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ARTICLE

The Ability of Runners to Identify Spatial and Temporal Variables of Speed During Endurance Running

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This study aimed to evaluate spatial and temporal perception in endurance runners as a mechanism of pacing control in comparison with other athletes (soccer players). A group of 38 endurance runners and 32 soccer players participated in this study. Runners displayed lower time differences and lower error than soccer players. Taking the athletic levels of endurance runners into consideration, significant differences ($p = .011$, Cohen's $d = 1.042$) were found in the time differences (higher level group = 33.43 ± 29.43 vs. lower level group = 123.53 ± 102.61). Significant correlations were found between time differences and performance in a Cooper test ($r = -.546$) and with the best time in a half marathon ($r = .597$). Temporal and spatial perception can be considered as a cognitive skill of endurance runners.

Keywords: pacing, performance, soccer

A popular form of physical exercise is recreational running, which has increased over the last years as a result of the associated health benefits and the lack of age or gender restrictions or technical demands. This increased interest in running has prompted a comparable increase in research and assessment efforts. Consequently, a lot of information has become available about running in relation to performance and in relation to the benefits of running for health, including

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physiological, psychological, and even social aspects (van Dyck, Cardon, de Bourdeaudhuij, de Ridder, & Willem, 2017).

Endurance performance involves the prolonged maintenance of constant or self-regulated power/velocity (Pageaux & Lepers, 2016). There are several factors that predict endurance running performance. The classic physiological variables linked to endurance performance are maximum oxygen uptake (VO_2max), %VO_2max at lactate threshold, and running economy (McLaughlin, Howley, Bassett, Thompson, & Fitzhugh, 2010) as well as biomechanical factors associated with mechanical efficiency (Moore, 2016). In addition, endurance exercises cause physiological adaptations such as the increase of heart and respiration rates, mood alterations, and metabolism changes; however, little is known about the effects of exercise on the perception of time (Ashare & Kable, 2014). In this sense, the factors related to motor control have not been analyzed deeply. For example, athletes have to make decisions about how and when to invest their energy for an optimal performance, and this process is known as pacing (Smits, Pepping, & Hettinga, 2014). The mechanisms of decision making in pacing are still unknown.

Successful participation in competitive endurance activities requires continuous regulation of muscular work rates to maximize physiological performance capacities. In this regard, athletes can make wrong decisions, using conservative strategies or unsustainable work rates that lead to decreased performance (Renfree, Martin, Micklewright, & St Clair Gibson, 2014). Some athletes suddenly reduce their speed in the midportion of the race, whereas other athletes will perform great accelerations in midrace or during the end of the race (de Koning et al., 2011). Therefore, athletes regulate their relative physiological strain during competition, and poor regulation of exercise intensity is associated with competition failure (Esteve-Lanao, Lucia, deKoning, & Foster, 2008). Accordingly, the analysis of changes in running speed during competition has been of interest (de Koning et al., 2011). Today, in endurance sports, it is very common for athletes to consult task-related feedback through external devices to self-regulate their physical effort (Smits, Polman, Otten, Pepping, & Hettinga, 2016). Several devices, such as GPS, smart watches, accelerometers, heart rate monitors, or power meters, among others, are often employed by endurance athletes (Van Hooren, Goudsmit, Restrepo, & Vos, 2020).

However, proper management of sensations of fatigue leads to optimal sport performance (Smits et al., 2014). In this regard, pacing control is related to several interoceptive and exteroceptive variables, such as psychological factors (i.e., perception of time, motivational state, knowledge about the endpoint, and the duration remaining); physiological factors (i.e., heart rate, ventilation rate, and blood lactate accumulation); biomechanical factors (body posture and movement coordination); and environmental factors (surface, elevation, and climate). In addition, pacing strategies differ according to the length of the athletic competition, the environment in which it is performed, the motivation of the runner, the knowledge and experience of the athlete, and the physical fitness of the runner (Gibson et al., 2006). In this sense, a psychobiological model indicates that the conscious regulation of pace is determined primarily by the following five different cognitive and motivational factors: (a) perception of effort, (b) potential motivation, (c) knowledge of the distance/time to cover, (d) knowledge of the distance/time remaining, and (e) previous experience/memory of perception of effort during exercise of varying intensity and duration (Pageaux, 2014).

