J Sci Cycling. Vol. 5(3), 28-34

RESEARCH ARTICLE **Open Access**

The Effects of Bicycle Geometry on Sprint Triathlon Running Performance

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Abstract

Previous research has shown that riding with a steeper (81°) than normal (73°) bicycle seat tube angle (STA) can improve subsequent run performance during Olympic distance triathlon that involve a 1500 m swim, 40 km cycle and 10 km run. However, such races often utilise pacing strategies during the run phase that may have influenced previous findings. Conversely, Sprint distance triathlons (750 m swim, 20 km cycle and 5 km run) are generally performed at a higher intensity, both during the cycle and run legs. Few studies have focused on Sprint triathlons, therefore, the purpose of this study was to investigate the effect cycling with different STA's had on subsequent sprint triathlon running performance. Ten trained amateur male triathletes (34.8 ± 10.9 years), completed two 20 km time trials on a cycle ergometer, one with a STA of 73° and one with a STA of 81°. Both conditions were followed immediately by a 5 km treadmill based running time trial and were completed as fast as possible. Time (min:s), heart rate (Beats.min-1), oxygen consumption (ml.kg.min-1) and rate of perceived exertion (RPE) were recorded for both run and cycle legs. Additionally, during the cycle leg, mean power output (W), mean cadence (rpm) and mean velocity (km.h-1) were recorded. For the run leg, velocity (m.s-1), stride length (SL, in m) and stride frequency (SF, in Hz) were additionally recorded. Running time improved significantly following cycling with the 81° STA compared to 73° STA (27:10 ± 3:09 vs. 27:59 ± 3:18 min:s respectively; p=.006; ES=0.25), along with running velocity (3.13 ± 0.37 vs. 3.04 ± 0.37 m.s-1 for 81° and 73° respectively; p=.007; ES=0.24). Stride length also increased significantly following the cycle with the 81° STA (2.20 ± 0.26 vs. 2.12 ± 0.27 m for 81° and 73° respectively; p=.007; ES=0.30). Overall cycle+run time was also significantly reduced in the 81° condition (63:31 ± 6:08 vs. 64:23 ± 5:10 min:s for 81° and 73° respectively; p=.042; ES=0.15). These results suggest that cycling on a bicycle with a steeper STA improves subsequent running and overall performance during a simulated sprint triathlon, possibly due to changes in lower limb biomechanics.

Keywords: Triathlon, Economy, Cycling, Running, Geometry.

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Received: 19 Sept 2016. Accepted. 08 December 2016.

Introduction

Triathlon is a multi-discipline event combining swimming, cycling and running, as well as a swim-cycle and a cycle-run transition (Millet and Vleck 2000). These events range from Sprint distances (750 m swim, 20 km cycle and 5 km run), Olympic distance (1500 m swim, 40 km cycle and 10 km run) to ultra-events, such as Ironman triathlons (3.8 km swim, 180 km cycle and 42 km run). Irrespective of event distance, cycling takes up the majority of time during triathlons, yet prolonged periods of cycling have been shown to impair running performance (Hue et al. 1998; Garside and Doran 2000; Bisi et al. 2012).

Triathlon performance can be influenced greatly by the ability to transition from one discipline to the next, in particular from the cycle to the run (Garside and Doran 2000; Jensen et al. 2008). A number of studies have investigated the effects cycling has on biomechanical (Hue et al. 1998; Garside and Doran 2000; Jensen et al. 2008) and cardiovascular variables (Hue et al. 1998; Jackson et al. 2008; Bisi et al., 2012) during running. Hue et al. (1998) looked at how 40 km cycling affected subsequent 10 km running performance during an Olympic distance triathlon. Cardiovascular demands during the run were higher following the 40 km cycle when compared with a 10 km control run. This was due to significantly higher oxygen uptake ($\dot{V}O2$), heart rate (HR), and minute ventilation ($\dot{V}E$) compared with during the control run. However, there were no significant differences in biomechanical variables, such as stride length (SL) and stride frequency (SF).

