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Exercise-related factors on the perception of time

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Abstract
Time perception is a fundamental aspect of human experience, influencing performance in sports, work environments, and daily activities. This review explores the physiological and psychological factors impacting time perception, particularly during physical exercise. Two prominent theoretical models, Scalar Expectancy Theory (ST) and Striatal Beat Frequency (SBF) Model, provide frameworks for understanding how the brain processes time intervals. Factors such as age, gender, body temperature, exercise intensity, and psychological state contribute to variations in time perception. Despite advancements in understanding time perception mechanisms, gaps in research persist, particularly regarding the effects of different exercise types and intensities on time perception. Enhancing our understanding of these factors can optimize performance and adherence in various domains.

Keywords: Time perception, scalar expectancy theory, striatal beat frequency model

Introduction

The perception of time, a relative measure influenced by various factors, is critical in numerous aspects of life, including sports, fitness, and work. Whether through the lenses of physics or physiology, time perception is pivotal in environments where actions are time-constrained and coordinated. Accurate time perception is a vital skill in sports such as basketball, football, tennis, gymnastics, figure skating, and ice hockey. It is equally crucial in work settings where synchronization is essential, such as in police and military operations. Moreover, time distortions may influence exercise adherence, as activities perceived as prolonged might discourage individuals from maintaining healthy exercise routines.

Two primary theories provide insights into the mechanisms underlying time perception:
Scalar Expectancy Theory (ST): This framework proposes that our perception of time relies on estimating the quantity of events occurring within a specific timeframe. It suggests that our internal timing mechanism operates by accumulating pulses generated by a pacemaker, with these pulses then tallied and compared to stored memories to gauge time intervals.

Striatal Beat Frequency (SBF) Model: This model accentuates the significance of the brain's striatum and the synchronization of neural oscillations in shaping time perception. It underscores the role of neurotransmitters, such as dopamine, in activating and orchestrating cortical structures to accurately measure time durations. The perception of time is relative and can be affected by age, sex, body temperature, state of health and fitness, mental concentration, and exercise intensity level. Physiological and psychological arousal, which are intrinsically linked with exercise and work also affect time perception. However, there is very little research examining the effect of the many types of exercise and activity on human time perception and thus this review is a call to further action in this area.
The concept of time has fascinated people for centuries, with ancient and modern philosophers and scientists unable to fully agree on its definition and characteristics. Despite the development of atomic clocks with nanosecond precision, which has led many to perceive time as a precise and objective measure, it remains a complex and often subjective phenomenon. However, according to Albert Einstein's theory of special relativity, time is relative (Einstein, 1905) [6]. Stephen Hawking's work revealed that time can be influenced by gravitation and postulated that it may even cease to exist within the confines of a black hole or at the moment of the Big Bang (The beginning of the universe) (Hawking and Hartle, 1972) [8].

To further complicate the issue, physicists argue that without the existence of time, one cannot speak of a period prior to the Big Bang since time did not exist. Hence, although time within a specified space-time continuum can be precisely monitored, the existence or perception of time can fluctuate.

Curently, research has begun to focus on the human personal experience of time, known as time perception (Wittmann and Paulus, 2009) [13]. Human perception of time is an important dimension in decision-making for everyday behavior and survival (Wittmann and Paulus, 2008) [13]. Time perception relates to our awareness of the passage of time, and this experience is intertwined with environmental, psychological, and physiological processes (Wittmann and Van Wassenhove, 2009; Wittman, 2013; Allman *et al*., 2014) [14, 10, 2]. For instance, it is commonly perceived that time passes more slowly when a person is bored or more rapidly for adults than for children (Burdick, 2017) [15]. While the neural basis for time perception is still unknown (Wittmann and Van Wassenhove, 2009) [14], two predominant models describe the process of time perception: scalar expectancy theory, often called the pacemaker-accumulator model, and the striatal beat frequency model (Allman and Meck, 2012; Allman *et al*., 2014) [1, 2]. These models highlight the effects of arousal (physiological or psychological) on the distortion of time.