It has been hypothesized that, during exercise, the brain must calculate whether an athlete's metabolic and biomechanical performances are appropriate for either the distance or the duration of an event to be performed (Faulkner, Parfitt, & Eston, 2008). Muscular power output is regulated in an anticipatory way, designed to prevent unreasonably large homeostatic disturbances. Sensed by peripheral nociceptors and transmitted via afferent feedback to the brain, this provides important information regarding the physiological state (Mauger, 2014). The efferent motor signals to skeletal muscles concern not only the space/time pattern of motion but also the setting of muscular performance and the current metabolic rate. Thus, motor learning includes not only somatosensory control but also metabolic control (Ulmer, 1996).

Despite that the main parameter allowing the establishment of pacing control is the knowledge of the endpoint of exercise, it seems to be the brain that regulates pace through an internal clock that knows the duration or distance still to be covered so that power output and metabolic rate can be regulated appropriately (Gibson et al., 2006). Therefore, every bout of exercise must have a start and a finish, and the knowledge of that endpoint can influence pacing, attentional focus, and motivation (Ashare & Kable, 2014). Under several circumstances and between individuals, time can be perceived as faster as or slower than objective measures. There are two different approaches to time perception: retrospective and prospective. The retrospective paradigm involves having an individual estimation of the time spent, whereas, in the prospective paradigm, participants know that they will be asked to judge the duration of a time period (Ashare & Kable, 2014).

To our knowledge, there is no published research that compares running that is self-controlled according to the perception of spatial and temporal parameters of running speed, manipulating attentional focus during running by knowing the time performed or the distance traveled under a retrospective paradigm.

Taking into account the information above and using a retrospective paradigm, the main purpose of this study is to evaluate spatial and temporal perception in endurance runners as a mechanism of pacing control and to determine how this ability can vary depending on the sport discipline (e.g., runners vs. soccer players, cyclical and acyclical sports, respectively) or on the performance level of the athlete (e.g., higher vs. lower level endurance runners). The authors hypothesize that endurance runners are able to identify the spatial and temporal variables of running speed more accurately than other athletes, with higher level athletes being more accurate.

Methods

Participants

A group of 38 male endurance runners (age 36 ± 9 years, height 173 ± 3 cm, and body mass 66 ± 8 kg) and 32 soccer players (age 22 ± 4 years, height 176 ± 6 cm, and body mass 69 ± 8 kg) participated in this study (Table 1). As a control group, the authors decided to incorporate soccer players because they do not control running pace during their training sessions. All participants were older than 18 years old and were free from injuries in the 6 months preceding their participation in the study. Moreover, all participants had trained for 1–3 hr a

Table 1 Age, Anthropometric Characteristics, and Training Experience of the Participants (i.e., Runners and Soccer Players Groups)

Variables	Runners *M* (*SD*)	Soccer players *M* (*SD*)	*p* value
Age (years)	36.64 (9.33)	22.71 (4.33)	<.001
Body mass (kg)	66.79 (8.87)	69.78 (8.67)	.246
Body height (m)	173.31 (6.54)	176.37 (6.97)	.122
Body mass index (m/kg^2)	22.19 (2.26)	22.38 (1.88)	.751
Training experience (years)	8.15 (5.76)	11.61 (6.26)	.053

day, 4–7 days a week, all year, for a minimum of 4 years of training experience. The participants were selected by convenience from local clubs. The runners were divided into two groups according to athletic level, taking into account their performance in the Cooper test. After receiving detailed information on the objectives and procedures of the study, each participant signed an informed consent form, which complied with the ethical standards of the World Medical Association's Declaration of Helsinki.

Procedure

Each athlete was tested individually on two occasions separated by 1 week. In the first testing session, the participants ran on asphalt for 40 min (Trial 1). Then, a week later, a distance of 8 km on asphalt (Trial 2) was covered. The participants were asked to refrain from strenuous physical activity on the measurement day and not consume any food for at least 2 hr prior to testing. The training sessions were carried out between 17:00 and 20:00 hr on an outdoor flat surface. Before the running exercises, the participants performed a standardized warm-up. The participants were then asked to run, with their own shoes, at a self-selected running speed. Some indications were given to the participants: "Run comfortably. Don't run too fast." No more guidelines were provided as to exercise intensity, apart from the participants being informed that they were to exercise at an intensity of their own choice. Moreover, the performance in each run was recorded as follows: the distance covered (in meters) during 40 min (Trial 1) and the time spent (in seconds) during 8 km (Trial 2). The difference between the distance covered and the distance perceived (Trial 1) or the time spent and the time perceived (Trial 2) were considered as the percentage of error. During testing sessions, information about distance covered or time spent, respectively, was hidden (i.e., their watches did not show that information). In order to control the potential influence of familiarization with the circuits, the routes were organized in places unknown to the participants.