Price and Donne (1997) suggested that changing bicycle frame geometry, through steepening the seat tube angle (STA), can improve the cycle-run transition by altering biomechanics and the aerodynamic impact of the cycling phase. Seat tube angle is defined as the position of the seat tube in relation to the ground (Jackson et al. 2008). Garside and Doran (2000) investigated the effect riding with a steeper STA had on subsequent running performance. Ten kilometre running time was significantly faster following a 40 km cycle with a steeper 81° STA compared with a standard 73° STA, with reduced time and greater SL and SF in the first 5 km compared to the second 5 km of the run.

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They proposed this was due to the ability to reach peak running velocity within the first kilometre of the run following the 81° STA condition. Whilst for the 73° condition it took until approximately the 7 km point before peak running velocity was achieved.

Garside and Doran (2000) used an intensity of 70 % $\dot{V}O_2$peak for the cycle leg of their simulated Olympic distance triathlon. Whilst this was lower than that observed by Kreider et al. (1988) for Olympic distance races, who reported a mean intensity of ~85 % $\dot{V}$O2max, it was comparable to that observed by Le Meur et al. (2009) during 'draft-legal' Olympic distance races. However, the workload used by Garside and Doran (2000) was constant in nature and therefore not realistic, as power output would vary based on course and fatigue during racing. Therefore, protocols used by Garside and Doran may have underestimated workloads during the cycling phase of Olympic distance triathlons, which may have influenced subsequent running performance during their study. Bernard et al (2009) reported that the Olympic distance triathlon cycle was characterised by variations in both aerobic and anaerobic contributions during a world cup race, greater than the constant-workloads classically used in laboratory testing. In addition, during real world racing, it is not uncommon for elite triathletes to aim for a negative split during the 10 km run, i.e. to run the second 5 km quicker than the first. This may be in response to the workloads during the cycle and to easy the cycle-run transition. Both Hausswirth et al. (2010) and Le Meur et al. (2011) investigated pacing strategies during Olympic distance triathlons and reported triathletes should actively aim to reduce running pace by approximately 5% compared to a controlled 10 km run during the early stages of the Olympic distance triathlon run leg. As such, this strategy would yield results in opposition to the findings of Garside and Doran (2000). Though little data exists reporting exercise intensity during sprint triathlon races, previous research has shown trained, amateur cyclists and triathletes performed 20 km cycle time trials (as used in sprint triathlon) at an intensity between 78-86 % $\dot{V}$O2max (Kenefick et al., 2002; Zavorsky et al., 2007). This is higher than the intensity used by Garside and Doran (2000). Subsequently, pacing strategies during the run may play a smaller role in overall performance during Sprint triathlons due to the higher cycling workloads, despite the lower total work performed during sprint triathlons. Therefore, the aim of this study was to determine if similar results to those reported by Garside and Doran (2000) would be found when altering STA on run performance following a self-paced cycling effort more typically seen during sprint triathlons. It was hypothesised that an increased STA would improve sprint triathlon performance, and that SF and SL would be increased.

Materials and methods

Participants

Ten trained amateur male triathletes (mean ± s.d. age 34.8 ± 10.9 yrs, stature 170.4 ± 6.8 cm and mass 66.5 ± 10.3 kg) volunteered to take part in the study. Triathletes were recruited from local triathlon clubs and all had a minimum of one-year experience racing and were familiar with the sprint distance format. Typical training volume ranged between 7-14 hours per week. Of the 10 triathletes, only 7 reported previous use of triathlon specific bicycles, with the remaining 3 using a standard road bike set up with clip on aero bars. Triathletes were informed both verbally and in writing of the test protocols and informed consent was gained. Ethical approval was granted by the University of Central Lancashire Ethics committee and was in accordance with the Declaration of Helsinki. Triathletes also completed a PARQ+ health screening questionnaire prior to taking part. Triathletes were instructed to refrain from training for 24 hours prior to testing, but to maintain their normal training schedules between test sessions. In addition, they were instructed to maintain their normal diet prior to testing and to consume a carbohydrate rich meal aiming for approximately 5 g/kg (~250-400 g) 2-3 hours prior to testing, as food and fluid intake would not be possible during exercise due to gas analysis.

