The Flying Rabbit: Using a drone as a pace-setter for youth middle-distance runners

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Abstract:
In middle-distance time-trial sports events like 1500-m run, good performance heavily depends on the pacing behaviour of the athlete. Going too fast too early can deplete the energy stores before the finish of the race, while holding back for too long can leave the athlete with left-over energy after the finish. Pacing is the result of a decision-making process regarding the distribution of effort over the expected duration of the race, which is under development during adolescence. The development of adequate pacing behaviour is therefore an important determining factor for future performance. Currently, very few tools are available to assist athletes with optimal pacing behaviour on the track. This study explores the use of a drone as a tool to help junior runners to better approximate their pacing plan in a 1500-m race. Eleven well-trained junior athletes performed four 1500-m races, while they tried to best approximate their pacing plan. Two races were Self-paced by the athletes, the other two were Drone-paced; a drone accompanied them on the track. For all races, split times, finish times and RPE scores were recorded. Pacing performance was compared between the Self-paced trials and the Drone-paced trials. The presence of a drone did not improve pacing performance in the first trials, while it did in the second trials. Over the course of the trials, pacing performance improved in the presence of a drone, while it worsened in the absence of a drone. RPE scores were not different between Self-paced and Drone-paced trials. This suggests that a drone can modulate pacing performance of junior runners.

Keywords: Pacing, Drone, Running, Sports, Youth, Athletes

1. Introduction

Every sports discipline has its barrier-breakers: athletes who change the perception of human limitations, breaking records deemed unbreakable and setting new milestones for future generations to beat. In 1954, the legendary Sir Roger Bannister was the first to ever run a mile in less than four minutes. More recently, in 2019, the Kenyan Eliud Kipchoge ran a marathon in 1 hour 59 minutes and 40 seconds, breaking the magic 2-hour barrier. Besides unmatched determination and athletic skill, there is another common denominator among these athletes that assisted their performance: rabbits (Gambaccini, 2013).

Both Kipchoge and Bannister took advantage of runners who participated not to win the race, but to set the pace. These pace-setters, often called rabbits, serve as a personified feedback based on the otherwise invisible race template (Fullerton, Lane & Devonport, 2017). Aside from drafting benefits (Hoogkamer, Kram & Arellano, 2017), the pace-setters' presence provides key cues to the competing athlete, who can then make in-race decisions to regulate their pace without having to constantly check their watch and make calculations themselves (Fullerton, Lane & Devonport, 2017). For example, a pace-setter can have the task to run at a pace of X seconds per lap, serving as a reference to the competing athlete whose goal is to complete a 1500m within 4 minutes. The pacer serves as an indicator of the proximity to the desired performance but can also counteract anxiety that can follow from having to pace solely based on internal feedback (Lane, Devonport, Friesen, Beedie, Fullerton & Stanley, 2016). Overtaking the pacemaker means you are ahead of the plan and risk early depletion of physiological resources, while lagging behind means you are underperforming.

Unfortunately, human rabbits are not available to every runner at any time as they are typically only available to a niche elite of runners on special occasions. Moreover, the running speed of a rabbit can unintentionally fluctuate providing inaccurate cues to the runner. The principle of setting a pace, however, could also be effectuated by non-human systems or actors as has already been demonstrated by the Wavelight technology (Wavelight, n.d.), which constitutes of LED lights lightening up on the side of the track based on a certain pace (Taylor, Atkinson & Best, 2021). Unfortunately, this technology is expensive and requires adjustments to the track itself. It is therefore not available to the average training athlete. This research investigates the potential of another alternative, non-human rabbit: an unmanned aircraft (a drone).

Thus far, drones in sports have been mainly used to record imagery. Such footage can either be used to analyse tactical arrangements (Islam, 2020), or to achieve new levels of broadcasting in sports, bringing the audience closer to the athlete (Iastrebov, Wong, Pang & Seet, 2014). However, besides imagery, a drone could also be used to accompany an athlete on the track, while its position could provide valuable pacing ques, in a similar way human rabbits would.

To our knowledge, this study is the first to introduce a drone to the athletics track in an academic setting, forming an important step in the developing relationship between technological tools and athletic performance. Therefore, the aim of this study was to examine the effect of a drone on pacing performance.

The following section outlines the different aspects around the phenomenon of pacing. It introduces different models of how pacing is dependent on processes that take place both inside the athlete's body, as well as in relation to the environment. Furthermore, it is explained how adolescence is an important period for an athlete with regards to pacing. Section 3 explains the method with which the empirical study is performed, and its results are outlined in section 4. The conclusion and discussion of the research are presented in the final sections of the paper, section 6 and 6.

2. Theoretical framework

2.1. Pacing Theory

Pacing is one of the most important determinants for a good performance in an endurance sport like running (Le Meur, Bernard, Dorel, Abbiss, Honnorat, Brisswalter & Hausswirth, 2011; Foster, Snyder, Thompson, Green, Foley & Schrager, 1993; Abbiss & Laursen, 2008; Skorski & Abbiss, 2017; Brick, MacIntyre & Campbell, 2014). A definition of pacing has been given by Edwards and Polman (2012, as cited in Edwards & Polman, 2013) as "The goal directed distribution and management of effort across the duration of an exercise bout". From this definition it follows that the ideal pace regulation balances the athletes' physical capabilities with the competitive demands such that the athlete can distribute their energy optimally over the course of the race. Moreover, following the definition of pacing provided, pacing is not exclusive to athletic performance but also occurs in daily life when balancing the activity levels of everyday tasks. This type of pacing is referred to as naturalistic pacing (Murphy & Kratz, 2014). For the purpose of this research, pacing is studied in the context of athletic performance.

