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Drafting in long-track speed skating team pursuit on the ice rink

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ABSTRACT

Drafting is distinctive for team pursuit races in long-track speed skating. This study aims to compare the impact of drafting on physical intensity (heart rate [HR]) and perceived intensity (ratings of perceived exertion [RPE]) per drafting position. Eighteen skilled male ($n = 9$) and female ($n = 9$) skaters (20.0 ± 4.8 years) skated three trials, in first, second or third position, with consistent average velocity ($F_{2,10} = 2.30$, $p = 0.15$, $\eta_p^2 = 0.32$). Differences in HR and RPE (Borg CR−10 scale) were compared within-subjects (three positions) using a repeated-measures ANOVA ($p < 0.05$). Compared to the first position, HR was lower in the second (benefit 3.2%) and third (benefit 4.7%) position and lower in third compared to second position (benefit 1.5%), observed in 10 skaters ($F_{2,28} = 28.9$, $p < 0.001$, $\eta_p^2 = 0.67$). RPE was lower when comparing second (benefit 18.5%) and third (benefit 16.8%) position to first ($F_{1.3,22.1} = 7.02$, $p < 0.05$, $\eta_p^2 = 0.29$) and similar for third and second positions., observed in 8 skaters. Even though the physical intensity was lower when drafting in third versus second position, the perceived intensity was equal. There were large interindividual differences between skaters. Coaches are advised to adopt a multidimensional, tailored approach when selecting and training skaters for a team pursuit.

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Speed skating; team-based collective pacing; time-trial sports; race strategy; performance; training

Introduction

In a variety of sports, athletes follow closely behind one or more other athletes, which is known as drafting (A. G. Edwards & Byrnes, 2007). This allows athletes to benefit from a decrease in aerodynamical resistive forces. The decrease affords a reduction of energy expenditure while maintaining similar performance (A. G. Edwards & Byrnes, 2007). Physical intensity expressed as heart rate (Foster et al., 2001) has been found to be lower for a drafting athlete in multiple sports, including cross-country skiing (9 beats per minute [bpm]) (Bilodeau et al., 1994) speed skating (7 bpm) (den Brandt FAP et al., 2021) short-track speed skating (6 bpm) (Rundell, 1996) inline skating (1.5 bpm) (Millet et al., 2003) and cycling (18 bpm) (Hausswirth et al., 2001). Reductions of physical intensity are larger when athletes are drafting in a group (Broker et al., 1999; Heimans et al., 2017). Four cyclists alternating the leading position can increase the average power output by around 25% for the leader, compared to a single rider (Heimans et al., 2017). Furthermore, the second cyclist in a group experiences a 30% reduction in the power output required to maintain competition velocity, in comparison to the leader. Lastly, the third cyclist experiences a 6% reduction in power output, compared to the second. It, therefore, seems that the physical benefits of drafting are highly dependent on the position of the athlete within the group. Alongside a reduction in physical intensity, a smaller number of studies also reported reductions in the perceived intensity for the drafting athletes (Millet et al., 2003; Zouhal et al., 2015).

The balance between saving energy (while drafting) and using this saved energy to increase performance is part of the goal-oriented decision-making process regarding the distribution of effort over an exercise task, which has previously been defined as "pacing" (A. Edwards & Polman, 2013). The outcome of an athlete's decision-making, also called the pacing behaviour, has a significant impact on athletic performance (Menting et al., 2022). In a highly interactive environment featuring multiple competitors, athletes regulate their energy expenditure based on the behaviour of their competitors (Konings & Hettinga, 2018b). It is not uncommon for athletes in these types of environments to exhibit a form of collective behaviour, in which competitors decide to temporarily cooperate rather than compete with each other (Hanley, 2015). Drafting is an example of this synchronisation of behaviour, as the drafting athlete needs to adapt their behaviour to that of the competitor in front of them (Hettinga et al., 2017). The adaptation of pacing behaviour to external factors (such as other athletes) has been shown to provide a greater physical challenge, compared to self-paced exercise (Lander et al., 2009). Drafting, therefore, presents an interesting and complex component within the pacing process.

