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The Global Model of Pacing Process for Long and Ultra-Long Distance

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Abstract

Pacing process can be thought as a complex process in which the subject controls the intensity of exercise at any time. It is a key factor determining performance, notably in ultra-endurance events. We agree with the fact that perceived exertion is central in the process of pacing as proposed in the central governor model and the psycho-motivational model, notably. But we claim that using effort, as a unique parameter, is not sufficient and that motivation should be integrated in a more complete manner. The aim of this paper was to explore the role of effort but also other perceptive parameters and motivation in fatigue regulation and pacing process. The impact of motivation and feelings were also envisaged in order to propose a novel model of pacing adapted to ultra-endurance. We explore the manner in which objective and subjective characteristics of the task but also the factors of motivation, emotional state, the level of acceptation of emotional state and physiological state interact which each other in order that the athlete self-selects his intensity during fatiguing exercise. Finally, we propose a new "global model of pacing process" (GMPP) based on the self-determination theory, the theory of goal setting and task motivation, and the theory of energy conservation, in order to have a more holistic view of this complex process.

Keywords

Pacing Strategy, Fatigue, Exercise, Emotions

1. Introduction

Ultra-endurance events as ultra-trails have been largely democratized and attract more and more athletes. It corresponds to exercise lasting several hours during which the development of fatigue is important.

If physiological resources are of importance, the manner in which athlete manages energy expenditure so that no factor will becoming limiting before the endpoint of exercise, named as pacing process, is a key factor determining performance (Baron, Moullan, Deruelle, & Noakes, 2011). It can be thought of as a complex process in which the subject controls the intensity of exercise at any time by taking into consideration physiological reserves in relation to the estimated time until the finish at that exercise intensity (Baron et al., 2011).

In this context, the role of effort is considered as of great importance, because as a muscle becomes fatigued, a progressive increase in the voluntary effort to enhance the facilitation system is added until the physical task requires a maximal effort (Taylor & Gandevia, 2008). Perception of effort is then considered as the conscious sensation of how hard, heavy and strenuous a physical task is (Marcora, 2010) whilst potential motivation is the highest effort a person is willing to exert in order to succeed in a task (Brehm & Self, 1989).

But we claim that using effort, as a unique parameter, is not sufficient and that motivation should be integrated in a more complete manner.

Motivation can be defined as the process that determines the direction and energisation of behavior (Gendolla & Richter, 2010). Unfortunately, methods that are required to study the process of motivation are too long and complex to be used during exercise. For this reason, sport psychologists' just use the perception of effort in order to estimate the level of motivation and its evolution during fatiguing exercise (Gendolla & Richter, 2010).

The aim of this paper was to explore the role other perceptive parameters in fatigue regulation and pacing process than only the effort. The impact of motivation and feelings were also envisaged in order to propose a novel model of pacing adapted to ultra-endurance.

2. The Role of Effort in Pacing Process

Based on motivational intensity theory (Brehm & Self, 1989; Wright, 2008), the psychobiological model of endurance performance (Marcora, 2008; Marcora & Staiano, 2010) proposes that the point at which people stop exercise is determined by perception of effort and potential motivation. Hence, the person consciously decides to stop exercising when the effort required by endurance exercise is perceived to exceed potential motivation, or when perception of effort is so extreme that continuing the task seems impossible.

Likewise, the central governor model proposes that what prevents the occurrence of catastrophic fatigue during exercise is the activation of a protective mechanism that precedes the failure in physiological systems (Noakes, St Clair Gibson, & Lambert, 2004, 2005).

The authors explain that all physiological systems are homoeostatically regulated specifically to prevent catastrophic failure, including irreversible widespread cell damage. This model proposes that physical activity is controlled by a central governor in the brain so that the human body functions as a complex system during exercise.

When exercise is performed until fatigue, the rising displeasure progressively reduces the conscious desire to override this control mechanism, insuring that the exercise intensity is appropriately regulated (Noakes et al., 2005).

3. The Role of Motivation in Pacing's Process

Individuals develop strategies that allow them to reach their goals, mobilise and monitor their behaviours in order to attain their goals (Seo, Barrett, & Bartunek, 2004). Emotional phenomena represent central mechanisms of self-regulation that help humans deal effectively with their environments (Damasio, 1994, 2000; Seo et al., 2004).

