Performance and psychophysiological effects of light-guided pacing during a 5000-m run

Performance and psychophysiological effects of light-guided pacing during a 5000-m run

Journal:	*International Journal of Sports Physiology and Performance*
Manuscript ID	IJSPP.2024-0202.R1
Manuscript Type:	Original Investigation
Date Submitted by the Author:	02-Sep-2024
Complete List of Authors:	Casado, Arturo; Rey Juan Carlos University - Fuenlabrada Campus, Sport Science Research Centre Hornillos, Alberto; Centro de Estudios Olímpicos del Comité Olímpico Español. 28043, Madrid., Club Atletismo San Ildefonso. 45002, Toledo.; Universidad Católica San Antonio de Murcia - Campus de los Jerónimos Foster, Carl; University of Wisconsin-La Crosse, Department of Exercise and Sport Science Ranieri, Luis; Rey Juan Carlos University - Fuenlabrada Campus, Sport Science Research Centre Renfree, Andrew; University of Worcester, School of Sport and Exercise Science Domínguez, Raúl; Universidad de Sevilla. 41005
Keywords:	athlete, behavior, endurance training, pacing, Wavelight signal

SCHOLARONE™
Manuscripts

Title

Performance and psychophysiological effects of light-guided pacing during a 5000-m run

Abstract

Purpose. In world-class middle- and long-distance running races, a 'Wavelight' signal has recently been used as a pacing guide for setting records. The aim of the present study was to compare performance and psychophysiological effects between light-guided, drafting and non-assisted pacing conditions in distance runners.

Methods. Fifteen male middle- and long- distance runners of national and regional standard ran three 5000-m time trials in a counterbalanced order with the following pacing distribution: the first 4000-m and last 1000-m were covered at submaximal and maximal intensities, respectively. The three trials (conditions) were: a) self-paced, b) guided by a light signal, and c) guided by a cyclist in front (drafting condition). Pace, heart rate (HR), Rating of Perceived Exertion (RPE), and affective valence were recorded every 500-m.

Results. No statistically significant differences were found between pacing light and self-paced conditions. Running time was shorter in the drafting vs. self-paced condition in the final 500-m section (p = 0.031; d = 0.76). No differences were found between drafting and light conditions. Similarly, whereas nine out of ten significant differences in terms of lower HR or RPE or higher affective valence responses were found in the drafting vs. self-paced condition (p = 0.004-0.041; d = 0.63-1.39), only four were found across the tests in the drafting vs. light condition (p = 0.005-0.016; d = 0.66-0.84).

Conclusion. Light-guided pacing did not influence performance or psychophysiological responses in distance runners during a 5000-m test, but drafting produced a large effect.

Keywords athlete, behavior, endurance training, pacing, Wavelight signal

Running head: Light-guided pacing in runners

Introduction

The term pacing defines the distribution of effort during an exercise session. It is a fundamental requirement for success in endurance disciplines particularly in pursuit sports such as running, cycling, skiing, rowing, speed skating.[1] An athlete's pacing strategy, the way the athlete intends ahead of time to distribute effort during a race, can have a considerable impact on performance.[2] Pacing is a complex interaction of anticipatory processes, knowledge of the finish point, previous experience, behavior of competitors and sensory information during the race.[3] The regulation of the Rating of Perceived Exertion (RPE) is a key factor in the optimization of pacing strategy and behavior in middle- and long-distance running events.[4] The brain can regulate exertion by integrating a wide range of signals from different systems[5] and the application of one or another pacing approach is based on a subjective, continuous decision-making process, starting from a series of physiological conditions, the psychological state, and both the anticipated and experienced behavior of other competitors.[6]

In endurance events, pacing behavior has been studied from physiological, cognitive and affective points of view.[7–9] The interaction among athletes makes races complex systems.[6] The proposed advantage of running behind other runners, drafting, has been studied, with demonstrated energy saving and psychological gains.[10–13] The favorable effect of drafting refers to the reduction of air resistance during races through the adoption of specific positions relative to other competitors. In this way, running behind a runner at 6 m/s (middle-distance running pace) results in a 4.5-6% reduction in VO_2.[14,15] However, it should be acknowledged that these outcomes were analyzed in extremely reduced sample sizes of 1[14] and 3[15] participants. In addition, running in a group during world-class distance track running competitions represents typical behavior in most successful athletes.[16] To achieve records in major athletic events, pacemakers, athletes who set the pace and run ahead of the presumed record breakers, have traditionally been used. These athletes are hired to lead the race and maintain the pace for as many laps as possible, usually up to the halfway or even two-thirds of the race.[17]

Recently, middle- and long-distance athletics events have included a light signal as an additional pacing guide through a technology called WaveLight, which emits a flash of light on the inner border of the track at the programmed pace.[18] A similar system also allowed Eliud Kipchoge to break the two-hour barrier at the unregulated Ineos1:59 event in Vienna in October 2019. He was assisted by a laser beam that marked a line on the road just in front of him, projected from a car moving at exactly sub-2h pace.[19] Since then, this technology has been used to break several track world, area, and national records in recent years (Table 1).

