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Original Article

Performance Level Influences Racing Profiles of 1-km Time Trial in Male High School Cyclists

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Abstract

Analyses of 1-km time trial (TT) racing profiles specifically for high school cyclists are lacking. This study aimed to clarify the racing profiles of male high school cyclists in a 1-km TT. The 1-km TT performance was analyzed in 50 male high school cyclists who participated in competitions held on the same track (333.3 m). The cyclists were divided into the High (n = 25, 72.9 ± 2.0 seconds) and Low (n = 25, 79.9 ± 3.1 seconds) groups based on their 1-km TT performance. We obtained panning shots of cyclists during the 1-km TT race and calculated the section velocity at every 83 m, average velocity, peak velocity, normalized velocity, and fatigue index from lap times. Analysis of variance showed significant main effects for section velocities and group, as well as a significant interaction in the 1-km TT velocity curve. The peak velocity was significantly higher in the High group than in the Low group ($p = 0.000$). However, the fatigue index did not differ between the groups. Significant negative correlations were found between 1-km TT record and velocity in each section and peak velocity in both groups ($p < 0.05$ or $p < 0.01$). In conclusion, the racing profiles of 1-km TT related to better performance are determined by higher peak velocity but are not influenced by the rate of velocity decline after reaching the peak velocity in male high school cyclists.

Keywords

Cyclists; Cycling; Racing Profiles; 1-km Time Trial

1 Introduction

In Japanese high school track cycling competitions, sprint events include sprint, 1-km time trial (TT), and Keirin, whereas middle- and long-distance events include 3-km individual pursuit, 4-km mass start race, 8-km scratch race, and 24-km point race. Track

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events are classified into sprint and middle- and long-distance categories based on a 1,000-m distance, which takes approximately 70 seconds (Craig & Norton, 2001). Among these events, coaches highlight the importance of the 1-km TT for evaluating cycling performance not only for sprint-oriented cyclists but also for those focused on middle- and long-distance events. Relationships have been reported between 1-km TT performance and physical characteristics across various levels, from high school to elite cyclists (Ikeda et al., 2009; Ishii et al., 2016; Nakamura et al., 2018; Nakamura et al., 2020). In contrast, analyses of 1-km TT racing profiles specifically for high school cyclists are lacking, with existing studies primarily focusing on college-level and elite cyclists (Corbett, 2009; de Koning et al., 1999; Nakazawa et al., 2020; Ohta et al., 2011; Wilberg & Pratt, 1988).

On analyzing the 1-km TT among elite track cyclists ranking eighth in world championships, de Koning et al. (1999) demonstrated a significant positive correlation between the time on the first lap (0–250 m) and the 1-km TT record ($r = 0.71$). Similarly, Corbett (2009) showed that the first lap time was significantly correlated with the 1-km TT record ($r = 0.73$) among elite cyclists. Similar results were obtained through simulations of the 1-km TT (van Ingen Schenau et al. 1992). In contrast, no significant relationship was found between time taken for the 750–1,000-m lap and the 1-km TT records (van Ingen Schenau et al., 1992). These findings may support the "all-out strategy" (Corbett, 2009; van Ingen Schenau et al., 1992), which suggests that maintaining maximum effort from the start is crucial for achieving a good record in 1-km TT. This strategy may be particularly effective in higher-level competitive cyclists. However, to our best knowledge, the association between the all-out strategy and 1-km TT records among junior-level cyclists has not been studied.

Higher peak velocity is also strongly related to the 1-km TT performance, with a significant negative correlation between 1-km TT records and peak velocity observed in elite cyclists (Ohta et al., 2011; Tissot Timing, 2020 [peak velocity was calculated by the authors from the official records on the website]) and high-level university cyclists (Nakazawa et al., 2020). In contrast, no significant relationship between peak velocity and 1-km TT record has been found in university cyclists (Ikeda et al., 2009). This suggests potential differences in racing patterns depending on competitive level and/or experience. However, no studies have examined the racing profiles of 1-km TT in high school cyclists.

In Japan, students often participate in competitive cycling after entering high school. We analyzed a homogeneous population of individuals who began competitive cycling at the high school level. By comparing their racing profiles with those of college-level and elite cyclists during the 1-km TT, we aimed to clarify the factors associated with better 1-km TT performance among high school cyclists. Therefore, this study aimed to elucidate the racing profiles of 1-km TT in male high school cyclists.