In this context, emotions are defined as the feelings of the change in visceral-afferent feedback (James, 1894).

Lander et al. have shown that self-paced exercise pose a reduced metabolic challenge when compared with matched-intensity enforced constant paced submaximal exercise (Lander, Butterly, & Edwards, 2009). It is likely that this is attributable to the ability to voluntary fluctuate power output in accordance with transient sensations of fatigue or feelings during the exercise bout. The voluntary behavioural change fluctuate pace is therefore a conscious decision based on subconscious physiological feedback from array of peripheral receptors. This suggests that pacing is a mechanism to minimize the conscious sensations of fatigue, which enables homeostasis to be defended during exercise.

Hence, it is now accepted that one function of emotion is to signal disparities between environmental conditions and personal priorities (Beedie & Lane, 2012) and emotional regulation has been defined as "the process of initiating, maintaining, modulation, or changing the occurrence, intensity, or duration of internal feeling states" (Lane, Wilson, Whyte, & Shave, 2011).

In accordance, Baron et al. have proposed that during exercise the athlete must monitor not only physiological reserves but also emotional reserves so that catastrophic failure in any physiological and emotional system does not occur before the finish line (Baron et al., 2011).

In fact, to be able to reach the finish line, what has to be saved is the motivation. We argue that pacing process in long to ultra long distance could be envisaged as a regulation of motivation associated with the ability to properly treat sensations (feelings) during the entire exercise in order that the finish line could be reach.

4. Which Psychological Parameters to Use?

According to Baron et al, the athlete must monitor the difference between the difficulty of perceived effort and the pleasure during exercise (Baron et al., 2011). This difference is named as "affective balance" (AB).

If the level of affective balance is near the high level of the maximal acceptance during exercise, the athlete must choose either comfort by reducing the exercise intensity or an increase in discomfort by maintaining the selected intensity in order to improve performance. To take into account this notion of internal conflict, the level of acceptance of AB could be defined as the difference between the desire to stop the exercise and the desire to continue (Baron et al., 2011) in accordance with the energy conservation principle (Gendolla & Richter, 2010).

Authors have used the desire to stop and the desire to pursue the exercise parallel to effort and pleasure by using adapted Borg scales (Borg, Ljunggren, & Ceci, 1985) to study pacing strategies during intermittent runs (Baron, Guilloux, Begue, & Uriac, 2014; Guilloux & Baron, 2015).

The motivation to pursue a fatiguing exercise is defined as the level of acceptance of effort. The more the motivation is, the more the level of consented effort is. On the contrary, when the motivation is down, subject would not support a high level of effort and his desire to continue for a given level of effort was decreased.

Thus, the authors proposed using the ratio between the desire to continue and the perceived effort in order to estimate the level of motivation (Guilloux & Baron, 2015) rather than effort (Gendolla & Richter, 2010). Logically, this ratio would decrease during exercise with the occurrence of fatigue. Their results effectively have shown that it decreased with time and the apparition of fatigue during intermittent 3-min runs. Moreover, this ration was lower and associated with a lower pleasure when a more important effort was asked whereas it was higher when the pleasure is higher.

The subjective task difficulty, the level of resources needed for the task, and the capacity to realize the task are also interesting parameters for studying emotional regulation and pacing process. They are key variables that determine resource mobilization in motivational intensity theory (Gendolla & Richter, 2010).

Yet, if perceived exertion corresponds to the subjective experience of how hard a physical task feels, fatigue could be considered as a feeling of diminishing capacity to cope with the stress induced by exercise (Micklewright, St Clair Gibson, Gladwell, & Al Salman, 2017). Hence, perceived fatigue is different of perceived exertion or effort and has to be independently tested, by using rating of fatigue scale (Micklewright et al., 2017).

5. The Global Model of Pacing Process (GMPP)

Pacing's process corresponds to the mechanisms allowing the control of power output between the start and the end of a sport's event. An optimum pacing strategy can be described as one that is employed during exercise to regulate the rate of energy expenditure in order to minimise external power losses and prevent premature fatigue and catastrophic failure in any peripheral physiological system before the expected endpoint (Baron et al, 2011).

In running, the speed is a good marker of mechanical power produced by the runner (Millet et al., 2000) and we use the term of "speed" rather than "power" because that is what is observed by coaches and athletes.