****Table 1 here****

This may have several advantages. Firstly, light-guided pacing would have allowed runners to avoid pace variation across the race.[18] Secondly, it would have reduced "external noise" in decision-making, maximizing their physiological potential.[11] Finally, pacers provided a draft for the lead runner. To the best of authors' knowledge, no previous study has either analyzed performance or psychophysiological effects of a pacing light as a pacing guide in distance runners.

Therefore, the main aim of the present study was to compare the psychophysiological response during a 5,000-m run and that of performance during the last 1000 m between light guided and drafting assisted pacing versus self-paced (non-assisted) conditions in trained middle- and long-distance runners. A secondary aim was to determine whether runners could achieve a more even pace through the light condition than through the self-paced one. The main hypothesis of the study was that lower heart rate (HR) and RPE, and better performance and affective responses, would be generated in both experimental (assisted) conditions compared with the self-paced condition.

Methods

Subjects

Fifteen well-trained male middle-distance athletes participated in this study. The athletes typically trained between five and seven days per week, competed at regional and national events, and had extensive experience with racing 5,000-m. Subjects' age height, weight and recent running performances are listed in Table 2. All participants were in good health and had no injuries in the previous four months. All participants were informed of the characteristics of the study and provided written informed consent, which was previously approved by the Ethics Committee of the Universidad Católica San Antonio de Murcia (CE072109).

****Table 2 here****

Study design

An ABC/CBA/BCA repeated measures counterbalanced crossover experimental design was used to assess performance and psychophysiological responses during the test. The test was performed in three different conditions: with the assistance of either a light signal (light) or a bicycle in front (drafting), and alone without any assistance (self-paced). The test consisted of completing a 5000-m time trial with the following pace distribution: 4000-m at submaximal intensity and the last 1000-m at maximal intensity. In this way, whereas the specific effect of the different pacing conditions at non-maximum and even pace on perceptive and physiological exercise response could be measured during the first 4000-m of the test, that effect at maximum speed and effort could be determined in the last 1000-m. A submaximal fixed and individually-based speed of 85% of the speed achieved in a 5000-m competitive race during the previous two months to the first test was selected to cover the first 4000-m section, which allowed for a comparison of HR, RPE, and affective valence responses between conditions. Given that 5,000-m race speed represents approximately 90-95% of the maximal aerobic speed (the minimum speed achieved at maximum oxygen consumption),[20] 85% of this pace would be just below the critical speed.[21] This specific pace to complete the first 4000 m of the test was selected because, theoretically, it would not surpass the boundary between the heavy and severe intensity domains and thus would not have yielded an excessive fatigue in the runners which in turn would not have allowed for a proper discrimination of RPE, affective valence and heart rate among conditions.[21] For the last 1000-m, participants were asked to increase the intensity up to maximal effort. In this way, performance in turn would be the variable which could discriminate the behavior of participants between conditions. The specific speeds were determined with the assistance of participants' coaches.

Procedures

Testing was carried out on a standard 400-m athletics track. The three tests were conducted under similar environmental conditions (22-24.5 °C and 35-42% humidity and wind speed < 8 $km \cdot h^{-1}$) in the afternoon and evening. Each participant performed the three tests within the same time window (± 2 h). Mass and height were measured in participants using a digital scale (DR400C, Detecto, Webb City, USA) and stadiometer (Detecto PHR, Detecto, Webb City, USA), respectively, before starting the warmup of the first test.

Participants were instructed to arrive at the testing location in a rested state, properly hydrated, having avoided any stimulants, without eating for at least 4 h, and having refrained from intense physical activity or training on the two previous days. Additionally, they were asked to wear the same shoe model during the tests.[22] The tests were separated by a time period ranging from four to six days, and on the two days before the tests, participants' training consisted of continuous low intensity training sessions of 30-40 min. The athletes always performed the tests after a warm-up of 15 min of low intensity continuous running, 5-10 min of dynamic stretching and a couple of 50-m accelerations on the track, which is similar to their normal pre-race competitive routine.