An important concept in the theory of pacing is the notion of fatigue. Fatigue has been described as an increase in the perceived effort necessary to maintain a desired force (Hawley, 1997). Over the course of many decades, different models have been proposed to explain how fatigue develops during exercise, limiting human performance. A discussion of these models is beyond the scope of this research, but readers are directed to Noakes (2000), Abbis & Laursen (2005) and Laurent & Green (2009). The ways in which the human body deals with fatigue have formed the basis of contemporary pacing models. Building upon these models, Noakes, Gibson & Lambert (2004) presented the most influential model, the Central Governor Model (CGM). This model holds that a 'central governor' region in the brain regulates the exercise intensity (Noakes et al., 2004). This central governor subconsciously performs metabolic calculations in response to physiological triggers. Based on these calculations, the exercise performance is constantly manipulated to prevented the body from exceeding metabolic limits, causing a threat to internal homeostasis (Noakes et al., 2004; Konings & Hettinga, 2018; Edwards & Polman, 2013). Fatigue is then considered as the conscious manifestation of these subconscious calculations (Noakes et al., 2004). In other words, the brain causes a sensation of fatigue so that the body does not exceed its limits, preventing potential harm to the body.

While the central governor projects the sensation of fatigue to the conscious brain (Gibson & Noakes, 2004), there is another process at play, regulated by this central governor, limiting the exercise intensity, called teleoanticipation (Ulmer, 1996). This process entails that exercise is paced in an anticipatory way, where the demands of the exercise are accounted for in a preplanned strategy, before the start of the race (Foster, Hendrickson, Peyer, Reiner, de Koning, Lucia, Battista, Hettinga, Porcari & Wright, 2009). By making an energy distribution estimation based on the finishing point, humans are able to monitor their metabolic disturbance. In other words, in advance of an exercise, the brain forms an idea of the required pace using a combination of prior experience and knowledge of the exercise demands, such that the body performs optimally, but without premature fatigue.

The concept of a central brain component, responsible for the regulation of exercise intensity, and thus pacing, has been impugned by other scientists (Venhorst, Micklewright & Noakes, 2018). Some scholars have pointed towards the observation that the human body can exceed its physiological limits, sometimes with catastrophic results (Esteve-Lanao, Lucia, De Koning & Foster, 2008). This seems to indicate that it is possible for the human body to consciously override the central governor (Smits et al., 2014), which is contradictory to the cornerstone of the CGM that homeostasis is the ultimate function (Noakes et al., 2004).

Another aspect of the CGM which has been questioned by scholars is its focus on internal processes, and therefore underrating what happens in the external environment of the athlete when making pacing decisions (Venhorst et al., 2018). To understand the underlying mechanisms of pace regulation, studies have investigated the direct coupling between perception and action, exploring pacing from a behavioural perspective (Smits, Pepping & Hettinga, 2014; Konings & Hettinga, 2018). This lead to an alternative perspective on the regulation of exercise intensity which presents pacing as a result of continuous decision-making. According to this so-called ecological approach (Smits et al., 2014), the athlete is constantly exposed to action possibilities that are present in the environment, called affordances (Hettinga, Konings & Pepping, 2017). For athletes competing in a race, such affordances could be the audience, the condition of the track, weather conditions, the stage of the competition or the position of competitors. These affordances present opportunities to act upon, which means that to act upon or to ignore affordances is the result of a decision-making process by the athlete. Hereby, the fit between the perceptual information from the environment and the action capabilities of the internal action system are determined (Smith & Pepping, 2010). For example, if an athlete is cheered up by a crowd and is in a good physical state, (s)he can decide to alter the pace. Thus, the ecological approach allows for the incorporation of the interactions between the athlete and the environment into the regulation of exercise intensity.

There have been a multitude of studies into the human-environment interactions with regards to pacing. Across a wide variety of sports disciplines, most studies have focussed on the competitive aspect -(for an overview, see Konings & Hettinga (2018)). One finding that has been repeatedly demonstrated is that performance is improved in competitive trials over non-competitive or individual trials (Konings & Hettinga, 2018). With regards to pacing differences in a competitive setting, one study found that the initial pace of cyclists was faster when competing with a fast starting opponent as compared to when competing against a slow starting opponent (Konings, Schoenmakers, Walker & Hettinga, 2016). Furthermore, Tucker and Noakes (2009) found that environmental cues can influence the perceived exertion of an athlete.

Taken together, the CGM ascribes the phenomenon of pacing to internal, subconscious processes, while from an ecological approach, pacing is the result of conscious decision making, taking into account external stimuli. Marrying both views, Edwards and Polman (2013) suggest a that it is more logical to assume that the brain responds unconsciously to minor metabolic challenges, while larger metabolic disturbances gain conscious attention and subsequent behavioural response. This middle-ground approach means that, in the process of pacing, the brain can subconsciously inform on pacing decisions, but can consciously respond to an intense stimulus, be it internal or external.

The debate about the exact nature of the regulatory mechanism involved in pacing is still ongoing. Aside from their differences, the models, approaches and theories do point out similar factors that seek to explain how exercise is regulated. The way athletes distribute their effort is the result of a complex process and depends on both the athlete's internal states, such as the biomechanical capacity, and external states, such as interactions with the environment (Renfree, Martin, Micklewright & Gibson, 2014). That means that pacing is determined by physiological, cognitive and environmental factors. In other words, what happens within the athlete as well as what happens around the athlete impacts the decision-making process during pacing. Furthermore, pacing literature shares the notion that pacing is a process. This process includes decisions made in anticipation of the race (pacing plan), knowledge of the end-point, prior experience and the behavioural expression of the continuous decision-making process during the race (Smits et al., 2014). The outcome of this process is then referred to as the pacing behaviour (Smits et al., 2014). This research will further delve into how the human-environment aspect could be influenced by the incorporation of a drone into the environment of an athlete.

2.2. Pacing Plan

Although internal and external stimuli have the potential to influence an athlete's pace during the exercise, athletes typically start a race with an overall pacing plan in mind (Foster, de Koning, Bischel, Casolino, Malterer, O'Brien, Rodriguez-Marroyo, Splinter, Thiel & Van Tunen, 2012). A pacing plan, sometimes also referred to as pacing strategy, can be considered as a pre-planned strategy of the distribution of effort over the course of the race, in an attempt to optimise performance (Edwards & Polman, 2013). Different pacing plans exist and are applied depending on the sports discipline, the distance and on tactical decisions (Wu, 2014). Furthermore, the goal of the exercise is an important factor for determining a pacing plan (Abbiss & Laursen, 2008). In time-trails, the goal is to complete the exercise in the fastest time possible (Coyle, 1999), whereas in head-to-head competitions, the winner is the athlete who crosses the finish line first, regardless of the completion time (Foster, Schrager, Snyder & Thompson, 1994).