We agree with the fact that perceived exertion is central in the process of pacing as proposed in the central governor model (Noakes et al., 2004, 2005) and the psycho-motivational model (Marcora, 2008; Marcora & Staiano, 2010). Nevertheless, we propose a new global model of pacing process in which other psycho-motivational parameters could be integrated in order to have a more holistic view of this complex process.

This model is based on the self-determination theory (Deci & Ryan, 1985, 2000; Ryan & Deci, 2000), the theory of goal setting and task motivation (Locke & Latham, 2002), and the theory of energy conservation (Gendolla & Richter, 2010). The global model of pacing process could be resumed as follow (**Figure 1**).

We propose that the subjective characteristics of the task (i.e. subjective task difficulty, the level of resources needed for the task and the capacity to realize the task) are analysed into the brain.

The synthesis of this analyse allows the athlete to do the best choice between the desire to spend enough energy to realize a performance and the desire to conserve enough energy in order that premature fatigue will not appear (Gendolla & Richter, 2010). The level of consented effort is dependent of this synthesis, probably by the activation of the ventral striatum (Schmidt, Lebreton, Cléry-Melin, Daunizeau, & Pessiglione, 2012). It impacts the level of self-selected intensity but of course the physiological state has also an important role on it. This point is in accordance with the central governor model (Noakes et al., 2004, 2005) in which both the consented levels of effort (conscious control) and physiological state (unconscious control) have impact on the self-selected intensity.

Hence, biological changes in peripheral systems act as afferent signals to modulate control processes in the CNS in a dynamic, non-linear, integrative manner to optimize performance and to prevent catastrophic failure during or after exercise (St Clair Gibson & Noakes, 2004; Tucker et al., 2006).

By this, muscle power output is continuously modified throughout the exercise bout by altering the number of skeletal muscle motors units recruited during exercise, thereby continuously varying the work rate and metabolic demand (Noakes et al., 2004). This corresponds to the physiological/unconscious part of the regulatory process (Baron et al., 2011).

Of course, the self-selected speed also impact physiological state because running fast draws more in physiological resources and adaptive capacities than running slowly. The self-selected intensity directly influences the pleasure in a minor part by the exteroception (for example the feeling of speed with the wind in the hair). But the major part of the emotional state depends on the physiological state by interoceptive mechanisms (Baron et al., 2011). On the other side, the level of pleasure directly influences the level of consented effort by the way of intrinsic motivation.