2 Material and Methods

2.1 Competitions Events for Analysis

Men's 1-km TT records from local-level competitions held on the same 333.3-m track in Japan were adopted and analyzed. We explained the purpose of this research to the event organizers in advance and obtained permission to record data on the track, and in the analysis, we implemented rigorous ethical measures to ensure that individuals could not be identified. This study was approved by the Ethics Committee of the School of Sport and

Health Science, Tokai Gakuen University (approval number: 2024-16) and conducted in accordance with the principles of the Declaration of Helsinki.

2.2 Participants

We analyzed the 1-km TT performance in 50 well-trained male high school cyclists (first, second, and third grades; n = 10, 16, and 24, respectively, with 1-km TT records between 68.59 and 84.99 seconds) who participated in the aforementioned competitions. The participants were divided into a High group (n = 25) and a Low group (n = 25) based on their 1-km TT records. The highest 1-km TT records over the past 3 years were analyzed, with participants in the highest school year at the time of data collection.

Additionally, 200-m TT records were used as an index of personal maximum velocity within 1.5 months before and after the 1-km TT race, and 200-m TT records were available for 35 participants (High group: n = 19; Low group: n = 16).

2.3 Video Shooting

The 1-km TT races analyzed were conducted on the same 333.3-m track. Each high school cyclist was recorded using a panning technique with two high-speed cameras (Panasonic, Lumix DMC-FZ300, shooting at 240 fps, or CASIO, EX-F1, shooting at 300 fps) positioned at the center of the track. To calculate the lap times and average velocity for each section, we measured distances of 83.3 m from the center lines of the home and back straights. These distance points were marked on the inside of the track, with short lines drawn toward the center. These markings did not interfere with the cyclists' performance during the 1-km TT races. Distances of 83.3 m were measured using a walking measure (TOEI LIGHT, TL12/G2006).

2.4 Video Analysis

A video analysis was performed using video editing software (QuickTime Pro 7; Apple). The time origin (zero frame) was set to the frame when the front tire's movement began. The subsequent frames in which the tip of the tire passed each distance point were recorded. The passing time was calculated by multiplying the frame number by the reciprocal of the frame rate (fps). The analysis was repeated until the analyst error was within one frame (0.004 seconds).

2.5 Racing Profiles Analysis

In this study, the following parameters were calculated.

- Average velocity in each section (km/h) = (83.3 m / lap times [seconds]) × 3.6
- Peak velocity (km/h) = adopted highest section velocity
- Bottom velocity (km/h) = adopted lowest section velocity after the peak velocity
- Normalized velocity (%) = average velocity in each section / peak velocity × 100
- Fatigue index (FI) (%) = (peak velocity – bottom velocity) / peak velocity × 100
- The relative peak velocity was calculated by dividing the peak velocity in the 1-km TT by the maximum velocity in the 200-m TT.

2.6 Statistical Analysis

All data are presented as means ± standard deviation (SD). For velocity curve analysis of the 1-km TT, a two-way analysis of variance (group × section velocity), with section velocity as a repeated measure, was conducted to examine the differences between the High and Low groups. If there was a significant interaction, Bonferroni adjusted *post-hoc* tests were used. The Student t-test was used to determine the differences between the High and Low groups for parameters, including the average velocity in each section, peak velocity, FI, 200-m TT record, and relative peak velocity.

Correlation analyses were performed between the 1-km TT record and velocity in each section of 83.3 m, peak velocity, and FI, and between peak velocity in the 1-km TT and maximum velocity in the 200-m TT. Statistical analyses were performed using SPSS software (version 24.0; IBM Corp.), and statistical significance was set at $p < 0.05$.

3 Results

3.1 Participants Characteristics

The mean 1-km TT records for the High and Low groups were 72.7 ± 2.0 seconds (range: 68.59–75.36 seconds) and 79.7 ± 3.1 seconds (range: 75.65–84.99 seconds), respectively. The mean school years were 2.6 ± 0.6 for the High group and 2.0 ± 0.8 for the Low group, indicating a significant difference between the groups ($p < 0.01$). The mean relative peak velocity for 35 participants was 92.5 ± 4.9%. The differences between the 1-km TT records obtained from the video analysis and the officially announced records from the competition were minimal (mean ± SD; 0.18 ± 0.26 seconds). Additionally, a significant correlation was observed between these parameters ($r = 0.998$, $p < 0.001$).