A pacing plan describes an athlete's planned pace over the race, by plotting a measure of effort over the duration or the race. Effort can be measured as the power output, but can also be represented in terms of (split) performance times or velocity (Abbiss & Laursen, 2008). A positive pacing plan means high effort at the start, followed by a gradual decrease in effort over the course of the exercise, while a negative plan is the opposite: a gradual increase of effort over the race. An all-out pacing plan, which is typically applied by sprinters or in exercises under 2 minutes (de Koning, Foster, Lucia, Bobbert, Hettinga & Porcari, 2011), means starting at maximal effort and maintaining for as long as possible. For middle distance athletes, who require greater aerobic contribution, a parabolic J-or U-shaped pacing plan is most applied during elite races (Casado, Hanley, Jiménez-Reyes & Renfree, 2020). With a J-shaped pacing plan on the 1500 m, the athlete paces at moderate speed in the first lap, slows down in the second lap, before accelerating in the third lap and maintaining or slightly decreasing speed during the last 200 meters (Casado & Renfree, 2018). In a U-shaped pacing plan, the athlete holds a lower speed in the middle of the race compared to the start and end.

Within the current pacing literature, different methods have been explored to guide athletes in following their assigned pacing plan (Skorski & Abbiss, 2017). Within a laboratory setting, the intensity of an exercise can be controlled automatically by an ergometer or treadmill (Abbiss, Peiffer, Wall, Martin & Laursen, 2009). Furthermore, athletes can be helped with visual or auditory feedback (Altavilla, Cejuela & Caballero-Pérez, 2018) to better adhere to their pacing plan.

Regardless of the type of pacing plan involved, the mere requirement to adhere to such a plan can take away the athlete's control over the situation, influencing performance and motivation (Skorski & Abbiss, 2017). Athletes can therefore also choose to self-pace their race. When self-pacing a race, an athlete can voluntarily fluctuate their effort over time based on internal sensations (Lander, Butterly & Edwards, 2009). Self-pacing a race has been shown to less physiologically challenging than following a pacing plan (Lander et al., 2009).

2.3. Pacing during adolescence

Adolescence is an important period in the development of athletes in which they learn, train and mature (Elferink-Gemser, Jordet, Coelho-E-Silva & Visscher, 2011). Pacing is one of the skills that develops in athletes, relative to their cognitive and physical capabilities (Micklewright, Angus, Suddaby, St. Clair, Sandercock & Chinnasamy, 2012). Furthermore, there is a learning effect with regards to pacing an exercise task (Foster et al., 2009), which suggest that repeated exposure to exercise tasks involving pacing can help in the development of the pacing skill. Adolescence is a period with increased exposure to various exercises during training and competition, which increases the experience athletes gain with pacing. It has indeed been demonstrated that pacing behaviour develops in athletes during adolescence (Wiersma, Stoter, Visscher, Hettinga & Elferink-Gemser, 2017).

Adolescence is also period in which athletes learn how to incorporate external stimuli into their pacing behaviour (Menting, Konings, Elferink-Gemser & Hettinga, 2019a). Therefore, during this period, coaches can let their athletes experiment with different environmental cues. By introducing various affordances, coaches can potentially enhance the perception-action coupling of young athletes (Menting, Hendry, Schiphof-Godart, Elferink-Gemser & Hettinga, 2019b). In this light, novel training methods have attempted to introduce athletes to various environmental conditions in a controlled setting using virtual reality (Craig & Cummins, 2015, as cited in Menting et al., 2019b). Furthermore, since pacing is under development during adolescence, young athletes have trouble selecting the right pacing behaviour which leads to optimal performance (Menting, Elferink-Gemser, Huijgen & Hettinga, 2019c). To properly guide the development of pacing behaviour in young athletes, it is important that they try out many different pacing scenarios and get an idea of how their (changing) body responds to different choices in the distribution of their effort (Elferink-Gemser & Hettinga, 2017). This research presents a novel environmental cue to adolescent athletes in a real-world setting.

2.4. Altering pacing behaviour

The pacing control mechanisms prove to be a robust asset of an athlete (Gibson & Noakes, 2004). Various studies have attempted to change pacing behaviour in different ways. One attempt was to override the pacing behaviour of elite speed skaters on the 1500m by enforcing the athletes to adopt a theoretically optimal pacing plan, which had a negative impact on performance (Hettinga, De Koning, Schmidt, Wind, MacIntosh & Foster, 2011). In another study, researchers offered a monetary incentive to athletes to change their pacing behaviour (Hulleman, De Koning, Hettinga & Foster, 2007). The participating athletes did not change their pacing behaviour compared to the non-incentivised trials. Also when researchers tried to alter pacing behaviour by introducing another runner during 5 km races, pacing behaviour did not change (Bath, Turner, Bosch, Tucker, Lambert, Thompson & Gibson, 2012). However, the studies mentioned above point out the robustness of pacing behaviour in time-trial competition. In head-to-head competitions, where athletes directly compete in the same lane, pacing behaviour can be adjusted in response to collective group dynamics (Renfree, Crivoi do Carmo, Martin & Peters, 2015) or higher athlete-opponent interdependency (Konings, Foulsham, Micklewright & Hettinga, 2020).

Whereas pacing behaviour in time-trials can be robust and hard to override, following the ecological approach, athlete-environment interactions could cause athletes to alter their behaviour during the race. One study specifically investigated how a competitor could alter pacing behaviour in time-trial races and found that the initial pace of cyclists could be altered by a faster starting opponent (Konings et al., 2016). However, most of the studies mentioned, involved a virtual opponent rather than a real person and were performed in a controlled laboratory environment. In a study with a real person as pacesetter on a track, runners did not set better times and even reported higher pre-run anxiety (Fullerton, Lane & Devonport, 2017).