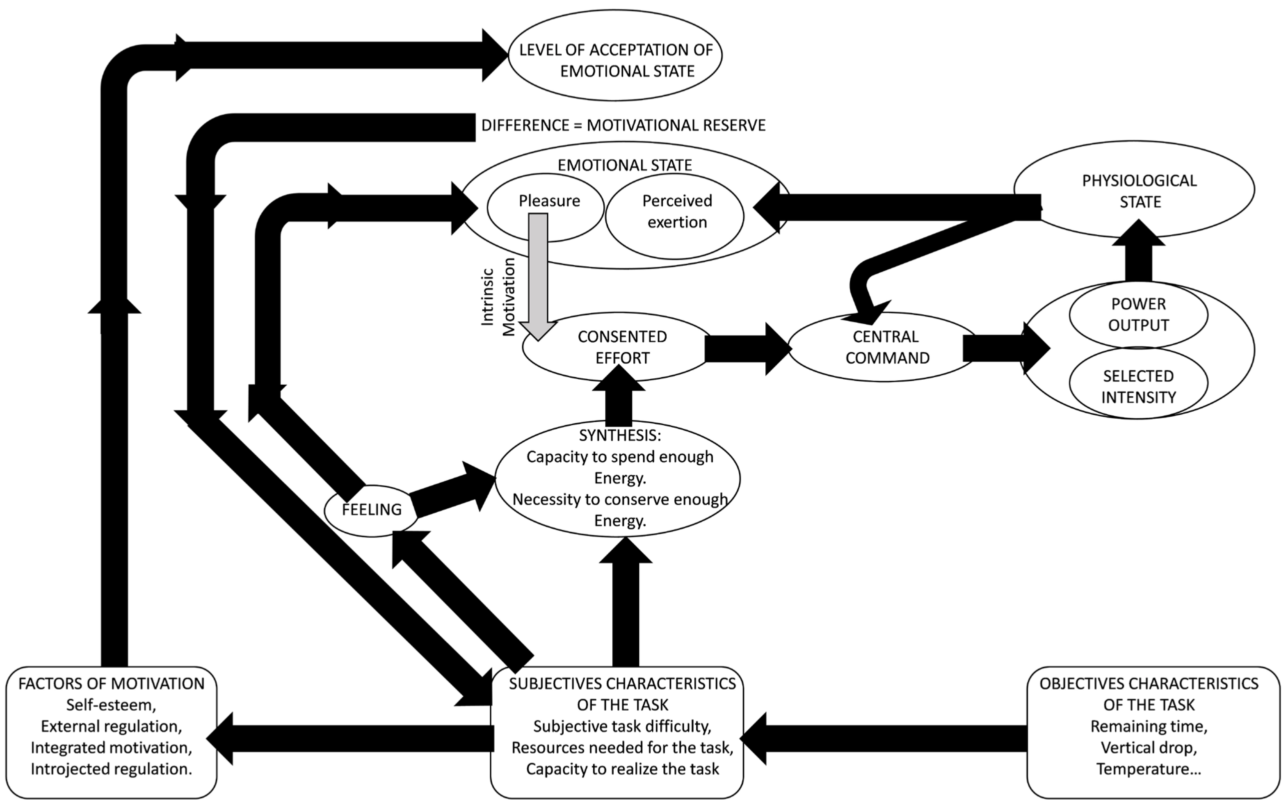

Figure 1. The global model of pacing process.

The physical and objective characteristics of the tasks (the estimate remaining time until the finish line, the vertical drop, the temperature, the adversity from the opponents, the current ranking …) impact the subjective characteristics of the task because it influences the subjective task difficulty and the estimating that the athlete has about his capacity to realize the task. In fact, even physical characteristics correspond to an interpretation by the athlete, because he cannot know with precision the remaining time but can only estimate it in relation with his capacity at this moment of the race.

Rather than taking into consideration only the level of emotional state (pleasure and perceived exertion) we argue that it is the difference between the level of acceptation of this emotional state and this emotional state that impact in important manner the pacing process (Baron et al., 2011). It is in accordance with the notion of potential motivation defined as the highest effort a person is willing to exert in order to succeed in a task (Brehm & Self, 1989).

We propose that this difference influence the subjective characteristics of the task and then the entire process loop.

The factors of motivation, including the external regulation (expected reward, social recognition), the introjected motivation (avoid guilt and shame induced by the decision to abandon), the integrated motivation (self and values system) and the self-esteem have an influence on the level of acceptation of the emotional state. For example, encouragements act by reinforcing the motivation.

When the athlete self-selects a moderate intensity, it is compatible with an important difference between the level of acceptance of the emotional state and the actual emotional state. It influences in positive manner the subjective characteristics of the task. In this condition, the task is subjectively considered as not too difficult and the capacity to realize the task is high. This reinforces the factors of motivation.

When the athlete runs at a more important intensity, the difference between the level of acceptation of the emotional state and the actual state is decreased and the task is considered as more difficult. This influence in negative manner the factors of motivation and then finally reduces the level of acceptation of the emotional state. But factors of motivation could be, on the other side, increased by this condition notably because athlete reinforces his self-esteem by the fact that he is able to select a so important speed. Hence, it could increase or maintaining the level of acceptance of emotional state, even if the intensity is high. Then the synthesis between the desire to spend energy and to conserve energy could remains unchanged and then also the self-selected intensity.

The reply from opponents also has an influence on pacing's process if the rank is important for the athlete, not only the capacity to finish the event (Konings, Schoenmakers, Walker, & Hettinga, 2016). It impacts the belief the athlete has the ability to interact with opponents by negative or positive feedbacks on subjective characteristics on the task and thus on the factors of motivation. Hence, the reply from the opponents acts as a summary feedback, moderating the goal effect (Bandura & Cervone, 1983).

The specificity of ultra-endurance events is that fatigue irremediably appears at any moment of the race. Fatigue has of course negative impact on physiological state and perceived exertion is increased. The subjective task difficulty is then necessarily increased. It negatively impacts the factors of motivation, notably the estimating that the athlete has about his capacity to realize the task. This decreases the self-esteem and all the motivational factors.