3.2 Velocity Changes and Racing Profiles during the 1-km TT

Changes in velocity with distance during the 1-km TT in the High and Low groups are shown in Fig. 1a. Significant main effects were observed for group ($p < 0.001$) and section velocity ($p < 0.001$), and a significant interaction was observed ($p < 0.001$). The significant interaction was due to 1) the peak velocity in the High group being higher than that in the Low group and 2) the peak velocity appearing at 250 m in the Low group and at 333 m in the High group, indicating that the section where the peak velocity appeared differed between the groups.

Normalized velocity changes calculated by dividing the velocity in each section by the peak velocity during the 1-km TT in the High and Low groups are shown in Fig. 1b. A significant main effect was observed for section velocity ($p < 0.001$) but not for group ($p = 0.069$). However, a significant interaction was observed ($p = 0.012$). The significant interaction shown in Fig. 1b was due to the aforementioned reasons. Additionally, as the solid and dotted lines intersect within the data area, Fig. 1b provides results that are easier to understand than those in Fig. 1a.

Table 1 presents the racing profiles of the 1-km TT in the High and Low groups. The mean values of the average and peak velocities were significantly higher in the High group than in the Low group ($p < 0.001$). In contrast, there was no significant difference in FI between the groups.

Table 1. Average velocity, peak velocity, and fatigue index in the 1-km TT between the High and Low groups

	High (n = 25)	Low (n = 25)	p value
Average velocity (km/h)	49.4 ± 1.4	45.1 ± 1.7	< 0.001
Peak velocity (km/h)	56.6 ± 1.8	52.1 ± 1.8	< 0.001
Fatigue index (%)	14.7 ± 2.8	16.1 ± 3.4	n.s.

TT, time trial; n.s., not significant; average velocity in each section (km/h) = (83.3 m / lap times [seconds]) × 3.6; peak velocity (km/h) = adopted highest section velocity; fatigue index (FI) (%) = (peak velocity – bottom velocity) / peak velocity × 100