The team pursuit has been an Olympic long-track speed skating event since 2006. It is a time trial-type race in which teams of three skaters have to skate six (women) or eight (men) 400-m laps as fast as possible. Whereas most of the events in long-track speed skating are individual races, in which drafting is hardly possible because skaters mostly skate in different lanes, in the team pursuit skaters can benefit from drafting by positioning themselves closely behind their teammates (A. G. Edwards & Byrnes, 2007). The importance of drafting in speed skating is emphasised by the fact that the aerodynamic drag force (related to skaters' velocity as well as the shape and frontal area of the speed skater) constitutes more than 80% of the total breaking forces working on a speed skater

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(De Koning & van Ingen Schenau, 2000). Speed skaters generally skate in a deeply crouched position, which causes a reduction of the frontal area, but also restricts the upper legs muscle blood flow. When fatigued, skaters unconsciously increase their knee angle in order to increase muscle blood flow, which simultaneously creates a larger frontal area and greater aerodynamic drag (De Koning et al., 2005). Drafting allows skaters to benefit from riding into a lower pressure vortex created by the leading skater, reducing the aerodynamic drag force (A. G. Edwards & Byrnes, 2007). Drafting could therefore potentially provide skaters the opportunity to temporarily skate in a less deep crouched position while maintaining a high speed. In a wind tunnel with two static skaters, reductions in aerodynamic drag force of, respectively, 16% at 2 m and 23% at 1 m distance between the skaters were found (van Ingen Schenau & van Ingen Schenau GJ, 1982). More recent research in a wind tunnel, which was executed with synchronised moving skaters, found an aerodynamic advantage of 25.7% for the drafting skater when they were following the leader as close as possible. At a distance of 1.89 m behind the leader, the aerodynamic advantage was 15% (Elfmark et al., 2019). This same wind tunnel study also found that skating is more effective when skating in synchronised motion, compared to non-synchronous skating. Therefore, in order to get full advantage from drafting, skaters need to skate as close together as possible, with the same technique and in the same stride pattern as the leader (Elfmark et al., 2019). Furthermore, it should be pointed out that there is a significant difference in the aerodynamic drag force created by either smooth or turbulent wind (D'Auteuil et al., 2012). On a speed skating ice rink, there is a highly turbulent flow created by the skaters circling the track with yawed airflow in the corners. This turbulence is created by the skaters, surrounding structures and the temperature of the surface of the ice. For this reason, results gathered in a wind tunnel might not directly convert to skating competition (D'Auteuil et al., 2012).

In the team pursuit, different race strategies are observed. The traditional strategy is to change position when cornering multiple times per race, so that the skater in second position takes the lead and the front skater moves to the third position. At the Winter Olympic Games in Beijing 2022, however, a revolutionising new push strategy was applied by several countries in which skaters stay in the same position throughout the race. Whereas this may avoid extra wind resistance during changing positions, the intensity for skaters per position is still unknown. In order to reach optimal team performance, speed skaters competing in the team pursuit need to optimise the complex decision-making process regarding the distribution of effort throughout the race as a team. The appropriate use of drafting and potential pushing of teammates is a key part of optimising this process. However, in order to make informed decisions on the use of drafting, insights into the magnitude of the drafting effect in a realistic and dynamic skating environment are needed. To the authors' knowledge, this study is the first to investigate drafting, in combination with pacing, during a team pursuit event in long-track speed skating. The current study aimed to develop a better understanding of the effect of drafting on the physical and perceived intensity in long-track speed skating. Within this investigation, the effect of positioning of the skaters within a group was of specific interest, which could give valuable information for the coaches and athletes in order to improve performances during the team pursuit. It was hypothesised that drafting will result in a greater decrease in physical and especially perceived intensity for each position after the leading skater.