In summary, adolescence is a crucial period for the development of pacing behaviour. Experimentation with different techniques to learn adequate pacing is important in talent development. A drone might provide one such method in the development of the skill of pacing in young athletes.

2.5. Present study

The present study aims to investigate whether drone can help to improve pacing behaviour in youth runners on the 1500m. The research question guiding this research is: *what is the effect of a pace-setting drone on the pacing performance of youth athletes on the 1500m?*. As follows from current pacing theory, the drone could act as an external stimulus to the runner, who, in turn, can decide to adjust their pace to the drone. Based on this notion, it is hypothesized that the drone will improve the pacing behaviour of youth athletes on the 1500m. To test this hypothesis, pacing performance will be compared between trials with and without a pace-setting drone.

3. Research Method

3.1. Participants

The study involved twelve well-trained talented middle distance runners from the youth selection (Male: n = 7, Female: n = 5; mean age, 17.4 years, SD = 2.4), who were recruited from a local athletics club. "Well-trained" was defined as taking part in regular, structured and supervised training (>3 days per week) including pacing exercises and participating in national competitions. The participants were selected by their trainer and were all able to run a 1500m under 6 minutes. All participants had experience of running on an outdoor 400m track. All participants and their legal caretakers were informed of the procedures in advance, and informed consent was provided prior to any data collection. The study was approved by the ethics committee of the Science faculty at the Leiden University, in the spirit of the Helsinki Declaration.

3.2. Experiment Design

Subjects were asked to run a 1500m on four occasions, separated by a minimum of three and a maximum of seven days. All runs were performed under similar, dry weather conditions and at the same time of the day. Participants were asked to not deviate from their normal physical activity pattern over the course of the four occasions, and to avoid serious exercise 24 hours ahead of each run.

In advance of the experiment phase, the trainer constructed a pacing plan for each participant and communicated this with the researcher and the participant. The pacing plan described the 400m lap times and the 1500m finish time, which the subject should be able to run for optimal performance, 10% below the pacing plan for their personal record. The runners in this group were all best familiar with a positive pacing plan, which is also what the coach assigned to them for this research. See table 1 for an example of a pacing plan for one participant.

Table 1. *1500m pacing plan for participant 10*

Total time: 4 min 10 s	
Split (m)	**Split time (s)**
0 – 400	65
400 – 800	66.5
800 – 1200	67.5
1200 – 1500	51

Participants were briefly informed about the purpose of the study and asked to match their pacing plan as closely as possible. Before each trial, participants were allowed to perform a 5 minute self-paced warm-up at low intensity, followed by a 5 minute rest period with no activity.

On the first and third occasion, the runners were asked to self-pace their run according to their pacing plan (Self-paced trials, SP1 & SP2). These formed the participants' baseline performance. Important to note here is that the use of the term Self-paced does not mean that athletes were free to pace their race based on internal sensations. Rather, the term describes that they had to try to adhere to their pacing plan by themselves, without the help of the drone.

On the other two occasions a drone flew with them over the track at the pace of the subject's pacing plan (Drone-paced trials, DP1 & DP2). Before each trial, the split times of the pacing plan were communicated once again with the participant and the participant was asked to indicate their rate of perceived exertion (RPE) using the RPE scale of Borg (1998), which ranges from 6 (no exertion at all) to 20 (maximal exertion). Lap times were hand timed using a stopwatch (Trifera) to the nearest second by the trainer and communicated to the participant when passing the 400m line.

After finishing the race, participants were asked again to indicate their RPE. In case of a Drone-paced trial, the participants were asked to complete a short questionnaire on a mobile tablet. The questionnaire was meant to assess the qualitative experience of the athlete when running with the drone, whether they enjoyed it, whether they thought it helped them and the chance for them to make other comments.

During the DPTs, a drone (DJI Mavic Air 2, see Appendix II for a photo) flew in proximity to, but at a safe distance from the runner. This meant that the drone flew at a hight of 3 meters and on the outer side of the track from the athlete. Although the drone would not always be visible to the athlete, its presence and position would be clear from the noise of the propellors. Although the drone was meant to fly autonomously, according to a pre-programmed mission aligned with the pacing plan of the individual participants, due to complications outlined further in section 5 (Discussion), the researcher controlled the drone with a remote controller. At any time, the researcher had the possibility to stop the drone or change its position.

3.3. Data Analysis

The pacing performance was analysed as the deviation of the raced time from the pacing plan, both per lap and per total time raced. Thus, a 0% deviation means that the athlete ran exactly the time that he/she was supposed to run according to the pacing plan. To analyse how much the total times deviated from the pacing plan, a variable (Total %Deviation) was constructed, which describes the absolute deviation from the plan as a percentage of the total planned time. For example, if the pacing plan of an athlete proposed a finish time of 4:10, and the athlete completed the race in a total time of 4:15, the deviation from the plan would be 5 seconds, which corresponds to 1.92% of the planned total time. Similarly, the deviation from the plan per lap was transformed to a percentage of the planned time for that lap. Comparing the deviation from the plan as a percantage of the pacing plan, rather than as a value in seconds, was considered a better choise due to the fact that the last lap consisted of 300m instead of 400m, which consequently means lower absolute deviation values when measured in seconds. Furthermore, for each participant an average was calculated for all split time deviations for each trial. Thus, the Total %Deviation is a number that represents the deviation of the set total time from the planned total time, while the Average %Deviation represents the average deviation of the

	Total time raced (s)				Deviation from plan (%)				Average Speed (m/s)			
Trial	**SP1**	**DP1**	**SP2**	**DP2**	**SP1**	**DP1**	**SP2**	**DP2**	**SP1**	**DP1**	**SP2**	**DP2**
Mean	274.45	274.36	277.18	272.64	1.56	2.32	3.05	1.17	5.49	5.49	5.43	5.53
Std. Deviation	18.35	17.84	16.42	18.85	1.72	2.73	3.34	1.20	0.35	0.34	0.31	0.36
Minimum	250.00	252.00	257.00	250.00	0.00	0.00	0.32	0.00	4.87	4.90	4.85	4.81
Maximum	308.00	306.00	309.00	312.00	5.36	10.00	10.00	4.00	6.00	5.95	5.84	6.00

Table 1 *Descriptive statistics of the mean total time, mean deviation from the pacing plan and the mean average speed on Self-paced trials (SP1, SP2) and Drone-paced Trials (DP1, DP2)*

four set lap times from the planned lap times. The Average %Deviation is important, because in principle, it was possible for an athlete to complete the race with a low deviation from the pacing plan, while all lap times had high deviation scores (say an athlete ran much slower than was planned for the first two laps, and much faster than the plan for the subsequent two laps).