HR was continuously recorded using the Polar Vantage M heart rate monitor and the Polar H7 chest strap (Polar Electro Oy, Kempele, Finland) which also recorded the time to complete the tests. RPE and affective valence values were indicated by participants and collected through a voice recorder (Xiaomi Redmi Note 9T mobile phone, Haidian, Beijing, China) every 500 m. Split times every 500 m and finishing times were double-recorded by two researchers using two Motus Millennium MT68 handheld chronometers (Sasso Marconi, Bologna, Italy). The average value of both times was calculated for analysis. The 6-20 Borg scale[23] was used to record RPE and Hardy and Rejeski's 11-point scale[24] for affective valence. RPE and affective valence scales were described and explained to participants two weeks before conducting the first test. Subsequently, they underwent a familiarization process with both scales which consisted of being asked to rate both RPE and affective valence at each training session during these two weeks.

During the pacing light condition test, a researcher rode a bicycle 4 m behind and aside the participant projecting two laser beams from an Urban Moov flashlight (T'nb, Salon-de-Provence. France) which was fixed to the bicycle's handlebar, on to the track surface 4 m in front of the runner, so the participant could see that light mark at the same position relative to him during the whole test. To keep the light at the same relative position to the participant, the researcher maintained the same relative position to the participant across the whole test through careful control of speed and position. The researcher was located behind the runner so that he could not have a visual reference of the researcher's position and could only see the light mark (see Figure 1A). The pace was set by the researcher during the first 4000 m while matching actual and expected split times to achieve the target constant pace every 100 m. In the last 1000 m of the test, the researcher followed the pace set by the participant while keeping the laser light projected 4 m in front of him on the track.

During the drafting condition test, the researcher rode a bicycle one m in front of the participant and set the pace (see Figure 1B). In the last 1000 m, the researcher was verbally asked by the participant to firstly increase the pace and then adjust it through the terms "more" and "less" to slightly increase and decrease the pace, respectively. During both light-guided and drafting conditions, the researcher received constant feedback from a S3 Magene (Qingdao, China) speedometer attached to the bicycle which assisted him to keep a constant pace. During the self-paced condition test, the participant adopted his own pace with the feedback of the split times indicated by his watch, in a similar way as the researcher did in both assisted condition tests. The researcher kept 4 m behind and aside the participant to record RPE and affective responses across the test (see Figure 1C).

Statistical analysis

Data are presented as mean ± standard deviation. Coefficient of variation (CV) of segment pace during the first 4000 m was analyzed for each condition using 500 m lap times. The normality of the variables lap times, HR, RPE and affective valence was checked using the Shapiro-Wilk test for each 500-m section and for the CVs being calculated. A repeated measures analysis of variance was used to analyze the differences between the experimental conditions. A one factor analysis of variance was used to compare CV of pace between conditions. Sphericity was checked using the Mauchly test. The Greenhouse-Geisser correction was applied when sphericity could not be proved (i.e., $p < 0.05$). For significant differences, pairwise comparisons were made using Tukey's correction and the effect size was calculated using Cohen's d, which was interpreted as small (≥ 0.2 to < 0.6), moderate (≥ 0.6 to < 1.2), large (≥1.2 to 2.0) or very large (≥ 2.0 to < 4).[25] If normality of distribution could not be proved (i.e., $p < 0.05$ in the Shapiro-Wilk test), a Friedman test was used to compare the outcomes between the experimental conditions. Pairwise comparisons were conducted through the Durbin-Conover test. In all cases, the level of significance was established at $p < 0.05$. However, since light-guided pacing does not provide reductions in aerodynamic resistance, as drafting does, statistically significant performance and psychophysiological differences between the former and self-paced conditions are not very likely. Therefore, given that small differences in performance, such as a few hundredths of a second, can mean the difference between a gold and silver medal or a bronze medal and fourth place,[17] and that absence of evidence does not imply evidence of absence,[26] non-statistical differences will be discussed. All analyses were performed using the JAMOVI 2.3 statistical package (The Jamovi Project, 2022).