Method

Participants

Eighteen Dutch national-level long-track speed skaters participated in this study (Male: $n = 9$, Female: $n = 9$). According to the classification of Swann et al. (Swann et al., 2015) based on the athlete's highest standard of performance, the athlete's success and experience at the highest level, the competitiveness of the sport in the own country as well as the global competitiveness of the sport, the participants can be defined as competitive elite athletes. The skaters had a mean age of 20.0 ± 4.8 years, a body mass of 69.4 ± 6.6 kg, a height of 179.7 ± 6.9 cm and extensive competitive skating experience (7.3 ± 2.6 years). All participants were technically proficient and familiar with skating with each other in teams. The participants were informed of the procedures of the study and signed a written informed consent before participating. The study protocol and informed consent procedure were approved by the Local Ethics Review Board Human Movement Sciences non-WMO studies (LTc Human Movement Sciences) with research reference number: 202000358. It is in accordance with the declaration of Helsinki. In order to assemble the skaters into groups, the 18 participants were first divided by sex, after which groups were composed based on the coach's assessment of current performance level, similarity in skating technique and anthropometrics (height and body mass). This resulted in six groups of three skaters. The coaches who were involved in the study knew the skaters well and had experience in coaching at the national level. The aerodynamic drag force (Fw) of each skater was calculated (Table 1) using the following formula: Fw = k v^2 (after first calculating air friction [k = 0.0205 l $\sqrt[3]{}$]), employing the method set out by van Ingen Schenau (van Ingen Schenau & van Ingen Schenau GJ, 1982).

Table 1. Aerodynamic drag force (N) for each participant and calculated mean for each team.

	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
Participant 1	18.9	17	16.1	21.3	20.7	21.5
Participant 2	18.8	17.2	17	20	23.7	23.7
Participant 3	18.8	17.8	16.7	20.7	22.2	23.7
Mean±SD	18.3 ± 0.1	17.3 ± 0.4	16.6 ± 0.5	20.7 ± 0.6	22.2 ± 1.5	23.0 ± 1.3

Note: Air friction k = 0.0205 l $\sqrt[3]{m}$, Aerodynamic drag force Fw=k v^2.

Study design

Each group of skaters performed four trials, each consisting of five laps of the inner lane of the racecourse (384 m). Between trials, skaters had at least 10 min of rest for recovery. The first trial was a warm-up in which the skaters practised riding at the instructed sub-maximal velocity, which had to be held constant during all trials. The instructed velocity was determined by the coaches, based on the sex and performance level of the group. During the following three trials, skaters rotated in their positioning between trials in the following order: 1, 2, 3–2, 3, 1–3, 1, 2 (Figure 1). The skater who was leading during the first trial was in the last position during the second trial and in the middle position during the third trial. In the aforementioned three trials, the skaters were instructed to keep the distance between each other as close as possible and within 0.5 m. In resemblance to official competition, every group had their own coach who provided them with lap times, in order to assist the skaters in adhering to the instructed velocity, as well as instructions regarding the correct distance between skaters and the synchronisation of skating technique.

Procedures

During the tests, the temperature of the ice surface varied between −6 and −8 degree Celsius and the air pressure between 1000 hPa and 1036 hPa. Lap times were recorded with stopwatches from the coaches in combination with live lap times recorded by a time-transponder worn on the ankle of at least one of the skaters in each group. In order to investigate the physical intensity, the skaters wore heart rate monitor straps (Zephyr bioharness 3.0) which continuously monitored the heart rate with a frequency of 24 measurements per minute[2]. Upon completion of the trials, heart rate data were transferred and stored using OmniSense software on a computer. The mean heart rate of the last three laps of each trial was used for statistical analyses. The perceived intensity was measured by means of the ratings of perceived exertion (RPE). Right before and after each trial, skaters were asked to select their rating from the Borg CR–10 scale (Borg, 1998); 0–2 rest/easy, 3–4 moderate, 5–6 hard, 7–8 really hard and 9–10 maximal intensity.