For the measurement of exertion, the RPE score from before the race was deducted from the RPE score from after the race to get a ΔRPE score for each participant for each trial.

3.4. Statistical Analysis

Changes in deviation from the plan per section and split times across different trials were analysed using a two-way (trail x section) ANOVA. The Total %Deviation, the Average %Deviation and the ΔRPE were further analysed using a linear mixed-effects model with restricted maximum likelihood estimation. P-values for fixed effects were calculated with t-tests using Satterthwaite's method (Kuznetsova, Brockhoff & Christensen, 2017). Variance across subjects (ID) was modelled as a random effects grouping factor. Mean total times raced for each trial were compared using a one-way ANOVA.

For every test, significance was accepted at $p \leq 0.05$ and the data is presented as means $\pm$ SD. All analyses were conducted using JASP (JASP Team, 2021).

4. Results

Of the 12 athletes who were recruited for the study, 11 completed the experiment phase in its totality. The data of the athlete who did not complete the study was removed before the analysis. As the 11 athletes raced 4 trials, a total of 44 races were recorded. A summary of the data collected is presented in Table 2.

4.1. Pacing performance on planned trial times

From the one-way ANOVA (Total %Deviation – trial), a significant difference between the deviations of the different trials was found ($F(3, 172) = 5.28$, $p = 0.002$, $\eta^2 = 0.08$). The mean total deviation percentages over the four trials are displayed in Figure 1. The difference in Total %Deviation between SP1 and DP1 was not significant ($F(1, 86) = 2.39$, $p = 0.13$, $\eta^2 = 0.03$). Between SP2 and DP2 this difference is significant ($F(1,86) = 12.30$, $p < 0.001$, $\eta^2 = 0.13$).

There seems to be a decrease in deviation between DP1 and DP2, while there seems to be an increase in deviation between SP1 and SP2. To check for this interaction, a linear mixed-effects model of %Deviation as a function of Trial type (DP or SP) and Trial number (1 or 2) revealed a significant interaction between Trial type and Trial number ($b = 0.66 \pm 0.12$ SEM, $p < 0.001$). This shows that the change in %Deviation over time (from first to second trial) is modulated by the presence of the drone. In other words, the degree to which participants' racing times deviated from the pacing plan increased in the case of Self-paced trials between trials 1 and 2, while this deviation decreased for Drone-paced trials. This can also be seen in Figure 2.

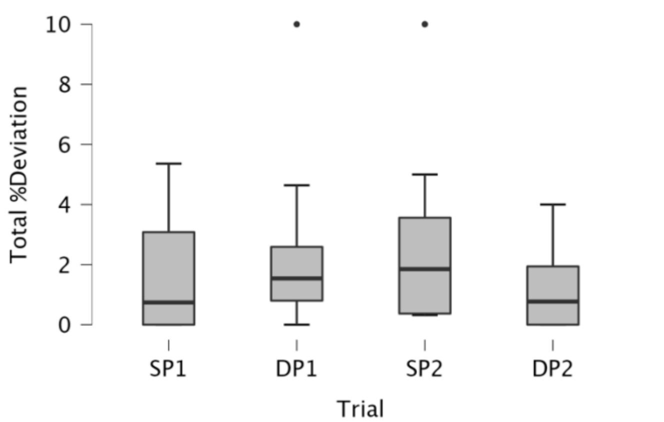

Figure 1 *Deviation from the pacing plan on different trials*

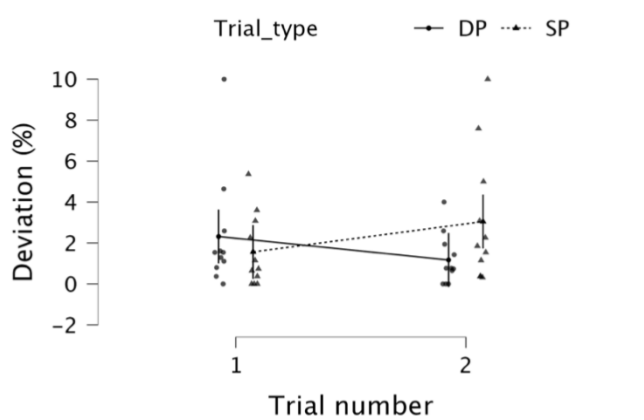

Figure 2 *A linear decrease in % deviation over the Drone-paced trials and a linear increase in the % deviation over the Self-paced trials*

4.2. Pacing performance on planned lap times

Similarly, the deviation of the actual split times from the planned split times are analysed and can be seen in Figure 3. There is a significant effect between the Average %Deviation and the trial ($F(3, 172) = 9.59$, $p < 0.001$, $\eta^2 = 0.14$). It was found that the difference between SP1 and DP1 in Average %Deviation is not significant ($F(1, 86) = 1.93$, $p = 0.17$, $\eta^2 = 0.02$), while the it is significant between SP2 and DP2 ($F(1, 86) = 19.41$, $p < 0.001$, $\eta^2 = 0.18$). Here, the linear mixed-effects model also revealed a significant interaction between Trial type and Trial number ($b = 0.16 \pm 0.03$ SEM, $p < 0.001$). This shows that also the %average lap deviation is modulated by the presence of the drone. In other words, the degree to which participants deviated from their lap times increased in the case of Self-paced trials between trials 1 and 2, while this deviation decreased for Drone-paced trials, see Figure 4.

An overview of how the athletes ran in comparison to their pacing plan is included in Appendix I.