Results

According to the results derived from the Shapiro-Wilk tests, non-parametric tests were used to analyze affective valence. Regarding CV analyses, differences were only found in CV of pace during the first 4000 m of the test between conditions (F (2, 28) = 4.168, $p = 0.005$; $\eta_p^2 = 0.229$). However, no differences were found between conditions in the post hoc analysis. CVs of pace were 1 ± 0.39%, 0.87 ± 0.26% and 0.74 ± 0.23% for the self-paced, drafting, and light conditions, respectively. Figures 2A and 2B show the lap times and the heart rate response at each 500 m sections, respectively. 5000-m running times were 17:35.8 min:s ± 0.0006 s, 17:34.2 min:s ± 0.0006 s, and 17:34.7 min:s ± 0.0006 s in the self-paced, drafting and light-guided pacing conditions, respectively. Overall running time was shorter in the drafting vs. self-paced condition in the final section ($p = 0.031$; $d = 0.76$). HR was lower in the drafting vs. self-paced condition from 1000-m to 3500-m ($p < 0.05$; d =0.68-1.39) and in the drafting vs. light condition from 2500-m to 3500-m ($p = 0.005$; d =0.77-0.84). The RPE and affective valence responses every 500-m are shown in Figure 2A and 2B, respectively. At 4500-m, RPE was lower in the drafting vs. self-paced ($p = 0.005$; $d = 0.85$). Affective valence was higher in the drafting vs. self-paced condition at 4000 m (p= 0.014; $d = 0.65$) and 4500 m ($p = 0.044$; $d = 0.63$) and in the drafting vs. light condition at 4500-m (p= 0.016; d = 0.66).

**** Figure 2 here ****

Discussion

The aim of the present study was to compare psychophysiological response to a 5000-m time trial and that of performance during the last 1000 m of the trial between pacing light and drafting assisted versus self-paced conditions in distance runners. The main findings were a significantly lower HR and RPE, and better performance and affective valence responses at some points across the tests in the drafting vs. self-paced condition. However, no significant differences were found between pacing light and self-paced conditions.

The potential drafting benefits of running behind another runner or, in this case, behind a cyclist can explain the observed findings. In addition to the previously mentioned 4-6.5% reduction in VO_2 derived from running behind another runner at 6 m/s,[14,15] (a slightly faster speed than that used in the present study [4.74 m/s]), running in a group resulted in a 3.5% improvement in running economy due to aerodynamic effects.[27] Indeed, the drafting effect has significant benefits in well-trained runners from physiological (less oxygen consumption, less accumulation of [Bla]) and psychological perspectives.[13]

However, in addition to energy saving, there is a benefit derived from drafting, which is also common to light-guided pacing, referring to the existing visual reference dictating the specific pace which should be adopted. This benefit could also be attributed to psychological processes,[12] such as a reduction in decision-making complexity and the consequent reduction in cognitive load and mental fatigue.[11] Casado et al.[10] also showed that elite middle-distance runners experienced a reduction in [Bla] and RPE and an increase in affective valence responses when they were completing a high intensity interval training session in a group, compared to individually. Therefore, light-guided pacing could help runners by reducing cognitive load and decision-making processes through the removal of "external noise",[11] so that runners may just “follow the light” instead of establishing themselves a constant pace throughout the race which is required to beat a WR[28] or a personal best performance.

Whereas nine significant differences with at least moderate effect sizes in terms of lower HR or RPE or higher affective valence responses were found in the drafting vs. self-paced condition, only four were found across the tests in the drafting vs. light condition. These results show that psychophysiological responses to light-guided pacing and drafting conditions are ‘more similar’ than those to drafting and self-paced conditions. This particular effect may be important during elite and world-class races, in which performance differences between rivals are on many occasions minimal and just a few hundredths of a second can differentiate a medalist from a non-medalist position.[17] Similarly, while no significant differences were found between self-paced condition and that in which another runner was present during 5000-m maximum time trials in pacing profile, performance, RPE and HR, performance perception was better in the latter in recreational runners.[29] It means that a positive performance-related influence existed.

Furthermore, it is noticeable the significant differences found between drafting and self-paced conditions in six out of ten sections in HR, whereas differences were only found in one and two sections in RPE and affective valence, respectively. According to Hardy & Rejeski,[30] RPE and affective valence were moderately correlated at easy and hard training intensities, but not at intermediate/ moderate intensity, as found in the present study (RPE~14 at 4000-m). However, affective valence shows greater variability with increasing metabolic demand and RPE is more dependent on physiological signals.[30]

Despite many middle- and long-distance running races are covered at fast pace during their early and middle sections, a submaximal pace was set up to analyze HR as a quantifiable index of physiological intensity, and how it was affected by pacing lights and drafting in the present study. This was easy to apply as the athletes were familiar with this type of training. It is noteworthy that there were no significant differences in HR in the last 1000-m, while RPE and affective valence were significantly different in one section. This lack of HR differences may be explained due to the fact that the last 1000 m was much more demanding than the previous 4000 m, and thus the last section's HR may be close to participants' maximum HR.