Physical activity serves as a type of physiological arousal (Duncan *et al*., 2016) [16]. However, there exists limited research on the impact of exercise-induced arousal on time perception. Moreover, consensus is lacking regarding dual-task exercise activities and their effects on time perception. For instance, a study involving obese children discovered that dual-task conditions (Such as listening to music while running or running in silence) decelerated the internal clock, enabling them to sustain running for longer durations (De Bourdeaudhuij *et al*., 2002) [4]. Conversely, swimmers exhibited no alterations in time perception during dual-task activities (De Bourdeaudhuij *et al*., 2002) [4]. Furthermore, conflicting findings have emerged from studies investigating the influence of varied temperatures on time perception. While some research suggests that elevated temperatures compress time perception, others argue that this effect only manifests once a certain level of perceived fatigue is reached (De Bourdeaudhuij *et al*., 2002) [4]. Currently, there are no investigations into the effects of isometric, concentric, or eccentric contractions, nor maximal exercise, on time perception. Additionally, it remains unclear whether specific durations or intensities of exercise trigger changes in time perception or if there exists an optimal exercise level concerning timing and time perception. Additionally, exercise may interact with several other factors in the perceived distortion of time, including age, sex, body temperature, state of health and fitness, mental concentration and intensity level. Age differences have yet to be explored pertaining to time perception in exercise. Similarly, fitness level has not been researched yet as a factor that may attribute to improved or impaired time perception during exercise. Even so, task knowledge has been linked to improved time perception and a higher task knowledge is often possessed by highly trained individuals (De Bourdeaudhuij *et al*., 2002) [4], In relation to sex differences, the limited research suggests women may perceive time to pass more slowly than men during exercise (De Bourdeaudhuij *et al*., 2002) [4], but the underlying mechanisms have not been elucidated. In one study which showed that women perceive time as passing more slowly, the results may have been unfairly influenced as the women ran at a higher intensity than men (De Bourdeaudhuij *et al*., 2002) [4], There's a shortage of research exploring the impact of the mentioned factors on human time perception. Precise time perception is a crucial skill in various sports, including those with time constraint regulations like basketball, North American football, tennis, gymnastics, figure skating, ice hockey, and others, as well as in work environments where synchronization of actions is essential, such as in police and military settings. Additionally, distortions in time perception may influence adherence to exercise regimens. People might be less inclined to continue engaging in healthy physical activities if they perceive them as dragging on. Therefore, the aim of this review is to investigate potential physiological and psychological factors influencing human time perception and the mechanisms underlying time perception and distortion during activity, including acute and fatiguing exercise.

Physiological Factors

Aging

Grown-ups frequently reflect on the swift passage of time, contrasting it with the perceived slowness of their childhood years. This ubiquitous sentiment has become ingrained in society, accepted almost as a universal truth: with age, time appears to accelerate. The impacts of aging manifest notably through alterations in sensory perception, cognitive functioning, and diminishing physical vigor, with degrees of severity varying among older individuals (De Bourdeaudhuij *et al*., 2002) [4]. These transformations exert significant influence on both physical and mental well-being, affecting mobility, independence, and overall life satisfaction. There are clear age differences in time estimations of short intervals; older adults tend to estimate short intervals less accurately and with greater variability (De Bourdeaudhuij *et al*., 2002) [4], These deficits are presumably a result from age-related changes in attention, working memory or the speed of information processing, as it relates to the pacemaker accumulator model of time perception. It must be noted that time perception for longer durations have not been studied with the elderly (De Bourdeaudhuij *et al*., 2002) [4],

Interestingly, it appears that perceptions of time may be linked to perceptions of age. In a study involving older individuals (Aged 60-92), those who viewed themselves as younger than their actual age tended to perceive time as passing more swiftly. Conversely, those who viewed themselves as old reported time passing more slowly (De Bourdeaudhuij *et al*., 2002) [4]. In another study, participants aged 60 to 84 were asked to identify the period of their life that seemed to pass most slowly; childhood emerged as the most common response (De Bourdeaudhuij *et al*., 2002) [4]. Two studies yielded conflicting findings when comparing perceptions between young and elderly participants. One suggested that the elderly perceived time as passing more rapidly, while the other found no significant age-related differences in time perception (De Bourdeaudhuij *et al*., 2002) [4]. The lack of consensus in the current research does not support the common view that time begins to pass more quickly as we age. However, these studies primarily focused on retrospective time estimation and not subjective time estimates (Estimating time as is passes presently). Understanding the effects of subjective time perception, and potential distortion, in elderly persons may lead to a further understanding of neurological alterations as well as the sociological issues the aging population is currently facing and allow for more “elder-friendly” environments.

Given the existing research on aging and time perception, it's surprising that the interplay between age-related distortions in time perception hasn't been examined in the context of exercise or physical activity. This research gap presents a significant challenge for contemporary society, especially with the aging population steadily increasing. Many health issues associated with aging can be prevented or mitigated by maintaining an active and physically fit lifestyle throughout one's lifespan. Promoting exercise programs for this demographic has become a key priority in public health initiatives (De Bourdeaudhuij *et al*., 2002) [4]. If an individual's perception of time deteriorates negatively as they age, it could impact their dedication to physical activity or adherence to exercise routines. For example, if older adults struggle to accurately assess short time intervals (De Bourdeaudhuij *et al*., 2002) [4], such as the duration of a single exercise set, it could hinder their ability to fully participate in exercise programs.

Adolescence

As previously noted, there's a widespread belief that time feels slower during younger ages. In a review conducted by (De Bourdeaudhuij *et al*., 2002) [4], an age-related improvement in the accuracy of time estimates and a decrease in temporal variability were observed. One common method used to assess time perception in children is through temporal reproduction tasks. In these tasks, children are tasked with determining whether the duration of a second stimulus matches that of an earlier one. However, findings from studies employing these tasks have yielded inconsistent results regarding the variability of time estimates (Over- or underestimations) among children (De Bourdeaudhuij *et al*., 2002) [4]. This inconsistency may stem from variations in participant ages across studies and the gradual enhancement of psychological functions between ages 3 and 10 (De Bourdeaudhuij *et al*., 2002) [4]. Once again, there's a paucity of information regarding how children perceive time during exercise.

