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VIEWPOINT

Technological advances in elite sport: Where does one draw the line?

Borja Muniz-Pardos,[1,2] Kenenisa Bekele,[3] Carlos Mayo,[4] and Yannis Pitsiladis[5,6]

[1]*EXER-GENUD (Growth, Exercise, NUtrition and Development) Research Group, FIMS Collaborating Center of Sports Medicine, University of Zaragoza, Zaragoza, Spain;* [2]*Faculty of Health and Sports Science, Department of Physiatry and Nursing, University of Zaragoza, Zaragoza, Spain;* [3]*Kenenisa Hotel, Addis Ababa, Ethiopia;* [4]*San Jorge University, Zaragoza, Spain;* [5]*Department of Sport, Physical Education and Health, Hong Kong Baptist University, Hong Kong, Hong Kong SAR; and* [6]*International Federation of Sports Medicine (FIMS), Lausanne, Switzerland*

In 2016, advanced footwear technology (AFT) changed the sport of long-distance road running. In only 5 years, all male and female world records from 5 km to the marathon were broken, with some suggesting that this stepwise change is mainly explained due to a mechanical advantage provided by AFT (1). A number of observational studies have witnessed this abrupt drop in racing times (2–4). For example, a recent study by Willwacher et al. (3) reported performance-enhancing effects of AFT in both track and road races on long-distance (>5,000 m) performance by up to 3.5% for women and 1.4% for men. Empirical data equally demonstrate a performance advantage of AFT over other traditional shoes (1, 4–6).

Numerous competitions during 2020 were suspended due to COVID and were accompanied by a reduced number of athletes running elite times in the track (Fig. 1). However, 2020 experienced an avalanche of national, European, and world records in track races. Notably, the number of athletes running elite times in track races from 800 m to 10,000 m increased by ∼30% when comparing 2019 with 2021 (range from 23% to 45% in males; range from 25% to 39% in females, across the five distances; Fig. 1). This remarkable occurrence is likely explained by two technological introductions: advanced footwear and pacing technologies. The first-ever spiked AFT was launched during the 2020 Diamond League in Monaco (14th August) (1). During this event, the 5,000-m male world record was broken by Joshua Cheptegei wearing AFT spikes; a record that had stood for 16 years. During this event, the Norwegian athlete Jakob Ingebrigtsen set a new 1,500-m European record in 3:28.68 wearing AFT spikes. Shortly after, both Mo Farah and Sifan Hassan broke the 1-h record during the 2020 Diamond League in Brussels, both wearing the new spiked AFT. Only 1 month later, during a race in Valencia, Joshua Cheptegei broke the 15-year-old world record in the men's 10,000 m in a time of 26:11.00 wearing the same spiked shoe. This event in Valencia also saw Ethiopian athlete Letesenbet Gidey break the 12-year-old world record in the women's 5,000 m with a time of 14:06.62. The benefit of these shoes is also latent in national-level competitions, as seen in Ireland with the six fastest 800-m indoor times in history by Irish women in only 3 wk. This plethora of national, European, and world records in such a short time is unprecedented and similar to the records evolution witnessed in road running.

Although the introduction of AFT may partly explain these fast times, there are other innovations that may have equally contributed to these records in the track. The use of pacing lights first appeared in the 1970s when the short-lived International Track Association (ITA) implemented pacing lights in international track events with the intention to improve spectator experience and entertainment. Some 50 years later, pacing lights were reintroduced in road running for performance enhancement purposes to assist Eliud Kipchoge in his attempt to run a sub 2-h marathon in Monza and Vienna, and later in the track with the introduction of the so-called WaveLight technology in international track athletics during 2020. This system consists of light emitters along the inner curb of the running track, which can be programmed to provide a moving light wave at a programmable pace (7). Although championships may exhibit different pacing strategies (e.g., negative, positive, and parabolic shape), time trial performance in prolonged events (>2 min) seems to be improved if athletes distribute their pace more evenly (8). Although the use of a pacemaker to assist with even-paced running during record attempts has historically been universal in athletics, undesirable fluctuations in running speed may still occur, given this is based on human intuition and experience. In addition, when the pacemaker steps off the track, it often coincides with high levels of fatigue with no aid in pacing for the final part of the race, which may be detrimental to performance. WaveLight technology seems to mitigate fluctuations in running speed and therefore would likely entail an ergogenic aid, as recently suggested (9). When comparing the pacing of both records in 5,000-m and 10,000-m male track running between the former (Kenenisa Bekele) and the current (Joshua Cheptegei) world record holders (Fig. 2), we can appreciate how WaveLight technology likely aided the Ugandan athlete to maintain a more even pace, which would have contributed to a greater performance. Although WaveLight technology provides constant accurate feedback of the running pace to athletes, previous record attempts could only see the clock through every 400-m split. Although pacing by technical devices was prohibited by World Athletics Technical Rules, in November 2019, an