Additionally, it is noteworthy that from the 500 m to 3000 m point (i.e., for the main part of the submaximal intensity section), the differences in HR between self-paced and drafting conditions were significant. At this intensity, well-trained runners can last much longer than the approximately 14 min needed to complete the first 4000 m of the running test in the present study, and it can be deduced that the benefit of pacemakers could be critical over longer distances.[31] Conversely, since participants were non-elite athletes and running at non-maximal intensity (i.e., moderate speed) during these first 4000 m, according to the theoretical square law for drag,[14] the drafting benefit during inherently faster elite competitions would be much greater than that observed in the present study.

Alternatively, an important aspect to consider refers to the pacing adopted through the pacing lights signal, since competition performance could be compromised by an incorrect pace (i.e., adopting an excessive or too conservative pace). In this regard, an excessive initial pace adopted might negatively influence performance[16] and the pace being selected to guide runners during a competition should accord to participants' performance standard. Finally, the lack of differences between conditions in CV of pace prevents confirming that light-guided pacing can assist runners to adopt a more even pace than that during self-paced running. Nonetheless, it does not imply that this technology cannot assist runners at a faster (i.e, competitive) pace, which cannot be controlled as easily as the submaximal speed used in the present study to calculate CV of pace. In this way, it remains unclear whether this technology can assist runners to adopt more even pacing approaches leading to faster performances during meet races, typically used during world record performances.[32]

This study is not without limitations. Firstly, the technology used in the present study to guide pacing through a light signal is different from that used during world-class races. Whereas a flashlight fixed to a bicycle's handlebar projecting two laser beams on the track just in front of the runner being guided was used in the present study, WaveLight technology comprises 400 LED lights located on the drainage covers of a track which flash to pace runners through a fluid motion.[18] In the present study, the lights were set at a clearly submaximal pace in well-trained but not elite runners, to test the effects on HR, RPE and affective valence. An important alternative experiment would be to set the lights so that they progressed at a pace that is equal to the runners' best performance, so that they would be close to their limit, which is the way the WaveLight technology is used in Diamond League races. Secondly, other physiological measures such as pulmonary gas exchange might have profitably been measured to determine whether the energy cost of running would have been different among conditions. However, that would have considerably reduced the ecological validity of the present study since athletes would have had to carry a portable gas analyzer throughout the tests.

Practical applications

A cyclist or runner can draft distance runners during training sessions, allowing them to achieve faster speeds with lower physiological strain and mental effort. Additionally, training in a group rather than individually may be considered a more interactive approach yielding a similar effect. Furthermore, light-guided pacing seems to be a useful tool which might assist distance runners to improve to a reduced extent their personal best performances. If that were the case, which remains unclear according to the findings of the present study, a debate could arise regarding whether the use of this technology is ethical and appropriate. On the one hand, WaveLight devices might not be available in all tracks and the natural decision-making process inherent to racing behavior would be conducted by an artificial and external device. On the other hand, this technology would not provide an energy cost reduction since it does not decrease aerodynamic resistance, although it still might support runners in their attempts to improve their performances.

Conclusions

Drafting provides psychophysiological and performance benefits in trained distance runners. Light-guided pacing neither generated a positive influence on performance, HR, RPE and affective valence, nor assisted runners to adopt more even paces.

Acknowledgements

Authors are grateful to all the runners participating in our study.

References

1. Foster C, Schrager M, Snyder AC, Thompson NN. Pacing Strategy and Athletic Performance. *Sports Medicine*. 1994;17(2):77-85. doi:10.2165/00007256-199417020-00001

2. Abbiss CR, Laursen PB. Describing and Understanding Pacing Strategies during Athletic Competition. *Sports Medicine*. 2008;38(3):239-252. doi:10.2165/00007256-200838030-00004

3. Foster C, de Koning JJ, Hettinga FJ, et al. Competition Between Desired Competitive Result, Tolerable Homeostatic Disturbance, and Psychophysiological Interpretation Determines Pacing Strategy. *Int J Sports Physiol Perform*. 2023;18(4):335-346. doi:10.1123/ijspp.2022-0171

4. Meyer H, Bruenig J, Cortis C, et al. Evidence That Rating of Perceived Exertion Growth During Fatiguing Tasks is Scalar and Independent of Exercise Mode. *Int J Sports Physiol Perform*. 2022;17(5):687-693. doi:10.1123/ijspp.2021-0334