Materials and Testing

The height (in meters) and body mass (in kilograms) of participants were measured at the beginning of the first testing session, and body mass index (BMI) was calculated (i.e., body mass [in kilograms]/(height)^2 [in meters]). A stadiometer (seca 222; SECA Corp., Hamburg, Germany) and a calibrated weight scale (seca 634; SECA Corp.) were used for that purpose.

A week before the experimental protocol, the runners' athletic performance was analyzed by running distance in the Cooper test (Cooper, 1968). Participants were instructed to run as fast as possible on an outdoor track during the 12-min test. The distance covered was recorded in meters. The participants were motivated and encouraged to reach the best score possible in the Cooper test (i.e., maximum distance in 12 min).

In addition, to monitor the cardiovascular response, heart rate was registered throughout the exercise using the Garmin Forerunner monitor 405 (Garmin International Inc., Olathe, KS). The average heart rate achieved in Trial 1 and Trial 2 was used for the subsequent analysis. In addition, the perceived exertion was also considered and the rating of perceived exertion (RPE) was recorded, for scoring items from 6 to 20 (low intensity to high intensity), after the two running protocols on a Borg Scale (Borg, 1954).

Statistical Analysis

Descriptive statistics are represented as mean ± *SD* and percentages. An analysis of covariance was used to compare several parameters between the runners and the soccer players, adjusted for age as a covariate. In addition, effect sizes for group differences were expressed as Cohen's *d* (Cohen, 1988). Effect sizes are reported as trivial (<0.2), small (0.2–0.49), medium (0.5–0.79), and large (≥0.8) (Cohen, 1988). A Pearson correlation analysis was conducted between the distance differences and the time differences with the training experience in years and scores on the Cooper test. Also, a simple linear regression analysis was used between the distance differences and the time differences with the athletic performance. In addition, a binary logistic regression was performed using the condition of endurance runners as the dependent variable versus soccer players or high versus low athletic levels, with the distance differences and the time differences as independent variables. The error thresholds that best discriminated between the endurance runners and soccer players or high versus low athletic levels were determined using the receiver operating characteristic (ROC) curve. The level of significance was set at $p < .05$. Data analysis was performed using SPSS (version 24; SPSS 219 Inc., Chicago, IL).

Results

Table 1 shows age, anthropometric characteristics, and training experience in runners and soccer players. The runners were significantly older than the soccer players, whereas nonsignificant differences were found in the rest of parameters. Taking into account athletic level, lower level runners displayed lower training mileage per week than higher level runners (51.34 ± 10.26 vs. 77.66 ± 10.15 km/week). Moreover, there were significant differences ($p < .05$) in age, training experience, and performance in the half marathon between the higher level group (age 32.60 ± 8.63 years old, training experience 11.08 ± 6.61 years, and best time in the half marathon 1.15 ± 0.05 hr) and the lower level group (age 39.52 ± 8.90 years old, training experience 6.47 ± 4.58 years, and best time in the half marathon 1.32 ± 0.19 hr).

Table 2 shows the physiological and perceptual responses to Trial 1 for both groups. Significant between-group differences ($p < .001$) were found in all variables. The endurance runners group exhibited higher distance covered, shorter distance differences, lower error rate, higher heart rate, and higher RPE than soccer players ($p = .003$).

Table 3 shows the physiological and perceptual responses to Trial 2. Some significant differences were found between groups. The runners reported shorter time perceived ($p < .001$), lower time differences ($p = .002$), and lower error than soccer players (p = .011).

The binary logistic regression analysis shows that higher distance difference is a risk factor to soccer players (Odds ratio = 1.004, 95% confidence interval [CI] [1.001, 1.006], $p = .002$). Figure 1 shows the ROC curve of endurance runners versus soccer players predicted by the distance differences (area under the curve [AUC] = 0.836, 95% CI [0.737, 0.936], $p < .001$) with the cutoff at 427.5 m (sensitivity = 0.714, 1 − specificity = 0.161). The binary logistic regression analysis shows that higher time difference is a risk factor to soccer players (Odds ratio = 1.010, 95% CI [1.004, 1.017], $p = .002$). Figure 2 shows the ROC curve of the endurance runners versus soccer players predicted by the time differences (AUC = 0.832, 95% CI [0.725, 0.939], $p < .001$) with the cutoff at 100.5 s (sensitivity = 0.960, 1 − specificity = 0.273).