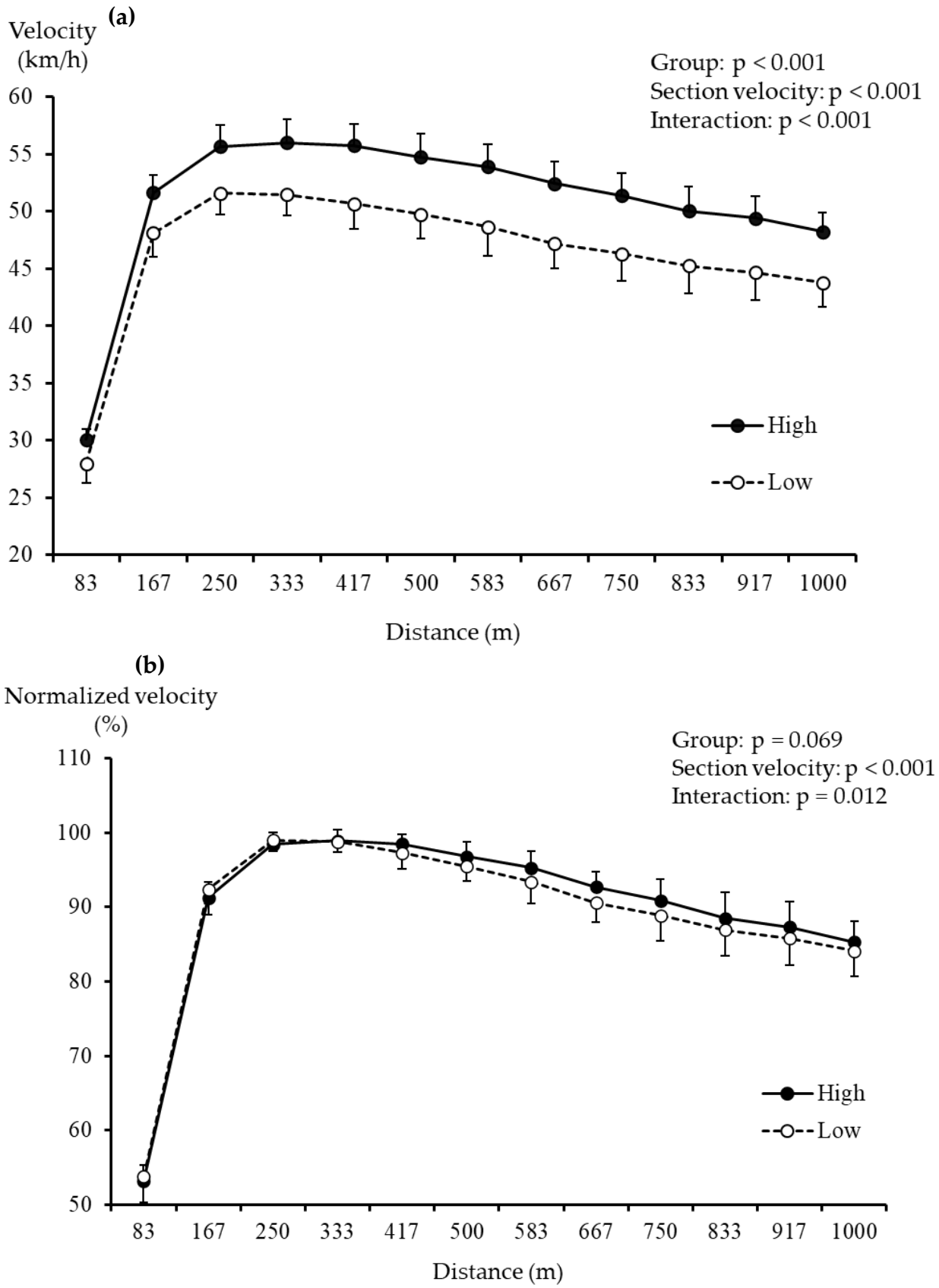

Figure 1. (**a**) The 1-km TT velocity curve between the High (filled circle) and Low (open circle) groups. The significant main effects are obtained in group and section velocity ($p < 0.001$), and a significant interaction is found ($p < 0.001$); (**b**) The normalized velocity curve of 1-km TT divided by the peak velocity between the High and Low groups. The significant main effect is observed in section velocity ($p < 0.001$) but not in group ($p = 0.069$). However, a significant interaction is obtained ($p = 0.012$).

3.3 Relationship Between 1-km TT Performance and Racing Profiles

Table 2 shows the relationship between the 1-km TT record and the velocity in each section of 83.3 m, peak velocity, and FI for each group. Significant relationships between the 1-km TT record and all section velocities were observed in both groups (High and Low groups: r = -0.45 to -0.92, $p < 0.05$ or 0.01 and r = -0.52 to -0.92, $p < 0.01$, respectively). Moreover, a strong correlation between the 1-km TT record and peak velocity was found in both groups (High and Low groups: r = -0.80 and r = -0.80, $p < 0.01$, respectively). In contrast, a significant correlation between the 1-km TT record and FI was observed in the Low group (r = 0.48, $p < 0.05$) but not in the High group.

Table 2. Relationships between 1-km TT records and racing profiles between the High and Low groups

	Section (m)												Peak velocity	Fatigue index
	0-83	83-167	167-250	250-333	333-417	417-500	500-583	583-667	667-750	750-833	833-917	917-1000		
High (n = 25)	-0.45 *	-0.80 **	-0.80 **	-0.70 **	-0.83 **	-0.90 **	-0.91 **	-0.92 **	-0.88 **	-0.86 **	-0.81 **	-0.81 **	-0.80 **	0.06
Low (n = 25)	-0.52 **	-0.70 **	-0.82 **	-0.70 **	-0.75 **	-0.83 **	-0.88 **	-0.92 **	-0.90 **	-0.93 **	-0.92 **	-0.89 **	-0.80 **	0.48 *

*p < 0.05; ** p < 0.01; TT, time trial. Correlation analyses were performed between the 1-km TT record and velocity in each section of 83.3 m, peak velocity, and fatigue index.