5. Tucker R. The anticipatory regulation of performance: the physiological basis for pacing strategies and the development of a perception-based model for exercise performance. *Br J Sports Med*. 2009;43(6):392-400. doi:10.1136/bjsm.2008.050799

6. Renfree A, Casado A. Athletic races represent complex systems, and pacing behavior should be viewed as an emergent phenomenon. *Front Physiol*. 2018;9(OCT). doi:10.3389/fphys.2018.01432

7. de Koning JJ, Foster C, Bakkum A, et al. Regulation of Pacing Strategy during Athletic Competition. Lucia A, ed. *PLoS One*. 2011;6(1):e15863. doi:10.1371/journal.pone.0015863

8. Renfree A, Martin L, Micklewright D, St Clair Gibson A. Application of decision-making theory to the regulation of muscular work rate during self-paced competitive endurance activity. *Sports Medicine*. 2014;44(2):147-158. doi:10.1007/s40279-013-0107-0

9. Gibson ASC, Lambert E V., Rauch LHG, et al. The role of information processing between the brain and peripheral physiological systems in pacing and perception of effort. *Sports Medicine*. 2006;36(8):705-722. doi:10.2165/00007256-200636080-00006

10. Casado A, Moreno-Pérez D, Larrosa M, Renfree A. Different psychophysiological responses to a high-intensity repetition session performed alone or in a group by elite middle-distance runners. *Eur J Sport Sci*. 2019;19(8):1045-1052. doi:10.1080/17461391.2019.1593510

11. Renfree A, Crivoi do Carmo E, Martin L, Peters DM. The Influence of Collective Behavior on Pacing in Endurance Competitions. *Front Physiol*. 2015;6. doi:10.3389/fphys.2015.00373

12. Trenchard H, Renfree A, Peters DM. A Computer Model of Drafting Effects on Collective Behavior in Elite 10,000-m Runners. *Int J Sports Physiol Perform*. 2017;12(3):345-350. doi:10.1123/ijspp.2016-0026

13. Zouhal H, Abderrahman A Ben, Prioux J, et al. Drafting's Improvement of 3000-m Running Performance in Elite Athletes: Is It a Placebo Effect? *Int J Sports Physiol Perform*. 2015;10(2):147-152. doi:10.1123/ijspp.2013-0498

14. Pugh LGCE. The influence of wind resistance in running and walking and the mechanical efficiency of work against horizontal or vertical forces. *J Physiol*. 1971;213(2):255-276. doi:10.1113/jphysiol.1971.sp009381

15. Davies CTM. Effects of wind assistance and resistance on the forward motion of a runner. *J Appl Physiol Respir Environ Exerc Physiol*. 1980;48(4):702-709. doi:10.1152/jappl.1980.48.4.702

16. Renfree A, Casado A, Pellejero G, Hanley B. More pace variation and pack formation in successful world-class 10,000-m runners than in less successful competitors. *Int J Sports Physiol Perform*. 2020;15(10):1369-1376. doi:10.1123/ijspp.2019-0852

17. Casado A, Hanley B, Jiménez-Reyes P, Renfree A. Pacing profiles and tactical behaviors of elite runners. *J Sport Health Sci*. 2021;10(5):537-549. doi:10.1016/j.jshs.2020.06.011

18. Taylor J, Atkinson G, Best R. Paced to perfection: Exploring the potential impact of WaveLight Technology in athletics. *BASES UK*. 2021;(68):8-9.

19. Hawkins D. Kenya's Eliud Kipchoge just became the first marathon runner to break the 2-hour barrier. *The Washington Post*. 2019.

20. Billat LV. Interval Training for Performance: A Scientific and Empirical Practice. *Sports Medicine*. 2001;31(2):75-90. doi:10.2165/00007256-200131020-00001

21. Foster C, Barroso R, Bok D, et al. Simple Approach to Defining Training Intensity in Endurance Runners. *Int J Sports Physiol Perform*. 2022;17(8):1312-1315. doi:10.1123/ijspp.2022-0018

22. Fuller JT, Bellenger CR, Thewlis D, Tsiros MD, Buckley JD. The Effect of Footwear on Running Performance and Running Economy in Distance Runners. *Sports Medicine*. 2015;45(3):411-422. doi:10.1007/s40279-014-0283-6

23. Borg G. Borg’s perceived exertion and pain scales. Human Kinetics, ed. *Human kinetics*. Published online 1998.

24. Hardy CJ, Rejeski WJ. Not What, but How One Feels: The Measurement of Affect during Exercise. *J Sport Exerc Psychol*. 1989;11(3):304-317. doi:10.1123/jsep.11.3.304

25. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc*. 2009;41(1):3-13. doi:10.1249/MSS.0b013e31818cb278

26. Altman DG, Bland JM. Statistics notes: Absence of evidence is not evidence of absence. *BMJ*. 1995;311(7003):485-485. doi:10.1136/bmj.311.7003.485

27. Schickhofer L, Hanson H. Aerodynamic effects and performance improvements of running in drafting formations. *J Biomech*. 2021;122:110457. doi:10.1016/j.jbiomech.2021.110457

28. Tucker R, Lambert MI, Noakes TD. An analysis of pacing strategies during men’s world-record performances in track athletics. *Int J Sports Physiol Perform*. 2006;1(3):233-245. doi:10.1123/ijspp.1.3.233

29. Bath D, Turner LA, Bosch AN, et al. The Effect of a Second Runner on Pacing Strategy and RPE During a Running Time Trial. *Int J Sports Physiol Perform*. 2012;7(1):26-32. doi:10.1123/ijspp.7.1.26

30. Hardy CJ, Rejeski WJ. Not What, but How One Feels: The Measurement of Affect during Exercise. *J Sport Exerc Psychol*. 2016;11(3):304-317. doi:10.1123/jsep.11.3.304

31. Muñoz-Pérez I, Lago-Fuentes C, Mecías-Calvo M, Casado A. Pacing and packing behaviour in elite and world record performances at Berlin marathon. *Eur J Sport Sci*. Published online August 28, 2022:1-8. doi:10.1080/17461391.2022.2111278

32. Casado A, Ranieri LE, Hanley B, Foster C, González-Mohíno F. Differences in pacing behaviour between global championship medal performances and world records in men’s and women’s middle- and long-distance running track events. *J Sports Sci*. Published online 2024.

Table 1. World, Area and National Records beaten using Wavelight technology

Athlete	Sex	Competition	Date	Place	Record	Time/ distance (min:s/m)
Lamecha Girma	M	World Indoor Tour Liévin	15/02/2023	Liévin	WR indoor 3,000m	7:23.81
Filip Ingebrigtsen	M	Impossible Games	11/06/2020	Oslo	NR 1000m	2:16.46
Jakob Ingebrigtsen	M	Herculis Monaco	14/08/2020	Monaco	ER 1500m	3:28.68
Joshua Cheptegei	M	Herculis Monaco	14/08/2020	Monaco	WR 5000m	12:35.36
Mo Farah	M	Memorial Van Damme	04/09/2020	Brussels	WR One Hour	21,330 m
Bashir Abdi	M	Memorial Van Damme	04/09/2020	Brussels	WR 20,000m	56:20.02
Sifan Hassan	W	Memorial Van Damme	04/09/2020	Brussels	WR One Hour	18,930 m
Joshua Cheptegei	M	NN World Record Day	07/10/2020	Valencia	WR 10,000m	29:11.00
Letesenbet Gidey	W	NN World Record Day	07/10/2020	Valencia	WR 5000m	14:06.62
Gudaf Tsegay	W	International Meeting Liévin	09/02/2021	Liévin	WR indoor 1500m	3:53.09
Sifan Hassan	W	FBK Games	06/06/2021	Hengelo	WR 10,000m	29:06.82
Letesenbet Gidey	W	Ethiopian Trials	08/06/2021	Hengelo	WR 10,000m	29:01.03
Jakob Ingebrigtsen	M	International Meetin Liévin	17/02/2022	Liévin	WR indoor 1500m	3:30.60
Team USA	M	The Track at Boston	15/04/2022	Boston	WR distance medley relay	10:33.85
Faith Kipyegon	W	Golden Gala	02/06/2023	Firenze	WR 1500m	3:49.11
Lamecha Girma	M	Diamond League	09/06/2023	París	WR 3000mSC	7:52.11
Faith Kipyegon	W	Herculis Monaco	21/07/2023	Monaco	WR Mile	4:07.64
Jakob Ingebrigtsen	M	Memorial Van Damme	08/09/2023	Brussels	WR 2000m	4:43.13
Gudaf Tsegay	W	Prefontaine Classic	17/09/2023	Eugene	WR 5000m	14:00.21

Performances were publicly available and found at World Athletics official website (www.worldathletics.org). M: man; W: woman; WR: world record; NR: national record; ER: European record; USA: United States of America; 3000mSC: 3000m steeplechase; NN: National Nederlanden; FBK: Fanny Blankers-Koen.