Correspondence: Y. Pitsiladis (ypitsiladis@hkbu.edu.hk).
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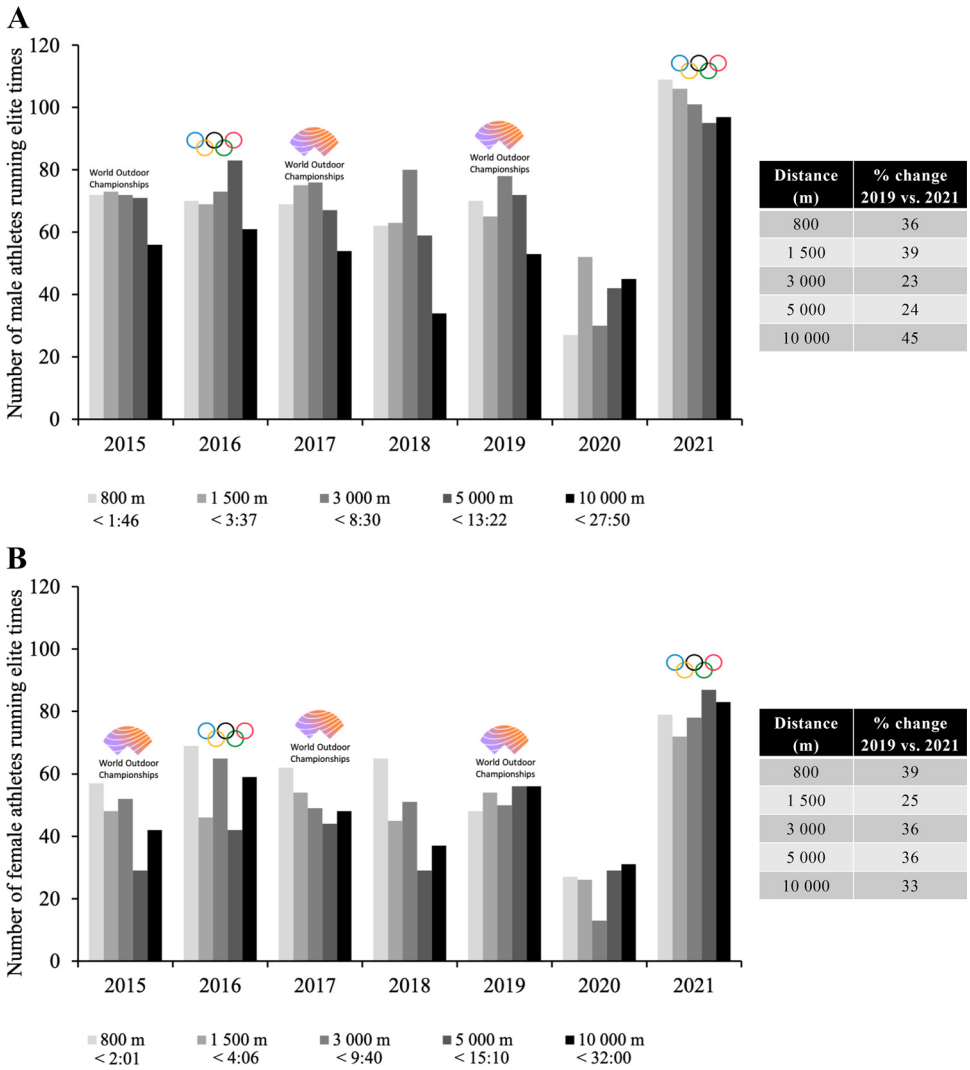

Distance (m)	% change 2019 vs. 2021
800	36
1 500	39
3 000	23
5 000	24
10 000	45

Distance (m)	% change 2019 vs. 2021
800	39
1 500	25
3 000	36
5 000	36
10 000	33

Figure 1. Number of athletes running in elite times from 800 m to 10,000 m in the track from 2015 to 2021 (times categorized by World Athletics) in males (*A*) and females (*B*). Of note, competitions during 2020 were reduced due to COVID and the first AFT spiked shoe was launched also this year. AFT, advanced footwear technology.

amendment was added stating "6.4. [. . .] the following shall not be considered assistance, and are therefore allowed: Rule 6.4.8 Electronic lights or similar appliance indicating progressive times during a race, including of a relevant record." However, Rule 6.4.4 of the same document, points out: "Heart rate or speed distance monitors or stride sensors or similar devices carried or worn personally by athletes during an event, provided that such device cannot be used to communicate with any other person." This is, however, contrary to the way WaveLight technology operates as it is used by athletes to get constant feedback of their targeted pace through an external, technological aid. Taylor et al. (9) concluded that the combination of traditional human pacing (for drafting), WaveLight technology (for accurate even pace), and novel shoe technology is a crucial factor for the records and personal bests witnessed in recent years.