Statistical analyses

Statistical analyses were performed using IBM SPSS (version 25.0; IBM Corp, Armonk, NY). Data were checked for normality of distribution and assumption of sphericity. If Mauchly's test of sphericity was violated, Greenhouse-Geisser was used for analyses. Because velocity is a key factor in drafting, it was important to have minimal variation between the trials. A repeated-measures one-way ANOVA was used to check for differences in lap times as an indication of velocity between the three trials for each group. In order to compare the physical intensity and perceived intensity between the three skating positions, two repeated measures one-way ANOVAs were used with either

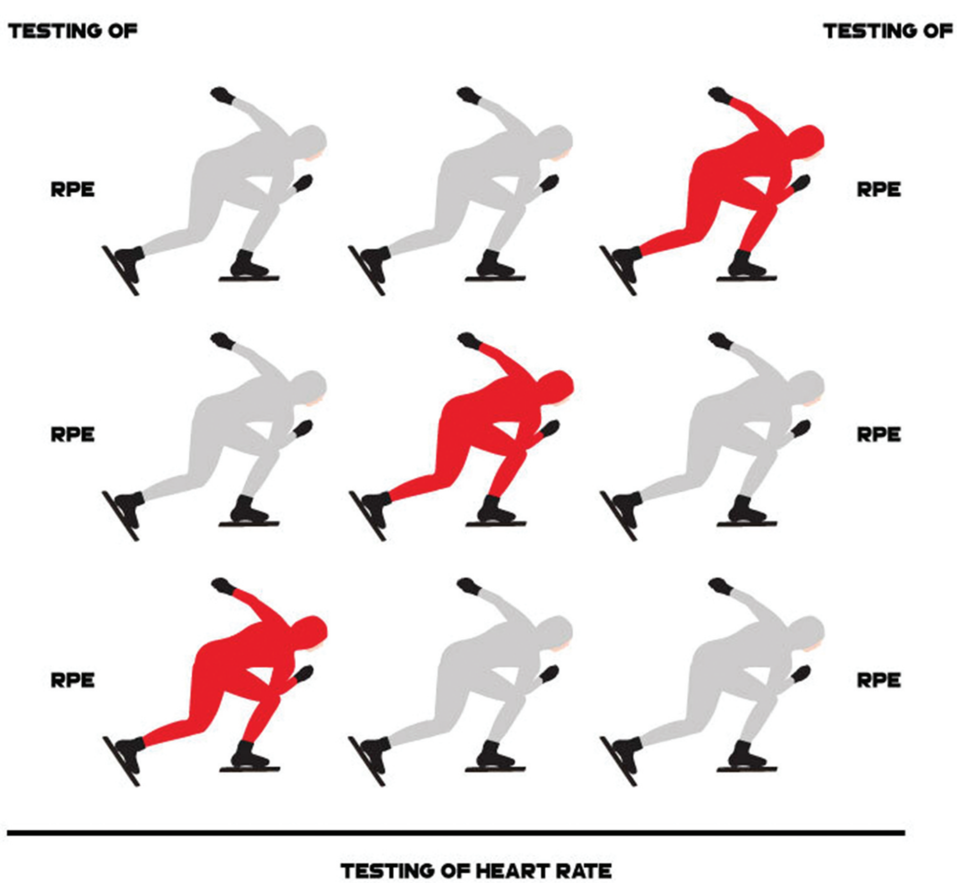

Figure 1. Overview of the 3 positions (first, second and third) and the testing procedure of RPE and heartrate.

heart rate or RPE as the independent variable and three positions (skating first, second or third) as within-subject factor. Effect sizes were calculated using partial eta squared (η_p^2). If a significant within-subject effect was found, indicating a difference in heart rate or RPE between the different skating positions, a post hoc analysis consisting of a paired-samples t-test was used to compare the percentage difference in heart rate or RPE of each skater performing in the three positions. Effect sizes for these t-tests were calculated using Cohen's d and were considered small (0.2–0.5), moderate (0.5–0.8) or large (>0.8) (Cohen, 1988). For all statistical tests, a *p*-value of 0.05 was chosen to represent statistical significance. All descriptive data are presented as mean and standard deviation (mean ± SD).

Results

There was no difference in velocity between the three trials for the six groups ($F_{2,10} = 2.296$, $p = 0.151$, $\eta_p^2 = 0.315$), as indicated by the lap times (35.2 ± 1.4 s, 34.8 ± 1.8 s and 35.2 ± 1.3 s). The standard deviations of aerodynamic drag force of the three skaters within each team did not exceed 1.5 N (Table 1), indicating a low variety of aerodynamic drag force between the different skaters within each group. All participants were fully recovered before the start of all three trials, indicated by an RPE value of 1.7 ± 1.3 at the start of the trials.