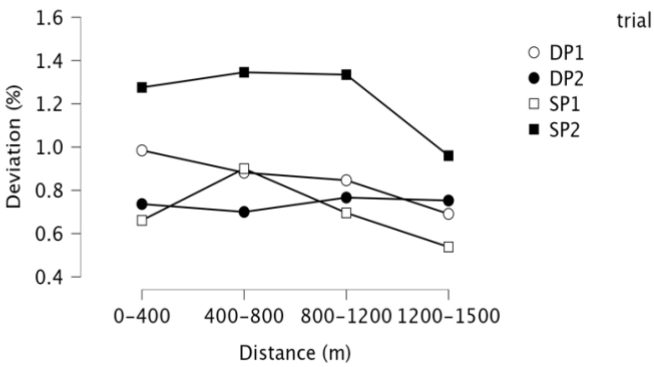

Figure 3 *Deviation from the pacing plan per lap for the different trials*

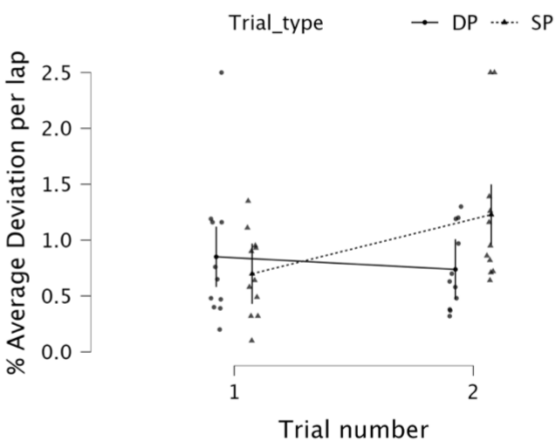

Figure 4 *Average %Deviation per lap decreases over the Drone-paced Trials and increases over the Self-paced trials*

4.3. Time raced

No difference in total race time between trials was found ($F(3, 172) = 0.49$, $p = 0.69$, $\eta^2 = 0.0084$) (Table 2), nor in the split times ($F(3, 160) = 0.45$, $p = 0.75$, $\eta^2 = 0.0084$) (Figure 5).

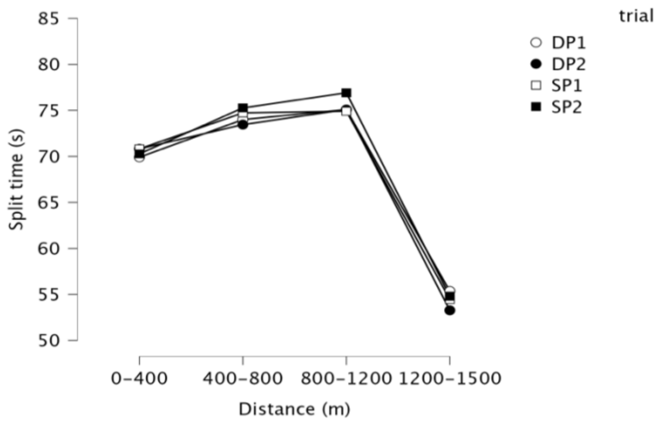

Figure 5 *Split times per distance for the different trials*

4.4. Average speed

No difference in average speeds between trials was found ($F(3, 172)$, $p = 0.60$, $\eta^2 = 0.01$) (Table 2).

4.5. Rating of Perceived Exertion

In Table 3, the ΔRPE scores over the different trials are reported. From the one-way ANOVA (trial – ΔRPE) follows that this effect is significant ($F(3, 172)$, $p = 0.01$, $\eta^2 = 0.06$). However, that effect is not significant between SP1 and DP1 ($F(1, 86) = 0.17$, $p = 0.68$, $\eta^2 = 0.002$), nor between SP2 and DP2 ($F(1, 86 = 1.59$, $p = 0.21$, $\eta^2 = 0.02$). A linear mixed-effects model of ΔRPE scores as a function of Trial type and Trial number revealed a significant effect for the trial number ($b = 0.65 \pm 0.13$ SEM, $p < 0.001$), but not for Trial type ($b = 0.11 \pm 0.13$ SEM, $p = 0.42$). Also no significant interaction between the trial type and trial number was found ($b = -0.24 \pm 0.13$ SEM, $p = 0.07$). In other words, ΔRPE scores are significantly lower in the final two trials (SP2 and DP2) than in the first two trials (SP1 and DP1, but this does not depend on the trial type.

	ΔRPE			
	SP1	**DP1**	**SP2**	**DP2**
Mean	8.45	8.18	6.66	7.36
Std. Deviation	3.09	3.04	2.88	2.33

Table 3 *ΔRPE scores per trial*

4.6. Qualitative assessment

The questionnaires that the athletes completed after both DPTs provide rich, qualitative insights into how the athletes experienced their races with the drone. All of the 11 athletes thought it was a fun experience to run with the drone. Some mention a feeling of competitiveness towards the drone ("*I* *wanted to stay in front of the drone"* and *"It felt like an incentive to stay ahead of"*). All athletes experienced the race with the drone different than without the drone, with seven athletes indicating it was *very different*. In terms of the degree to which the athletes felt helped by the presence of the drone, five answered *somewhat*, four others indicated *quite a bit* and three answered *not so much*. Eight of the athletes felt that the drone was best compared to "*an opponent"*. Also "*a distraction"*, "*a trainer"*, "*a buddy"* and "*a watch"* were mentioned. For most athletes, it was the sound of the propellors drone that indicated its position, while they hardly ever saw it. No athlete was scared of the drone and seven of the athletes would like to run with the drone more often.

In the final part of the questionnaire, where the athletes could freely express other thoughts about their experience, many interesting comments were made. Three athletes mentioned that they felt helped by the drone only when it flew ahead of them. Not only because that means the drone is visible then, but also because it then servers as a "*target point"*. One athlete felt the drone was distracting him/her, "*costing unnecessary energy"*, while another said he/she *"was thinking about the position of the drone"*.

The effect of the drone on the athlete seems to depend on how the drone flew. After the second trial, athletes could compare the trails and some indicated that they benefitted more when the drone was flying more constantly, or more close to them.