Taking into account the athletic levels of endurance runners, there is only a significant difference ($p = .015$, Cohen's $d = 1.042$) in the time differences (higher level group = 33.43 ± 29.43 vs. lower level group = 123.53 ± 102.61). The binary logistic regression analysis shows that higher time difference is a risk factor to lower level runners (Odds ratio = 1.022, 95% CI [1.002, 1.042], $p = .033$). Figure 3 shows the ROC curve of the high- versus low-level runners predicted by the time

Table 2 Physiological and Perceptual Data Obtained During a 40-min Trial in Two Different Groups (i.e., Endurance Runners vs. Soccer Players)

Variables	Runners *M* (*SD*)	Soccer players *M* (*SD*)	*p* value	Cohen's *d*
Distance covered (m)	8,604.1 (948.8)	6,283.7 (263.5)	<.001	3.324
Distance perceived (m)	8,811.0 (943.1)	6,144.6 (1230.6)	<.001	2.516
Distance differences (m)	271.1 (241.0)	962.3 (832.5)	.004	1.212
Error (%)	3.22 (2.94)	15.54 (13.83)	.002	1.321
Average heart rate (beats/min)	151.48 (11.64)	133.39 (13.46)	<.001	1.468
RPE (6–20)	13.13 (1.70)	11.72 (1.77)	.003	0.828

Note. Error (%): It means the difference between distance covered and perceived (in percentage). RPE = rating of perceived exertion.

Table 3 Physiological and Perceptual Data Obtained During an 8-km Trial in Two Different Groups (i.e., Endurance Runners vs. Soccer Players)

Variables	Runners *M* (*SD*)	Soccer players *M* (*SD*)	*p* value	Cohen's *d*
Time spent (s)	2,267.6 (300.9)	3,113.4 (114.1)	<.001	3.620
Time perceived (s)	2,258.6 (322.1)	3,217.0 (596.6)	<.001	2.107
Time differences (s)	82.7 (91.0)	341.2 (462.2)	.008	0.655
Error (%)	3.75 (3.59)	10.90 (14.78)	.017	0.716
Average heart rate (beats/min)	149.03 (22.55)	145.12 (27.20)	.546	0.164
RPE (6–20)	12.92 (1.81)	13.64 (2.46)	.191	0.345

Note. Error (%): It means the difference between time spent and perceived (in percentage). RPE = rating of perceived exertion.

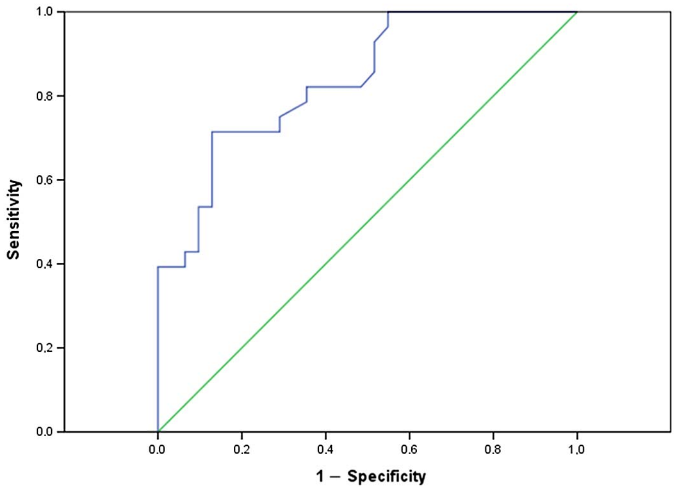

Figure 1 — ROC curve of endurance runners versus soccer players predicted by distance differences.

differences (AUC = 0.773, 95% CI [0.615, 0.930], $p = .008$) with the cutoff at 73 s (sensitivity = 0.579, 1 − specificity = 0.143).

A Pearson correlation analysis showed a significant relationship between time differences and athletic performance in terms of the Cooper test ($r = -.690$, $p < .001$) and best time in the half marathon ($r = .646$, $p < .001$). A linear regression analysis showed that time differences predicted the scores in the Cooper test ($R^2 = .298$, $p = .003$; Figure 4). Finally, no significant correlations were found