The heart rate monitor strap of three participants became too loose during the test, causing unreliable readings. These data have therefore been excluded from further analysis. The descriptive data of the heart rate and RPE of skaters in the first, second and third positions. are shown in Table 2. A significant within-subject difference in the heart rate ($F_{2,28} = 28.9$, $p < 0.001$, $\eta_p^2 = 0.67$) and RPE ($F_{1.3,22.1} = 7.02$, $p < 0.05$, $\eta_p^2 = 0.29$) was found between the three positions (first, second and third). Skaters benefited from drafting with a reduction of 3.2% in heart rate when skating in the second position compared to the first position ($t = 5.00$, $p < 0.001$, $d = 0.4$) and 4.7% in the third position compared to the first position ($t = 6.69$, $p < 0.001$, $d = 0.6$). Skating in third position compared to second position resulted in a reduction of heart rate ($t = 2.74$, $p < 0.05$, d = 0.2). The RPE measured after the trials was 18.5% lower for skaters in the second position ($t = 2.88$, $p < 0.05$, $d = 0.7$) and 16.8% lower in the third position ($t = 2.69$, $p < 0.05$, $d = 0.7$) compared to the first position. However, no difference in RPE was found between the third position compared to the second position ($t = 0.00$, $p = 1.00$, d = 0.0).

Interindividual differences are shown in Table 3. For HR, four different patterns became clear. The most observed pattern (*n* = 10) was with HR being highest in the first position, followed by HR in the second position and with HR being lowest when skating in the third position. For RPE, seven different patterns became clear. The most observed pattern (*n* = 8) was when RPE was highest in position 1, followed by equal RPE in positions 2 and 3. In three skaters, RPE was highest in position 1, followed by position 2 and lowest in position 3.

Discussion

On average, physical and perceived intensities are highest in first position compared to drafting in the second or third position. Even though the physical intensity is lower when drafting in third versus second position, the perceived intensity is equal. However, interindividual differences are large with four different patterns observed for HR and seven for RPE.

Results from this study on team pursuit racing demonstrate that on average the physical intensity was reduced by 5.8 bpm for skating in second position compared to being in first position. Although this reduction of 3.2% is comparable with other studies investigating the effect of drafting behind a leading speed skater (den Brandt FAP et al., 2021; Rundell, 1996) it may seem only a minor reduction compared to studies formed in cycling (6–30%) (Hausswirth et al., 2001). The difference from the current study, however, is larger when compared to inline skating (0–3%) (Millet et al., 2003). When performing at the highest level of competition, it is essential to distribute the available energy optimally in order of each skater's to give a maximal performance. Winning or losing at the world-class level is not seldom a matter of a fraction of a second. For example, in the 2023 ISU World Speed Skating Championships in Thialf, the difference between the gold medal won by the Dutch men team (218.27 s) and the silver medal won by Norway was only 0.17 s. As such, the amount of reduction in heart rate due to drafting found in the current study is considered meaningful and impactful. It can provide

Table 2. Heart rate (bpm) and RPE (0–10) for each position and between the positions (mean ±SD) (**p* < 0.05).

	First position	Second position	Third position	Δ first – second	Δ first – third	Δ second – third
Heart rate (*n* = 15)	182.1 ± 12.9	176.3 ± 14.9	173.7 ± 14.8	5.8 ± 4.5*	8.4 ± 4.9*	2.6 ± 3.7*
RPE (*n* = 18)	5.4 ± 1.7	4.2 ± 1.7	4.2 ± 1.7	1.2 ± 1.8*	1.2 ± 1.9*	0.0 ± 0.8

Table 3. Interindividual differences in heart rate and RPE at positions 1, 2 and 3. The percentage of skaters characterised by each pattern is displayed.