Equipment and Conditions

The cycling phase was completed on a cycle ergometer fitted with an 8 strain gauge powermeter (SRM Scientific Ergometer, SRM, Jüllich, Germany). This has been previously validated by Jones et al. (1998). The running phase was completed on a motorized treadmill (Pulsar 3p, h/p/cosmos, Nußdorf, Germany). Seat Tube Angle (STA) on the cycle ergometer was altered for the two trials, with one condition using a more standard road bike STA of 73°, and the second condition using a steeper 81° STA more commonly found on triathlon specific bicycles. As the SRM ergometer had a fixed seat tube, the STA was adjusted by manipulating the saddles horizontal setback distance from the centre of the chainring to the centre of the

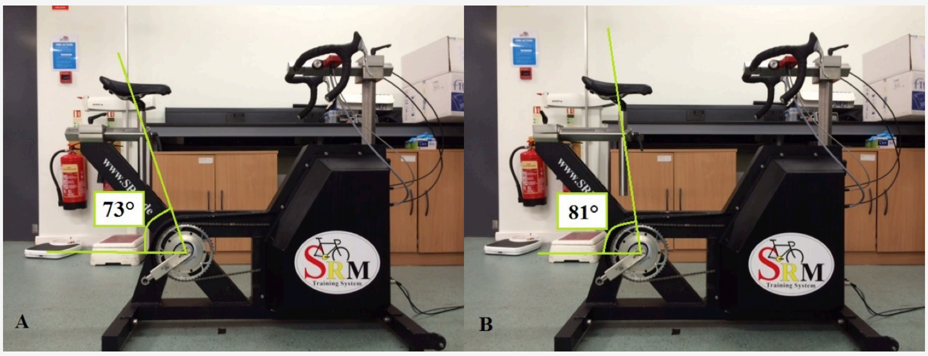

Figure 1. Illustration of the seat tube angles (STA) for (A) 73° and (B) 81°.

saddle, whilst saddle height was adjusted to the triathletes preference (Figure 1).

Prior to testing, triathletes completed a self-paced 10 minutes warm-up on both the cycle ergometer and the treadmill, so that they were familiarised with the equipment and the testing protocols. Triathletes completed the cycle and run sections of a simulated sprint distance triathlon (20 km cycle, 5 km run), using the 73° and 81° STA on two separate occasions. Each test session was separated by seven days and conducted at the same time of the day to minimise circadian influences and the order of testing was randomized. Though the triathletes were instructed to limit forward and backward movement on the saddle during the cycle, it was anticipated that some movement would occur, as it would out in the field. The triathletes were not informed which condition they were completing and were instructed to perform both cycle and run phases as fast as possible. Triathletes were provided with visual feedback of distance, power output, speed and cadence on the bike, as most would normally have this information during a typical race. Distance and speed on the treadmill was also provided. Cadence and workload were self-selected throughout both cycling trials. Following the 20 km cycle, a simulated triathlon transition took place. This involved dismounting the ergometer, changing into appropriate running footwear and mounting the treadmill to commence the 5 km self-paced run. Triathletes were instructed to change as quickly as possible. During the simulated transition, gas analysis was paused to allow the triathletes the opportunity to have a drink of water. Upon commencing the run, gas analysis was resumed. The speed on the treadmill was then set to an initial 8 km.h-1 and adjusted by the participant for the remaining duration of the run. The gradient of the treadmill was 1 % in order to simulate outdoor running (Jones and Doust, 1996).

Heart Rate (Beats.min^{-1}) was monitored using a Garmin Forerunner 305 watch (Garmin, USA) whilst oxygen uptake ($\dot{V}O2$; ml.kg-1.min-1) was measured using an automated online gas analyser (Metalyzer 3B, Cortex, Germany). The gas analyser had previously been validated by Meyer et al. (2001). Rates of Perceived Exertion (RPE) was determined using the Borg scale (6-20) (Borg, 1982). Mean cycling velocity (km.h-1), mean power output (W) and mean cadence (rpm) were also recorded throughout the bike section, using the SRM cycle ergometer. Stride frequency and stride length were monitored using a Garmin footpod, that attached to the laces of the triathletes' footwear and connected wirelessly to the Garmin Forerunner 305. Currently, the Garmin foot pod has yet to be scientifically validated in published research papers. However, Long (2011) reported the systems was valid when compared to video derived measures of stride frequency in his unpublished Master's thesis. Stride Frequency (Hz) was determined from running cadence (Step.min-1) divided by 60 s. Stride Length (m) was then calculated as Stride Length (m) = Velocity (m.s-1)/ Stride Frequency (Hz). All data with the exception of RPE were recorded continuously throughout testing. Following data collection all data were averaged for the duration of the trials and for each 1 km of the cycle and run phases to show temporal changes during each trial.