Table 2. Mean, standard deviation, and confidence intervals (95%) of weight, height, age and recent running performance level of participants

	Mean ± standard deviation	Confidence intervals (95%)
Age (years)	33.6 ± 10.5	27.73 – 39.39
Height (m)	1.73 ± 0.05	1.70 – 1.77
Mass (kg)	62.9 ± 5.0	60.1 – 65.64
Recent finishing time in a 3000 m race (min:s ± s)	9:11.0 ± 26.4	8:56.36 – 9:24.64
Recent finishing time in a 5000 m race (min:s ± s)	15:51.3 ± 45.6	15:26.06 – 16:16.6

Performances were achieved during the two months before the tests.

Figures' titles and legends

Figure 1. Graphical representation of the relative positions of the researcher and participant in the light (A), drafting (B) and self-paced (C) conditions during the tests

Figure 2. Split times (A), heart rate (B), rate of perceived exertion (RPE) (C) and affective valence (D) reported every 500-m.
*Significant differences between drafting and self-paced conditions; † Significant differences between drafting and light conditions ($p < 0.05$).

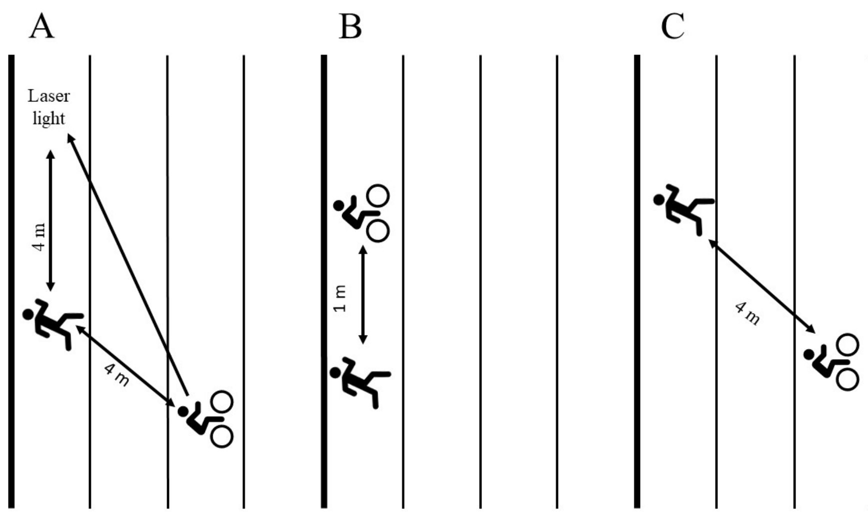
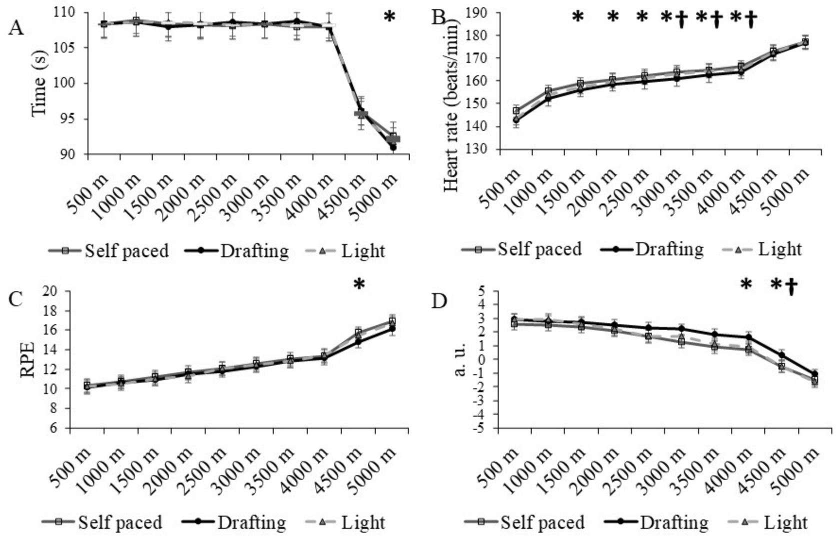


Figure 1. Graphical representation of the relative positions of the researcher and participant in the light (A), drafting (B) and self-paced (C) conditions during the tests

338x190mm (96 x 96 DPI)



Split times (A), heart rate (B), rate of perceived exertion (RPE) (C) and affective valence (D) reported every 500-m. *Significant differences between drafting and self-paced conditions; † Significant differences between drafting and light conditions ($p < 0.05$).

279x170mm (96 x 96 DPI)