Gender

A single study (De Bourdeaudhuij *et al*., 2002) [4] delved into sex differences in time perception during exercise. In this study, 11 male and 11 female recreational runners were enlisted. They were instructed to run at 75% of their average daily run distance, opting for a pace of their choosing. For instance, if their typical daily run spanned 10 km, they would cover 7.5 km. Throughout the run, participants remained unaware of time or distance markers and were only informed upon reaching the designated distance. Findings indicated that women tended to run at a swifter self-selected pace compared to men, yet reported significantly lower time estimates. Consequently, women perceived time as passing more slowly than their male counterparts. Notably, these disparities in time perception persisted before, during, and after each run. These outcomes suggest that women may allocate more attention to time during exercise than men, potentially leading to a quicker accumulation of pulses in the accumulator (scalar expectancy theory). However, a notable limitation of this study is that men and women exercised at differing intensities due to the self-selected nature of the intensity measure. Consequently, some of the observed differences in time perception might be attributed to women consistently opting for higher intensities compared to men.

Body Temperature

Body temperature variations occur naturally throughout the day and in response to different factors such as illness (e.g., fever), physical activity, psychological stress, and ambient temperature (De Bourdeaudhuij *et al*., 2002) [4]. Fluctuations in body temperature can influence timing behavior (De Bourdeaudhuij *et al*., 2002) [4], and several explanations have been proposed to elucidate this phenomenon.

It has been suggested that the brain contains a temperature-sensitive time mechanism (De Bourdeaudhuij *et al*., 2002) [4]. This idea, derived from animal research, aligns with scalar expectancy theory, which often explains timing processes (De Bourdeaudhuij *et al*., 2002) [4]. Time compression, where perceived time is shorter than actual time, typically occurs with increased core temperature due to the pacemaker emitting pulses at a faster rate, similar to other physiological processes accelerating at higher temperatures (De Bourdeaudhuij *et al*., 2002) [4].

Classical physics can also explain these mechanisms: an increase in temperature leads to an increase in entropy, suggesting that time seems to pass more quickly with increased entropy (De Bourdeaudhuij *et al*., 2002) [4]. This aligns with the concept that time progresses in a certain direction when entropy increases, as per the second law of thermodynamics.

Nevertheless, in humans, an exercise-induced rise in core body temperature leads to a corresponding increase in brain temperature, making it difficult to isolate the effects of cerebral temperature in many contexts. This phenomenon indicates that exercise-induced rises in core body temperature may distort time perception (De Bourdeaudhuij *et al*., 2002) [4]. Nonetheless, the specific impacts of exercise-induced increases in cortical temperature remain unexplored.

Physical activity and Intensity

The type and intensity of exercise have been shown to influence time perception (De Bourdeaudhuij *et al*., 2002) [4]. Although research on this subject is limited, the ground-breaking study by De Bourdeaudhuij *et al*. (2002) [4] demonstrated the effect of time perception distortion across varying exercise intensities.

In this study, the Wingate anaerobic cycling test and endurance exercise (Rowing ergometry) were compared. The findings indicated that during higher intensity exercise, time seemed to pass more slowly relative to actual time. This phenomenon is believed to result from increased sensory awareness of physical discomfort during maximal or high-intensity exercise, attributed to the secretion of catecholamines inducing a state of hyperarousal (De Bourdeaudhuij *et al*., 2002) [4]. Hyperarousal leads to the processing of a greater amount of neural information, creating the perception that more time has elapsed than in reality (Scalar expectancy theory: increased number of pulses collected in the accumulator) (De Bourdeaudhuij *et al*., 2002) [4]. During high-intensity or maximal exercise, this heightened arousal and awareness compress the experience into a shorter period, contributing to the observed time distortion. It's important to note that this experiment involved recreationally active individuals, thus limiting the generalizability of the results to this population (De Bourdeaudhuij *et al*., 2002) [4].

Psychological and Emotional Impacts

A positive emotional state seems to expedite the experience of time, possibly due to attentional factors that disrupt the pacemaker-accumulator model process (De Bourdeaudhuij *et al*., 2002) [4]. Engaging in goal-oriented activities may lead to distraction, causing pulses to be collected later, thus distorting the representation of the interval's start (De Bourdeaudhuij *et* *al*., 2002) [4]

Conclusion

Time perception is a multifaceted construct influenced by a range of physiological and psychological factors. Accurate time perception is essential for optimal performance in sports, work environments, and exercise routines. While existing theories like the Scalar Expectancy Theory and Striatal Beat Frequency Model provide a foundation, more research is needed to explore the diverse factors influencing time perception. Addressing these gaps can lead to significant advancements in enhancing performance and adherence in various domains.

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