Pattern	Heart rate (*n* = 15)	RPE (*n* = 18)
Position 1 > 2 > 3	66.7% (10)	16.7% (3)
Position 1 > 2 = 3	13.3% (2)	44.4% (8)
Position 1 > 3 > 2	13.3% (2)	5.6% (1)
Position 2 > 1 > 3	6.7% (1)	5.6% (1)
Position 1 = 2 = 3		11.1% (2)
Position 2 > 3 > 1		5.6% (1)
Position 3 > 2 > 1		11.1% (2)

valuable information to the skaters and their coaches. A larger reduction of 4.8% was found when the third position was compared with the first position. As noted earlier in cycling research, the physical benefits are highly dependent on the position of the athlete within the team (Heimans et al., 2017). On average, the perceived intensity was reduced when skating in second position with 18% compared to leading. This is in line with a small number of studies in running and skating which also found significant reductions in perceived intensity while drafting in second position (den Brandt FAP et al., 2021; Millet et al., 2003; Zouhal et al., 2015). A similar reduction was found when comparing the third position to the first position, concluding that on average the perceived intensity did not differ between the drafting positions. This implies that skating in either the second or third position results in a similar lower perception of exertion compared to skating in front.

However, despite significant within-subject differences with moderate effect sizes for the total group of skaters, there are large differences between individual speed skaters, especially with respect to their perceived intensity. This may be related to the relatively small sample size of the study. Still, when further unravelling those interindividual differences, it becomes clear that in all but one speed skater, HR was indeed lower in a drafting position compared to the leading position. Although the skaters were grouped according to the coach's perceived performance level, variability in their training status could contribute to the variation in HR. However, this observation did not hold for perceived intensity. It became clear that one-third of the skaters perceived a drafting position either equally ($n = 2$) or more ($n = 4$) demanding than the leading position. A possible explanation is that those skaters prefer to set their own pace, despite increased physical strain. Previous literature has provided evidence that physiological strain is higher when performing a trial with an externally set pace, compared to a self-paced trial (Lander et al., 2009). The variety in patterns for HR (4) and especially RPE (7) marks the necessity to take an individualised approach when selecting a group of skaters and training for the team pursuit.

Within speed skating, the team pursuit is a unique event, which to a certain extent combines the task requirements of long-track and short-track speed skating. In individual long-track events, optimal performance can be achieved when a skater adopts a pacing behaviour that optimally matches their performance characteristics (e.g., muscle fibre type distribution, anaerobic and aerobic capacities) to the task demands (Bellinger et al., 2011). In short-track speed skating, but also in running, the presence of competitors forces athletes to incorporate environmental factors into their pacing behaviour (Jones & Whipp, 2002; Konings & Hettinga, 2018a). The presence of competitors affords the opportunity for drafting, allowing the athlete to save energy for the key final section of the race (Konings et al., 2016). Although drafting in this setting offers a tactical advantage, it is not without drawbacks (Menting et al., 2020). The adoption of an externally imposed pace has been shown to be more physically demanding compared to self-paced exercise (Lander et al., 2009). Given the results of the current study, it could be reasoned that these same skaters could also experience a higher perceived intensity. The drafting athlete also needs to overtake the leading athlete before the window of opportunity is closed. Within the team pursuit event, features from both events are combined. The variation in physical characteristics between athletes means that differing pacing strategies could lead to optimal performance, even when the task characteristics and environmental factors are constant (Bellinger et al., 2011, 2021). Previously, in running it has been shown that when athletes collectively adopt a pace, it is likely that the majority of athletes will spend either too much or not enough energy for optimal task performance (Menting et al., 2021). By using the adaptation of physical intensity afforded by drafting in specific positions, these differences between athletes could be (partly) mitigated, therefore allowing for a synchronised performance of the athlete collective. Besides the known physical benefits, drafting is thought to impact factors such as goal setting, motivation and self-efficacy, amending the athlete's view of the exercise task (Zouhal et al., 2015). This process could explain the findings from the current study.