3.4 200-m TT Performance and Relative Peak Velocity

Table 3 shows the 200-m TT performance and relative peak velocity in the subgroups of participants. The maximum velocity was significantly higher in the High group than in the Low group (High and Low: 61.3 ± 2.6 km/h versus 56.4 ± 3.5 km/h, $p < 0.001$). However, the relative peak velocity did not differ significantly between the groups (High and Low: 92.2 ± 3.3% and 92.9 ± 6.5%, respectively).

The maximum velocity of the 200-m TT was significantly higher than the peak velocity of the 1-km TT in both groups ($p < 0.001$). The peak and maximum velocities in the subgroup of participants were significantly correlated (r = 0.67, $p < 0.001$, data not shown).

Table 3. The 200-m TT performance and relative peak velocity between the subgroups of participants

	High (n= 19)	Low (n = 16)	p value
200-m TT (km/h)	61.3 ± 2.6	56.4 ± 3.5	< 0.001
Relative peak velocity (%)	92.2 ± 3.3	92.9 ± 6.5	n.s.

TT, time trial; n.s., not significant. The relative peak velocity was calculated by dividing the peak velocity in the 1-km TT by the maximum velocity in the 200-m TT.

4 Discussion

We recruited high school cyclists who started competitive cycling after entering high school and analyzed a 1-km TT race held on the same track (length: 333.3 m). The data analysis in this study was conducted using almost homogeneous participants, and it was not influenced by differences in track profiles. In previous studies analyzing the velocity changes in a 1-km TT, the section velocity was calculated using the lap time displayed on an electric bulletin board (Corbett, 2009; de Koning et al., 1999) or it was acquired from the number of frames shot with a high-speed camera (Wilberg & Pratt, 1988). In the present study, two high-speed cameras were used to shoot videos from the center of the track using the panning technique. Because the shooting was conducted by standing at the intersection of the line connecting the home and back straights and the line connecting the first and second centers, and a high shooting speed (300 fps) was used, the lap time could be accurately calculated (to the nearest 0.0033 second). Previous studies demonstrated velocity curves every 125–333 m (Corbett, 2009; de Koning et

al., 1999; Ikeda et al., 2009; Nakazawa et al., 2020; Ohta et al., 2011; Wilberg & Pratt, 1988) and could not reveal small velocity changes. In this study, however, the lap time was measured every 83.3 m, and more detailed velocity profiles were obtained.

To clarify the effects of the performance on racing profiles during the 1-km TT, we divided the 50 participants into two groups depending on their 1-km TT records. As expected, the 1-km TT record was significantly higher in the High group than in the Low group. The maximum velocity of the 200-m TT in the High group was also significantly higher than that in the Low group. In Japan, a record of at least 69.00 seconds is required to participate in a 1-km TT national competition for high schools. Although the High group did not reach this record, it included many high-ranking winners at prefectural competitions, and many cyclists in the High group had experience participating in regional and/or national competitions. Thus, in this study, we analyzed cyclists at an almost highly competitive level during high school. Additionally, considering the inclusion of the Low group, we analyzed cyclists covering a wide range of competitive levels, from upper to lower levels, during high school.

Cyclists with better 1-km TT goal times exhibited faster section velocities and higher peak velocities across all sections than their counterparts. These results are consistent with those of previous studies conducted among university and elite cyclists. Ohta et al. (2011) reported that cyclists with better 1-km TT goal times had higher peak and sectional velocities. Therefore, achieving higher peak velocities positively influenced the performance of high school cyclists.

In this study, the 1-km TT records and the peak velocities of the High and Low groups were significantly different. Additionally, both High and Low groups demonstrated a significant negative correlation between 1-km TT record and peak velocity. A significant relationship between the 1-km TT record and peak velocity has also been observed in university and elite cyclists (Nakazawa et al., 2020; Ohta et al., 2011; Tissot Timing, 2020). Therefore, regardless of competitive level or experience, peak velocity has a substantial impact on the 1-km TT performance.