The introduction of technological innovations such as the ones described here and the debate that has already transpired raise an intriguing question: Where does one draw the line between normal evolution of the sport versus an unfair advantage provided by the assistance of technology, being against the spirit of the sport? This term is used analogous to its use by the World Anti-Doping Agency (WADA) when determining whether a substance should be added or not to the WADA prohibited list (10). Undoubtedly, overall sporting performance is a result of a combination of factors (11), and a different weighting of these factors is observed in different athletes and sports. In line with this, previous research suggested that recent records in long-

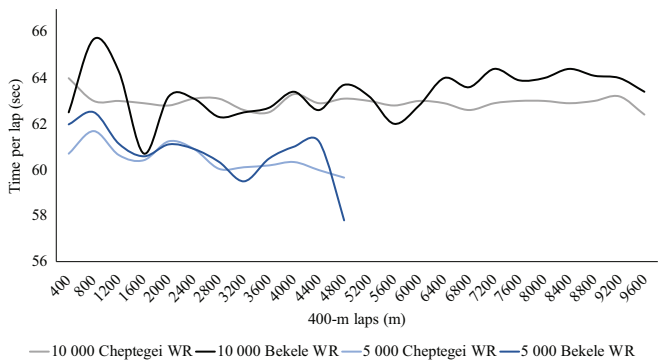

Figure 2. Pacing by the former 5,000-m and 10,000-m world record holder (Kenenisa Bekele) and the current world record holder (Joshua Cheptegei). Pacing calculated through the time per 400-m lap.

distance running can be explained by factors such as encapsulated carbohydrate, optimized training strategies, the physiology of athletes, or technological innovations (12). In response to this, our group highlighted in an editorial that recent records are technologically mediated, given that no other nontechnological factors (e.g., training programs and physiology of athletes) have changed as much in such a short time (1, 13). An illustration of this is the sudden drop in records witnessed in the track in only 2 years (Fig. 1), where fueling is not possible and the other proposed factors are unlikely to have influenced as much in such a short time. Athletes attempting a record are now benefiting from an external aid that was not accessible before 2016 (for AFT) and summer 2020 (for WaveLight pacing), and this makes it impossible to compare race performances between records set before and after the introduction of these technologies.

Irrespective of what side of the argument one falls in terms of the merits or not of these technological innovations, the introduction of new ergogenic technology in sport, such as AFT and WaveLight technology, has all sparked greater research interest in the science of training and performance enhancement, which is already positively impacting our understanding of the determinants of human performance and the physiological adaptations to training, and this in turn is expected in time to lead to further record-breaking and excitement in the sport. However, before the use of WaveLight technology expands in official competitions, we suggest that records performed with technology-assisted pacing should be differentiated from those records performed without the assistance of such technology with an "asterisk." This would be similar to the differentiation among female records established in mixed/only female races. Therefore, if an athlete wishes to break a nontechnology-assisted record, they could still do so by using traditional pacing. This measure would allow for a fairer comparison between athletes. In a similar confident note, we argue that the introduction of pacing technology alters the sport well beyond any reasonable evolutionary step, and hence this technology, while having a role in aiding spectator interest and excitement, must be dealt with differently by an athlete running under his or her own volition and unassisted by feedback. Notably, providing feedback to the athlete or a third party, such as involving the transmission of live physiological or biomechanical data, is now considered against the rules of the sport of athletics (personal communication from World Athletics). Therefore, there requires to be some level of consistency (i.e., feedback allowed or not allowed?). Another example for the need to control and regulate the introduction of technology in competition will also be required in other athletic disciplines. World Athletics recently proposed an important change in the long jump regulation, replacing the take-off line with a wide take-off zone, which would consider valid jumps any attempt within such a take-off zone (14). In reality, this would mean that every jump would count, which would discard the traditional skill of performing an optimal run phase prior to the jump. This case is analogous to the current situation with WaveLight technology and, if finally accepted, would also need to be differentiated from previous records. Sports organizations are required to intervene with fair measures to protect the integrity of the sport.

DISCLOSURES

K.B. is a professional athlete sponsored by Anta (Quanzhou, People's Republic of China) and former 5,000 and 10,000 World Record holder. C.M. is a professional athlete sponsored by adidas (Herzogenaurach, Germany). Y.P. is the founder of the original Sub2 marathon project now affiliated to Human Telemetrics (London, UK). None of the other authors has any conflicts of interest, financial or otherwise, to disclose.

AUTHOR CONTRIBUTIONS

B.M.-P., K.B., C.M., and Y.P. conceived and designed research; B.M.-P. drafted manuscript; K.B., C.M., and Y.P. edited and revised manuscript; K.B., C.M., and Y.P. approved final version of manuscript.

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