5. Discussion

Pace-setting athletes (rabbits) are often used in athletic events to help the competing athletes optimize their pacing performance. We hypothesized that a drone could be used for the same purpose, that pacing performance would be improved by the presence of a drone. In this study, pacing performance was measured as the degree to which athletes deviated from their pacing plan. This research found that the presence of a drone did not improve pacing performance in the first trials (SP1 and DP1), but it did in the second trials (SP2 and DP2). A comparison between trial numbers learns that pacing performance was improved over the course of the Drone-paced trials, while it worsened over the course of the Self-paced trials. In other words, after the first Drone-paced trial, the athletes could decrease the deviation from their pacing plan in the second Drone-paced trial, while the deviation increased in the second Self-paced trial. Important to note here is that, if an athlete ran faster than was projected in the pacing plan, in this analysis counted as weak pacing performance due to the deviation from the planned time. Clearly, running a faster finish time than projected counts as a good performance. At the same time, running faster split times than projected in the pacing plan can result in early depletion of energy resources or an uneven speed profile, which are not beneficial to overall performance.

5.1. Pacing performance

There are multiple potential explanations for the finding. For one, the improvement of pacing performance over the Drone-paced trials could be due to familiarization with the drone. That is, while in the first Drone-paced trial the athletes had to get used to running with the drone, in the second Drone-paced trial they could benefit from its presence. Following a pacer is a skill the requires learning (Fullerton, Lane & Devonport, 2017) which supports this explanation for our finding. Further support comes from several answers from the post-DP2 evaluation form. Some of the comments that do seem to confirm this explanation are: "*I felt less worked up this time", "Last time I had much more trouble keeping up with the drone", "this time I felt more helped by the drone"*.

Another potential explanation for this finding is that the researcher had become more familiarized to flying the drone by the second Drone-paced trial. As was mentioned in section 3.3, the drone was initially supposed to fly autonomously, according to a flight plan, using an app called Litchi. Potentially due to the monochrome surface of the track, the Visual Positioning System of the drone had difficulties maintaining a consistent altitude throughout the race. Therefore, during the experiment phase, the researcher controlled the drone himself. This meant that, at times, the drone fell behind or flew ahead of the pacing plan. Despite many hours of practice in advance of the experiment phase, there was still a learning curve at play throughout the experiment, which might have resulted in more stable flying performance during the DP2 compared to the DP1. This was mentioned also by one of the athletes in the questionnaire: *"the drone seemed more constant, (which) was very nice"*.

5.2. Drone as a stimulus

Regardless of the explanation for the increase in pacing performance over the course of the Drone-paced trials, the finding that the presence of the drone modulated pacing performance is an interesting one. It is likely that athletes used their relative position to the drone as a cue to their performance against the pacing plan. This is supported by some of the answers from the athletes to the questionnaire. For example, one athlete mentioned: *"(it was a) stimulus that reminds you what the pace is"*, while another said: *"the drone can help if you don't know how fast you run"*.

Previous research has shown that the environment of an athlete can invite the athlete to alter the pacing behaviour (Hettinga et al., 2017; Smits, Pepping, & Hettinga, 2014). Athletes are constantly presented with affordances, upon which they can decide to act (Smits, Pepping, & Hettinga, 2014). In terms of pacing, this decision can be to either slow down, maintain, or speed up their pace. A multitude of experimental and observational studies have demonstrated that competitors are a type of affordance that can significantly alter pacing performance (Hettinga et al., 2017). In a laboratory setting, the presence of an opponent evoked a faster starting pace in cyclists and among short track speed skaters (Konings et al., 2016). In a real race setting, it was found that the pacing response was heavily dependent on the behaviour of competitors (Konings & Hettinga, 2018). In this light, the drone might have taken the role as a competitor too. Also this was mentioned repeatedly by the participating athletes in the evaluation form. For example, some responses were: *"I saw the drone as an opponent which motivated me to run faster than the drone"* and *'I felt a little more competition (I wanted to stay ahead of the drone) than without the drone"*. This is interesting, because in essence the races performed in this research were of the type of a time-trial, where the goal is to compete against the time, rather than an opponent. In time-trial competitions, the presence of other competitors has not been shown to alter pacing behaviour in previous research (Hettinga et al., 2011; Massey, Whitehead, Marchant, Polman & Williams, 2020). Pacing with a drone thus seems to similar behaviour as an opponent would and transforms a bout from a time-trial into a head-to-head race. It is interesting to note that in that sense, the drone functioned more as a competitor to the athletes than as a rabbit, as was the intention with this research.

Nonetheless, whether functioning as rabbit or competitor, the drone can alter the coupling between perception and action. After a first trial with the drone, this coupling worsened during the Self-paced trial, but improved in the second Drone-paced trial. Young athletes benefit from exposure to different stimuli, to recognize relevant cues from the environment, which can later help them in a competitive setting (Elferink-Gemser & Hettinga, 2017). Other innovative ways to strengthen this coupling have previously been explored, for example using interactive virtual environments (Stone, Strafford, North, Toner & Davids, 2018). The advantage of a drone on the track is that it can be done in the most realistic setting for the athlete, on the track itself.

Furthermore, the drone might present an external motivational factor. Motivation has been closely related to pacing, because it can impact the feeling of fatigue (Gibson, Baden, Lambert, Lambert, Harley, Hampson, Russell & Noakes, 2003), which is a limiting factor to performance. From the questionnaire, it was clear that athletes were enjoying the races with the drone more than without the drone. Enjoyment of an exercise leads to increased persistence and is closely related to intrinsic motivation (Wankel, 1993). For the development of talents, coaches are advised to create a motivational environment, in which the athletes enjoy the exercise (Menting et al., 2019b). Therefore, in the future, drones might more often be used in athletics training.