The location where the peak velocity is reached differed between university, elite, and high school cyclists. Here, the Low and High groups achieved peak velocity between 167–250 and 250–333 m, respectively. In contrast, university and elite cyclists reached a peak velocity between 250–375 m (Nakazawa et al., 2020) and 375–500 m (Tissot Timing, 2020), respectively, showing a difference of >100 m compared with the distance of elite cyclists. As their competitive abilities develop, cyclists tend to prefer higher gear ratios. Consequently, as the gear ratio increased, the acceleration time to reach the peak velocity increased, resulting in delayed attainment of the peak velocity. Improving muscular strength and power is essential for pedaling at higher gear ratios. For high school cyclists, whose bodies are not fully developed and who have a maximum of 3 years of competitive experience, the location of achieving the peak velocity may be similar to that observed in this study. However, high school cyclists who perform well in national competitions may display peak velocity locations resembling those of elite or university cyclists. This study presents areas for future research.

However, the FI values did not differ significantly between the groups. This finding is consistent with those from reports on elite cyclists. Although no significant correlation was found between FI values and 1-km TT records in the High group, a significant correlation was observed in the Low group. Similar to that in the High group, no significant relationship was reported among elite cyclists

(Corbett, 2009; Ohta, et al., 2011; Tissot Timing, 2020), indicating that the Low group is a distinctive population. The Low group included 18 participants with <2 years of competitive experience. This novice status likely influenced their unfamiliarity with racing bicycles and tracks as well as their inability to select the optimal gear ratio.

Incidentally, as aforementioned, the 1-km TT performance depends on the peak velocity achieved during sprinting. However, the mean value of relative velocity, calculated by dividing the peak velocity during the 1-km TT by the maximum velocity during the 200 m-TT, was 92% for both the High and Low groups, with no significant difference. To our best knowledge, no previous studies have investigated the relationship between relative velocity and 1-km TT performance. However, our data suggest that the assertion from previous research, which emphasizes the importance of an "all-out strategy" for achieving a higher peak velocity from the very start to improve 1-km TT performance, may not be supported. Future studies should explore the relationship between relative velocity and 1-km TT performance in elite cyclists to validate this hypothesis.

This study has some limitations. First, we recruited 50 cyclists who had 1-km TT records ranging from 68.59–84.99 seconds. However, only one cyclist was able to participate in national-level 1-km TT races during high school. In the future, the 1-km TT racing profiles of higher-performance-level high school cyclists need to be analyzed. Second, we did not conduct an awareness survey of participants, i.e., regarding their racing plan, pacing strategy, and gear ratio. Performance in middle- and long-distance events depends on pacing strategy (Abbiss & Laursen, 2008; Corbett, 2009; Wilberg & Pratt, 1988). Although the 1-km TT event is not considered a middle- or long-distance event, we should investigate whether high school cyclists employed any pacing strategies. High school cyclists with higher-performance-level may have employed some pacing strategies. Additionally, the gear ratio influences 1-km TT records, and the higher-performance-level, the more cyclists tend to prefer a higher gear ratio (Ikeda et al., 2009; Ohta et al., 2011). For a detailed analysis of the pacing strategy, gear ratio, and other factors, we need to investigate how cyclists performed the 1-km TT before and/or after the race. Third, the track was divided into 83.3-m sections, and then section velocity was calculated; therefore, it was not possible to identify changes in velocity between the straight and curves of the track. In track cycling, the forces acting on the cyclists differ between the curves and straights, often resulting in variations in velocity. Although the results of the high school cyclists in this study can be compared with findings of velocity analyses conducted on 250-m tracs used in international competitions, subtle changes in velocity between curves and straights could be captured.

In addition to revealing that peak velocity and velocity in each section strongly influenced 1-km TT records, we clarified that 1-km TT racing profiles were affected by competition levels in male high school cyclists. In conclusion, the racing profiles of 1-km TT related to better performance are determined by a higher peak velocity but are not influenced by the rate of velocity decline after reaching the peak velocity in male high school cyclists.

5 Practical Applications

Previous studies on elite cyclists have demonstrated that peak velocity significantly influences 1-km TT performance. Consistent with these findings, the results of the present study revealed that peak velocity dominated 1-km TT performance in even novice cyclists

who began competitive cycling after entering high school, and their peak velocity during 1-km TT was highly correlated with the maximal velocity of 200-m TT. Thus, in novice cyclists, improvement of the muscle contraction speed in pedaling could be primarily focused on, with the secondary focus being pedaling with a high gear ratio and resistance training for enhancing muscular power.

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Conflicts of Interest: The authors declare no conflict of interest.

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