A challenging aspect of the team pursuit is the transition strategy. A traditional way to pace a race with three team members is when the skaters regularly change positions in the curve. Some teams change more often than others and there are different changing ways; first skater goes to last position, or third skater goes directly to the leading position. When skaters change position, two instead of one skater suffers the extra wind resistance, resulting in a greater physical challenge for the team. Not changing at all is a new approach to the team pursuit race with three skaters. The first skater is pushed by their drafting teammates and will therefore be the only skater suffering all wind resistance. This ´push strategy´ results in less energy loss to wind resistance and was found to be very successful at the Winter Olympic Games of 2022 in Beijing with the winning teams (Canada, women and Norway, men) applying this strategy (Team Data, 2022). Also, in the 2023 World Speed Skating Championships successful teams applied this strategy. Still, it remains unclear whether this new strategy is most beneficial for every team, and more research is advised. Furthermore, for this approach, it is important to know the benefits per position, taking into account the variation in skills of the team members, to come up with the optimal order for the individual skaters in the team. The current study provides reference data, which can be used to interpret results from future experiments in which skaters apply different team pursuit strategies.

It should be pointed out that skaters need to be collaborative when racing the team pursuit. During the team pursuit, synchronising the skating movement and staying as close as possible to the leader is beneficial (Elfmark et al., 2019). These drafting skills are an important factor in achieving the possible aerodynamic advantage (Bilodeau et al., 1994; den Brandt FAP et al., 2021; Hausswirth et al., 2001; Millet et al., 2003; Rundell, 1996). However, more research is warranted to measure these drafting skills in practice. The key to winning the team pursuit event might be a multidimensional approach (Elferink-Gemser et al., 2011; Konings et al., 2015). Drafting skills, collective pacing behaviour, preference for a certain position and an optimal formation of the team in terms of anthropometrics regarding skater's frontal area may be more important than how fast skaters can skate on individual races.

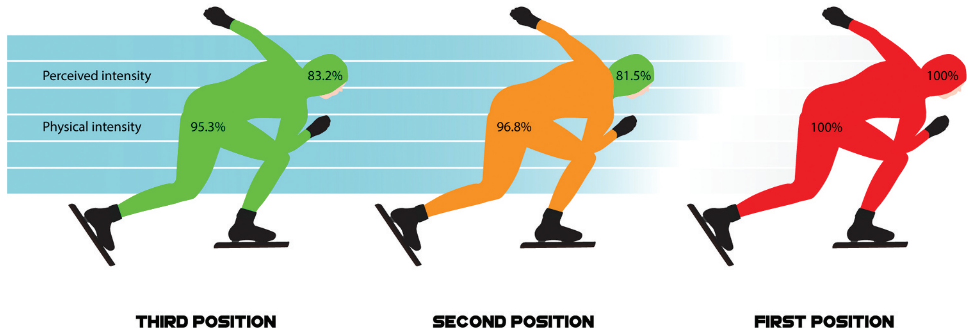

Figure 2. Schematic overview of the average impact of drafting on physical intensity and perceived intensity when skating in first, second or third position.

Practical implications

The current study demonstrated that when three speed skaters follow closely behind one another, each position will come with different requirements in terms of physical and perceived intensity (Figure 2). This unique and valuable information can help athletes and coaches to achieve optimal performances during the team pursuit. The findings of the current study will be a resource for coaches in team selection and can aid in the optimalisation of the team's positioning during the race. The positioning of the skaters will impact their ability to optimally distribute their efforts over the course of the race, and impact the collective team performance. Using the full potential of each skater is also useful in training sessions, where the detailed information from this study, can result in an optimal setup. The team members can be put in the right positions in order to optimise training sessions. On average, the leading position is most demanding, followed by the second and third positions. However, there are large interindividual differences and some skaters experience skating in front as the least intensity, while others prefer a drafting position. As such, it is important to investigate not only the physical capabilities of each skater but their personal preferences as well to adopt a tailor-made strategy for a team instead of a "one-fits-all"-strategy. Besides, it is advised to take the frontal area (Heimans et al., 2017) of the individual skaters into account. The calculation for friction force as used in the method section of this research could be used. Most important is to take into account all these preferences of the athlete in order to reach maximal performances.

Conclusion

When three speed skaters follow behind each other, the physical and perceived intensity are highest in first position. Even though on average the physical intensity is lower when drafting in third versus second position, the perceived intensity in those positions is equal. A key finding, however, is the large interindividual difference, which encourages coaches to adopt a multidimensional, tailor.

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