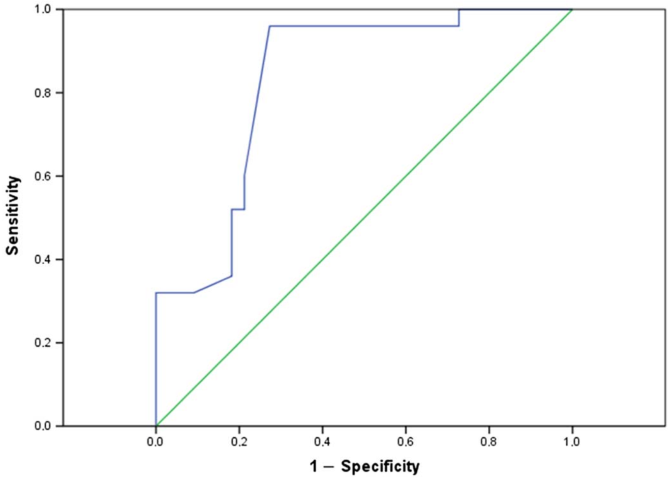

Figure 2 — ROC curve of endurance runners versus soccer players predicted by time differences.

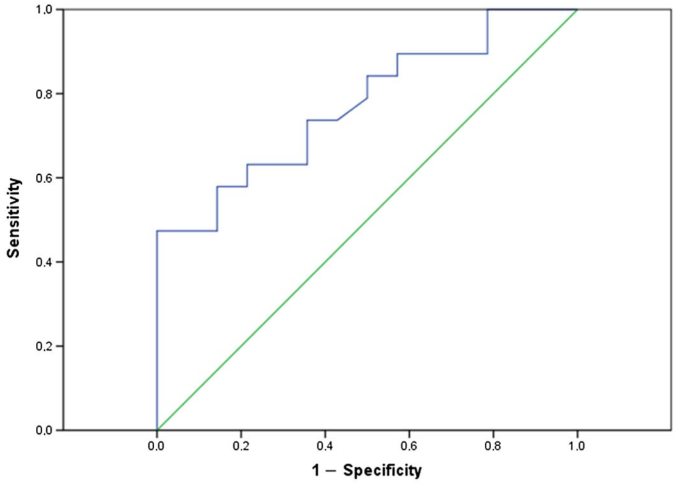

Figure 3 — ROC curve of high-level endurance runners versus low-level endurance runners predicted by time differences.

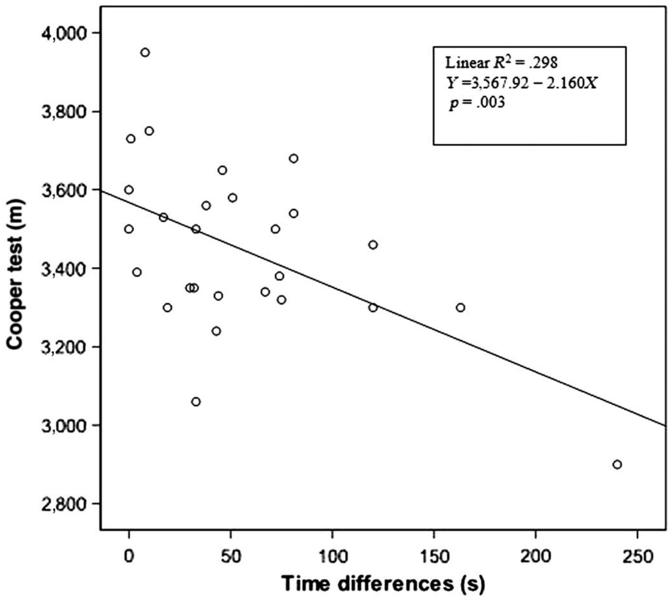

Figure 4 — Scatter plot between time differences and results obtained in the Cooper test.

between age, training experience, and error rates either in runners or in soccer players.

Discussion

This study examined the role of pacing in managing and distributing effort to successfully accomplish endurance tasks. The purpose of this study was to evaluate spatial and temporal perception in endurance runners as a mechanism of pacing control and to determine how these behavioral processes of pacing control can vary between athletes according to their athletic level and in comparison with other athletes (i.e., soccer players). The main finding of this study was that when endurance runners and soccer players were compared, the runners showed a lower error rate than soccer players in spatial and temporal perceptions. Moreover, when runners were compared according to athletic level, the higher level group showed a lower error rate than the lower level group in temporal perception. The results suggest that spatial and temporal perception are much more developed in endurance runners than practitioners of any other sport modality in which the manipulation of pace and effort are not determinant (e.g., football). Moreover, a previous study noted that exercise intensity distorts time perception, especially during maximal exercise (Edwards & McCormick, 2017). In the current study, the RPE did not show association with perception error. Even so, the runners exhibited higher RPE and heart rate peak than the soccer players during a 40-min trial.