5.3. Rate of perceived exertion

Despite a difference in RPE scores between the first two and the last two trials, there was no difference in mean RPE scores between trials with or without the drone. This means that the drone did not have an effect on the perceived exertion of the athletes. In other words, the presence of a drone did not make athletes go through certain exertion thresholds. It has been suggested however, that when motivation is increased, the sensation of fatigue decreases (Gibson et al., 2003). At the same time, an increase in motivation does not necessarily result in lower RPE scores, as was shown in an earlier study where the introduction of a second runner did not result in significant changes in RPE scores while it did increase motivation (Bath et al., 2012). Similarly, in the present study, no differences in RPE scores were found between the two conditions. A difference is that, in the study by Bath et al., also no change in performance was found either between the conditions, whereas the present study does find a difference in pacing performance between the SP2 and DP2. However, again, there is an important difference between performance measured as the time to complete a race, and performance measured as the deviation from the pacing plan. This could propose a possible explanation for the finding that pacing performance was altered between SP2 and DP2, while RPE scores did not significantly change between these trials.

5.4. Obstacles

If, in the future, serious attempts are made to incorporate drones more often in the training regime of athletes, the author of this study deems it important to share some of the obstacles that were encountered during this study. First of all, although modern-day drones can easily reach speeds above 50 km/h, high speeds do impact flying accuracy, especially in corners. In that case, unsafe situations cannot be ruled out anymore. Therefore, for high speed sports like speed skating, today's drones might not be applicable. Furthermore, entering the airspace should be done with care and respect for existing fauna. During the first attempts of this research, a pair of Oystercatchers (*Haematopus ostralegus*) fiercely protected the airspace around the athletics track from the invasive drone. The research was therefore postponed until after the breeding season. Finally, weather conditions can interfere with a scheduled flight. Precipitation can damage a drone and wind can unexpectedly alter the position.

7. Conclusion

This research has shown that a drone can alter the pacing performance of youth athletes on the 1500m. Although this effect was not present over all trials, over the course of the trials, pacing performance improved in the presence of a drone, while it worsened in the absence of a drone. This leads to the conclusion that a drone can potentially be used to support pacing performance of junior runners. The introduction of a drone as a pace-setter is novel within the academic context, and is worth further exploration for potential application in athletic talent development programs. To this date, drones are not without their practical limitations and shouldn't be considered as ready-made options for any athletics coach. Future generations of athletes will continue to explore ways to break barriers and set new records. This research explored the potential of a new companion on the track: a drone.

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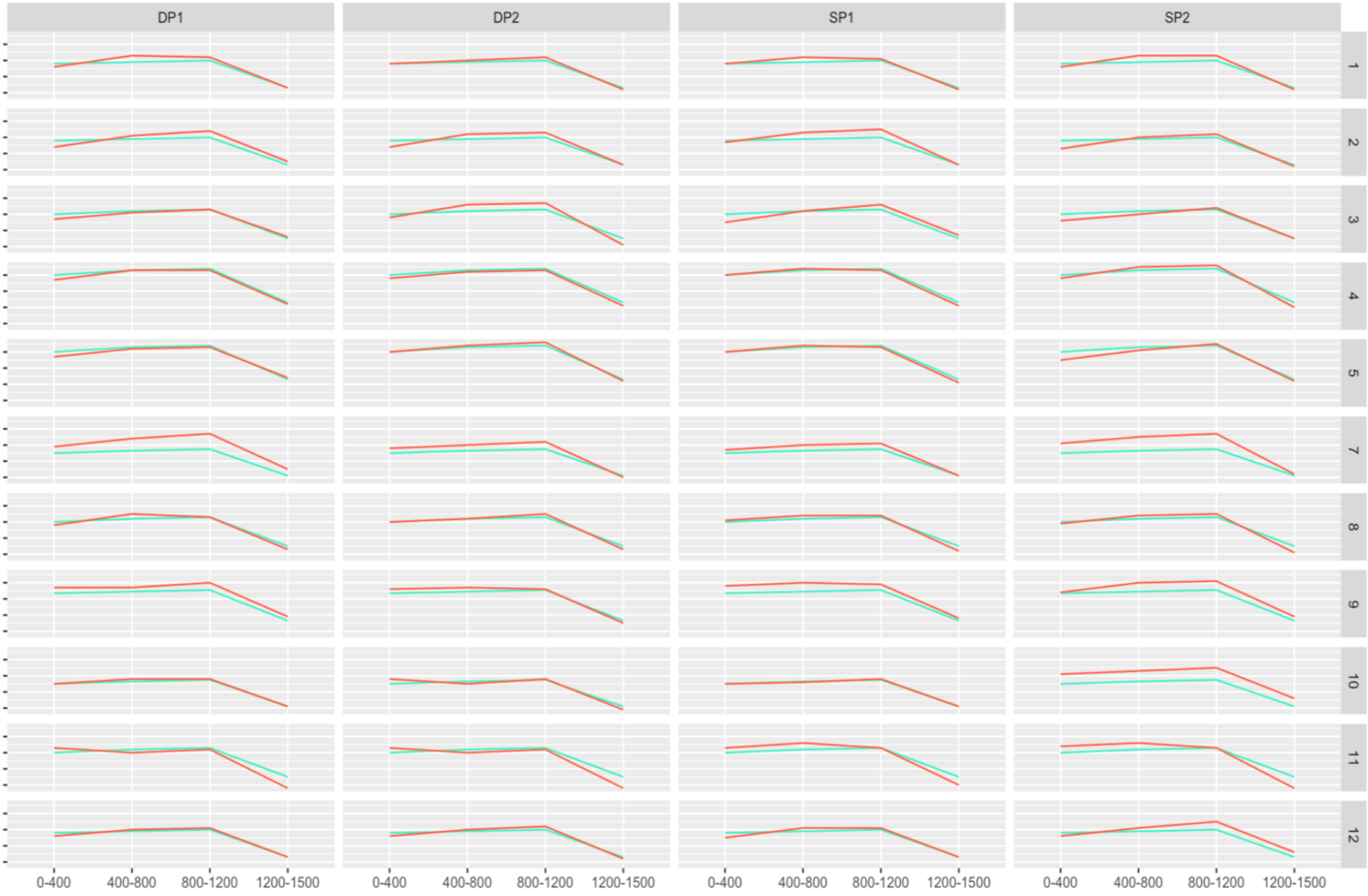
Appendix I



Overview per athlete of actual performance (coral) and the pacing plan (green) per trial

Appendix II

The drone on the track