In certain conditions, athlete could be able to find motivational resources allowing transcending his capacity to resist to the emotional disagreements of fatigue. When questioned participants, they often say that they seek this emotional state in ultra-endurance events that could refers to a mental state of "sublimation". The "flow" is an example of this state (Csikszentmihalyi & Jackson, 1999). It is described as the "flow" as state in which athletes are totally immerged in their activity and that nothing else matters. This is in accordance with the concept of individual zones of optimal functioning (Hanin, 1995) in which maximal performance is observed with optimal emotion arousal.

In this context, the factors of motivations are increased because there is an optimal congruence between the manner in which the athlete perceived his capacity to realise the task and the goal associated to this task. This allows increasing the capacity of performance (Jackson, 1992).

When fatigue is so extreme, motivation is largely decreased and integrated motivation is probably the last bulwark that allow athlete to pursue effort, if it is in congruence with its values and needs (Ryan & Deci, 2000).

In this condition ultra-trail's athletes often say that they questioned themselves about the sense of their effort, of their implication in this so difficult task. Certain athletes explained that they like these so difficult moments because their questioned their-self so deeply that they "reflect on the sense of their lives". They explained that this allows them to pursue their effort until the finish line. We think that it is associated with a positive impact of motivation on the level of acceptance of emotional state, but also because athlete is able to draw in his motivational reserve in more important manner than usual.

Likewise, in elite cycling it is often observed that teammates are able to transcend for their leader in more important manner than for themselves. This is possible if the effort is in extreme congruence with their values, notably because they think that their leader has a real chance to win and that it is of great value for them. This context is sometimes observed during a break away in which a teammate is extremely fatigued and he has important difficulty to follow the members. If his leader joins the breakaway, teammate is sometimes able to transcend and largely increases his speed to help the leader, probably by increasing his mental acceptance of emotional state and drawing in more important manner in his motivational reserve.

When psycho-physiological mechanisms of adaptation to the fatigue are overload, it influences in negative manner the synthesis in the way of a decrease of the desire to continue at the actual intensity to reach the goal. The desire to stop is increased because of the difficulty to resist to the disagreements of fatigue.

This finally leads to a decrease of the consented effort and the athlete will thus reduce the self-selected intensity in order to avoid the catastrophic failure in any psycho-physiological systems (Baron et al., 2015, 2011). We argue that pacing process consist for the athlete in controlling his consented effort during the event in order that the subjective task difficulty remained on a level that could be maintained in relation with the estimate remaining time until the finish line. If the subjective task difficulty is too important, it reduces the belief that the athlete in his capacity to realise the remaining task.

Among the event, fatigue will progressively reduce both the physiological capacities and the motivational reserve.

It is well known that, with fatigue, spatiotemporal (stride frequency and stride length), kinematics (the movement pattern), kinetics (the forces that cause motion) and neuromuscular factors (activation and coactivation of muscles) of running economy are affected (Saunders, Pyne, Telford, & Hawley, 2004). Thus, athlete faces a vicious circle because the more fatigue, the more he will spend energy to conserve the same speed.

Millet et al. have already shown in one case study that ultra-long running modified the running pattern (Millet et al., 2009). Indeed, a higher stride frequency, a reduced aerial time with no change in contact time, a lower maximal vertical force and loading rate at impact, a decrease in both potential and kinetic energy changes at each step were observed. Authors have suggested that running pattern modification was a strategy to reduce the potential dangerous effects of fatigue rather than to decrease energy cost of running.

Both peripheral and central mechanisms contribute to muscular fatigue during endurance exercise.

At the peripheral level, alterations of neuromuscular propagation, failure of excitation-contraction coupling and modifications in the intrinsic capability of force production are involved (Millet, 2011). This decrease in force production is probably caused by inhibitory mechanisms resulting from thin afferent fibre (group III-IV) signalling. This corresponds to spinal adaptation, whereas supraspinal mechanism of fatigue during prolonged exercise is probably due to the accumulation of serotonin in brain (Davis & Bailey, 1997). This may occur since branched chain amino acids and fatty acids are used by the muscle to produce energy (Boyas & Guével, 2011). Hence, the central component of fatigue during ultra-endurance event is, in fact, proposed as the main explanation for neuromuscular fatigue (Martin et al., 2010; Millet et al., 2002; Millet et al., 2011), probably to reduce neural input to working muscles to limit fatigue and damage (Millet, 2011; Noakes, 2007). According to, RPE is probably affected by both central and command output and muscles afferents (Amann & Secher, 2010).

