sympathetic activation, apart from an increase in respiratory rate. Basically, there is a parallel and simultaneous coactivation of the motor control and cardiovascular centers during exercise and the recovery phase (Chicharro & Vaquero, 2006)

In this regard, some links may be established between the particular training features of each sport and the adaptations associated to their cardiovagal responses, which

means in turn greater effectiveness in the vagal activation response and a more pronounced sympathetic withdrawal. These findings are supported by Duarte et al, who evaluated 177 subjects, establishing a 16-week physical exercise protocol that increases the vagal response during the rest to exercise transition (Duarte & Araujo, 2013). It is along these lines that our group has reported that, after a high intensity intervallic exercise protocol, there is an improvement in the fast component of VO₂ uptake kinetics, increasing the recovery time following physical exertion (Espinoza & Zafra, 2018). A high intensity intervallic training was applied in both protocols, phase III from Skinner's triphasic model, over the ventilatory anaerobic threshold II (80-85% VO₂ max) (Skinner & Mclellan, 1980). This could explain the different behaviors observed in heart rate recovery, which in turn would link this variable to the different types of training. Within this context, Futsal is the sport that presents the most aerobic-anaerobic transitions, as well as acyclic features (Burnley & Jones, 2007). However, these studies included sedentary, overweight subjects (not athletes as in the case of this study) and, given the specificity of the evaluation process in use, it may not be completely comparable to Futsal training features. Therefore, it must be taken into account that there is little room for a comparison with the present study.

Regarding the central and peripheral physiological adaptations that will foster a high intensity intervallic training system (Fernández & Tunez, 2009), the peripheral transitory oxygen deficit associated to this kind of training will foster also a higher quantity of cellular adaptations, among which the rise of the hypoxia (HIF-1) induced factor deserves a special mention. It is expressed in kidney tubular cells, which will lead to increased production of erythropoietin, thus increasing red blood cells and finally improving the absorption and transport of oxygen. Additionally, muscle oxygen transport will also benefit due to increased production of myoglobin. These adaptations also touch upon carbohydrate metabolism due to stimulation of PFK (phosphofructokinase) activity, which phosphorylates Fructose-6-phosphate into Fructose 1.6 biphosphate, increasing energy production rates through glycolysis and a greater production and activation of Glut-4 transporters (Glucose transporter protein, regulated by insulin), increasing in turn glucose intake to muscle cells to produce energy more efficiently through glycolysis (Pilegaard & Bangsbo, 1999). These adaptations also imply modifications that may affect the quick response to oxygen uptake kinetics, such as the peripheral component that, according to the description by Wu et al (1999), would raise the mRNA related to the fast component of PGC-1st and TFAM after a HIIT session, considered essential to mitochondrial biogenesis through stimulating the mitochondrial transcription that favors resynthesizing high energy phosphagens associated with the fast component of oxygen uptake kinetics and consequently helping post-exercise recovery.

In addition, we also found the peripheral mechanisms associated to the delivery and consumption of O_2 in muscles. In spite of the scant available evidence about uptake kinetics in competitive sports and the exploratory nature of our study, the results for off tau kinetics in VO₂ were statistically significant, clarifying how the behavior of this variable is influenced by, among other factors, the prevailing energy intake in each of the sports from the study. No evidence was found in the existing literature about the VO₂ uptake kinetics of different sport disciplines regarding the prevailing energy features in each discipline, but there is some research that focuses on overweight and sedentary population (Aubert & Beckers, 2003) which might help to reinforce this

idea. They point out toward the implementation of a 5x55x5 exercise protocol (of a high intensity intervallic character, or HIIT) for a ten-day period with a decreased fast-tau (or fast phase). From this, it can be inferred that the type of adaptation induced by exercise or by a specific type of training, such as different sport disciplines, could determine VO₂ tau kinetics to be relatively steep. Several adaptations are fostered by this training system, both central and peripheral, among which it is relevant to highlight both a sympathetic-adrenal activation and cardiovagal improvements, which translates into higher effectiveness in terms of vagal activation and a steeper withdrawal of sympathetic activity regarding oxygen consumption, an area in which it became apparent that the Futsal group showed a steeper tau for VO₂ uptake kinetics because the fast phase of the latter depends from the autonomic nervous system, mainly from vagal activation. There is a consensus regarding the link between poor Heart Rate recovery after physical exertion and a high probability of dying from a different cause (< 12 bpm in the first minute of the recovery) (Berne, 1980). The data from the present study, on the other hand, shows that for Futsal, Weightlifting and Triathlon, athletes presented a physiological indicator higher than twelve bpm in the first minute of recovery, something that is associated to anticipatory sympathetic withdrawal. High sympathetic activity is a strong predictor of low survival, while a high vagal tone is cardioprotective. In general, the effect of SNA activity over cardiac activity can be summarized as follows: sympathetic stimulation can accelerate the depolarization of the SA node, causing tachycardia and lowering heart rate variability (HRV) as well as the parasympathetic stimulation reduces the discharge rate of the SA node, producing bradycardia in turn and increasing HRV (Aubert & Beckers, 2003). According to this, the features that correspond to each type of training would induce an anticipatory response of the vagal tone, causing a premature reaction of fast recovery kinetics. An important aspect to consider is the impact that the test applied in this study had on each one of the sport disciplines. It is plausible that VO₂ uptake kinetics may be influenced by the intensity with which exercise is performed, considering the sudden changes of HR in the rest-exerciserest transitions of the fast phase of VO₂ kinetics, which in moderate intensity exercises responds mainly to vagal withdrawal and, in high intensity exercises, to the combined action of vagal withdrawal and sympathetic stimulation. HR recovery kinetics may present the most activity in these two SNA branches when exercise intensity is higher, showing a faster recovery. In the case of this study, the results are probably influenced by the intensity that the test stimulus meant for each group, where it was observed that for the Futsal group, it meant harder exertion than for the other two, according to the results obtained in the study.

Finally, it is worthy of note that, among the athletes involved in the study, and according to subjective variables, such as the perception of exertion during and after the protocol, weightlifters showed that the test meant a lower effort for them than for Futsal players. It was also demonstrated that the test brought lower physiological stress, during the protocol, for the triathletes, who also have bicycling as part of their discipline, which may translate into higher biomechanical efficiency and familiarity with this task.

LIMITATIONS

In regards to the limitations of the present study, the time of day for the application of the Astrand test was one of them, given that the evaluations took place at different

times, regardless of each group of athletes, between 10 AM and 3 PM. One other aspect that may have influenced the results, was the variable time for recovery that each group and athlete had in their last training session before the test was applied.

CONCLUSION

Given the results of the study, it may be concluded that the tau of VO₂ uptake kinetics is steeper for sports with a greater aerobic-anaerobic interphase than for sports which are either predominantly aerobic or anaerobic. According to what has been described, neural and metabolic adaptations at both the central and peripheral levels favor specific features of acyclic training systems, bearing a positive influence in the speed of recovery after exercise. However, more studies are needed to establish comparisons between acyclic sports or, through other protocols, further homologate the specific features of each sport on one hand, and standardize even more the intensity perceived by the athletes.

ETHICAL CONSIDERATIONS

All participants signed a letter of informed consent which was properly sanctioned, along with all other procedures, by the Ethics Committee at Santo Tomas University in Santiago, Chile. The researchers involved in this study paid also acted in accoedance to the Helsinki Declaration regarding research work in human beings.

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