In the current study, the higher level athletes showed better perceptual performance than the lower level runners. In this sense, pacing is influenced by an interaction between feedback and previous experience (Micklewright, Papadopoulou, Swart, & Noakes, 2010). Particularly in endurance runners, the ability to perceive and control running speed can be a learned pattern after a long experience of training and competition. In this regard, beginning runners may not have as well-developed metacognitive skills as more experienced elite runners, which indicates that the runners' metacognitive skills and attentional strategies develop as they achieve more experience (Brick, Campbell, Sheehan, Fitzpatrick, & MacIntyre, 2018). Although previous studies have shown the effects of experience and age on pacing control (Ferrauti, Bergermann, & Fernandez-Fernandez, 2010; Menting, Elferink-Gemser, Edwards, & Hettinga, 2019; Menting, Hendry, Schiphof-Godart, Elferink-Gemser, & Hettinga, 2019), the findings of the current study do not support the previous research. In this regard, no significant correlations were found between age, training experience, and error rates either in runners or in soccer players.

There is limited information about the mechanisms responsible for this ability. It has been demonstrated that metacognitive strategies such as planning, monitoring, reviewing and evaluating, and metacognitive experiences are very relevant to cognitive control and cognitive strategies employed in elite endurance runners (Brick, MacIntyre, & Campbell, 2015). Metacognition has been associated with different concepts (e.g., thinking about thinking, self-regulation, executive control, metamemory). These concepts highlight the role of executive functions in the overseeing and regulation of cognitive processes (Livingston, 2003). Therefore, metacognition implies the interaction between two key elements: knowledge and regulation (Lai, 2011). In this sense, regular monitoring of internal sensory (e.g., perceived exertion) and environmental (e.g., split times, competitors) information might create implicit or explicit metacognitive feelings that, somehow, might help to create a representation of the task (Brick, MacIntyre, & Campbell, 2016) and, thereby, increase effectiveness in performing it (e.g., pacing control). A prior knowledge of task demands, together with reliance on bodily and environmental information, may be sufficient for experienced athletes, which brings into question the importance of in-race instantaneous task-related feedback via external devices for optimized performance (Smits et al., 2016). In this regard, the importance of pacing control is an essential element for endurance performance, which is related to the correct and accurate interpretation of several sensory inputs that athletes perceive, such as muscle pain, heart and ventilatory rate, stride frequency, or sweating, among others. It seems clear that pacing strategy is organized in an anticipatory way designed not only to optimize performance but also to prevent unreasonably large homeostatic disturbances during exercise (de Koning et al., 2011). Therefore, fatigue and accompanying perceptual mechanisms might be relevant variables for decision making in pacing (Smits et al., 2014).

Another potential explanation for these results may be related to brain regulation (Edwards & Polman, 2013). Edwards and Polman's theory indicates that a central regulator operates to control exercise performance but achieves this without the requirement of an intelligent central governor located in the subconscious brain. It seems likely that brain regulation operates at different levels of awareness, such that minor homeostatic challenges are addressed automatically without conscious awareness, whereas larger metabolic disturbances attract conscious awareness and evoke a behavioral response. On the other hand, it has also been suggested that exercise-induced pain is one of several determinants of endurance performance, primarily because it facilitates awareness of the physiological state and, consequently, helps to regulate pace during moderate to long self-paced exercise (Mauger, 2014). These two theories support the view that brain regulation might play a key role in exercise performance but that the mechanisms underlying this effect have not yet been fully elucidated.

Some limitations need to be addressed to properly interpret these findings. First, a comparison between sexes was not possible. Second, the training background of runners was not controlled (e.g., experience in interval training or number of competitions per season were not recorded), which might be an explanation for the differences found between athletic level groups. Finally, the age difference between the groups is another limitation and a confounding factor that must be analyzed. It was not possible to investigate the significant relationships between age and error rates because the sample size was too small. Further work needs to be done to establish this relationship. Notwithstanding these limitations, the current study provides some insight into the pacing control ability of endurance runners.

Conclusion

In conclusion, the results obtained show that temporal and spatial perception can be considered as an extremely well-developed cognitive skill in endurance runners, especially in high-level endurance runners.

From a practical standpoint, since pacing control seems to be an essential element for endurance performance, prescribing training via speed perception or time perception might be an effective and simple procedure to optimize athletic performance in endurance runners. Therefore, the training of spatial–temporal perception of endurance runners during their preparation program might help runners to improve the management of running speed and effort and, thereby, improve sport performance.

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