With fatigue, the "mental" image of changes in the internal physiological milieu induces a "feeling" which allow our conscious cognitive processes to be aware that a change has occurred (Damasio, 2000; Parvizi & Damasio, 2001). According to St Clair Gibson et al, this explains how the conscious perception of physiological changes is recognized as the conscious perception of the sensation of the fatigue (St Clair Gibson et al., 2003). But athletes also sometimes describe that, for a given RPE, "feeling" are not always the same. It is not easy to translate this "feeling" in scientist language but we claim that this field observation could not be ignored.

In this context, for a same RPE, power output or speed is lower when they "feel bad" and higher when they "feel good". We think that this "feeling" provides from the comparison between the expected level of subjective characteristics of the task for a given speed and the real subjective characteristics at this moment. Hence, the "mental" image of change in subjective characteristics of the task induces a "feeling" of task difficulty. Of course, if the comparison reveals that task is subjectively considered as more difficult than expected, the synthesis between the capacity to spend enough energy and to conserve enough energy is modified and the athlete reduces his consented effort. But if athlete decides to pursue at the selected speed, it increases the RPE. Of course, it also negatively impacts the factors of motivations and thus the level of acceptance of the emotional state.

In any cases, if physiological demand exceeds the physiological capacities or if motivation becomes insufficient to maintain a minimal motivational reserve, the athlete will drop.

It is in accordance with the psychobiological model of endurance performance (Marcora, 2008; Marcora & Staiano, 2010) that proposes that the athlete consciously decides to stop exercising when the effort required by endurance exercise is perceived to exceed potential motivation, or when perception of effort is so extreme that continuing the task seems impossible.

Even if this model is compatible with field observations and with the results of precedent studies (Baron et al., 2015; Guilloux & Baron, 2015), other protocols should be designed in order to test it in other conditions.

6. Conclusion

This model proposes an explanation of the regulatory process of power output or speed during prolonged self-paced exercise. Motivation, perceptual parameters, and feelings are considered as central in this process in which athlete is autonomous. This autonomy is of importance for the performance of this process. This allows that pacing could be optimal for the athlete's physiological condition (Hettinga, de Koning, Hulleman, & Foster, 2012). If consented effort is clamped, power output could freely vary based on the psychophysiological state of the athlete that continuously evolved with time. But if power output is clamped, the absence of such variations limits performance. Mauger and Sculthorpe have already shown that using protocol with clamped RPE until maximal value allow reaching higher VO_{2max} than that observed in maximal incremental exercise tests in which power is clamped (Mauger & Sculthorpe, 2010).

We think that there are tree ways to product a level of power output, i.e. freely controlled, in responses to the opponents and clamped PO. In the two first conditions, athlete uses perceptual parameters in order that PO or speed is consistent with his psychophysiological state of the moment. If athlete decides to spend more energy than allowing by his state (to reach the expected chronometric performance or to follow the opponents), he feels no good because effort is not really consented but rather undergoes and fatigue will appears prematurely (**Figure 1**).

In the last condition, the clamped PO could be consistent with the consented effort, by chance and exercise will be prolonged for a long time without any catastrophe in psychophysiological systems. The athlete feels good. But if the clamped PO exceeds the self-selected effort for a given duration, fatigue will prematurely appears and athlete feels not good.

Feelings during exercise are good markers of the adequacy between the PO and the real psychophysiological capacity of the athlete. Whereas technological tools are becoming more powerful and democratized, the athlete should learn listening to his feelings to be efficient during ultra-long distance events. His brain remains the most effective tool to detect his capacity, avoid premature fatigue, and realize the best performance.

The main contribution of this article is to propose a global vision of pacing strategy and fatigue during long duration exercises. Physiological and psychological parameters interact each other to control intensity in order that a compromise could be found between maximal performance and dangerous fatigue.

Experimental researches are needed to confirm the importance of all these parameters in this process.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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