Statistical analysis

All statistical analyses were performed using SPSS Version 22 (SPSS Inc. Chicago, IL, USA). Data were confirmed to be normally distributed by means of a

Table 1. Physiological and kinematic responses (mean ± SD) during a simulated sprint triathlon cycle and run using 73° and 81° seat tube angles.

	Seat tube angle				
	73°	81°	*p*	ES	% change
Cycling (20 km)					
Time (min:s)	36:23 ± 2:52	36:21 ± 3:22	0.96	0.01	0.07
HR (Beats.min^{-1})	159 ± 18	158 ± 16	0.91	0.06	0.63
VO_2 (ml.kg.min^{-1})	41.4 ± 4.0	43.2 ± 9.1	0.52	0.26	4.17
Power (W)	162 ± 36	162 ± 34	0.99	0.00	-
Cadence (Revs.min^{-1})	96 ± 8	97 ± 8	0.69	0.13	1.04
Velocity (km.h^{-1})	33.2 ± 2.7	33.2 ± 2.9	0.92	0.00	-
RPE	14.6 ± 1.5	14.8 ± 1.7	0.79	0.12	1.36
Running (5 km)					
Time (min:s)	27:59 ± 3:18	27:10 ± 3:09	0.006*	0.25	1.78
HR (Beats.min^{-1})	169 ± 16	173 ± 16	0.10	0.25	2.32
VO_2 (ml.kg.min^{-1})	45.5 ± 5.2	47.9 ± 9.4	0.30	0.32	5.02
Velocity (m.s^{-1})	3.04 ± 0.37	3.13 ± 0.37	0.007*	024	2.88
Stride Frequency (Hz)	1.47 ± 0.07	1.45 ± 0.06	0.36	0.31	1.37
Stride Length (m)	2.12 ± 0.27	2.20 ± 0.26	0.007*	0.30	3.64
RPE	15.6 ± 1.8	15.9 ± 1.6	0.34	0.07	1.89
Total Time (Cycle+Run) (min:s)	64:23 ± 5:10	63:31 ± 6:08*	0.042	0.15	0.97

* indicates significantly different to 73° STA (p<.05).

Shapiro–Wilk test. Paired t-tests were used to determine any significant difference between variables during the cycle and run phases for the 73° and 81° STA conditions. Where significant differences were found, effect size (ES) was determined using the Cohen's d method (Cohen 1988), where values <0.2 were considered small, ~0.5 as moderate and >0.8 large. Statistical significance was set at the level of $p \leq .05$. All values are expressed as the mean ± standard deviation.

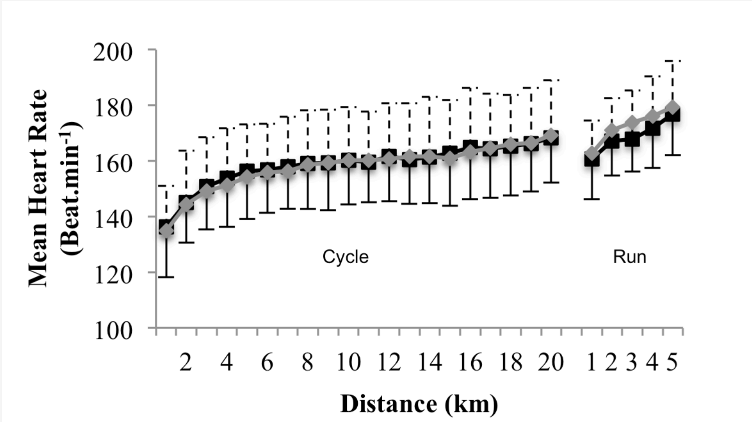

Figure 2. Temporal responses (mean ± SD) in HR (Beats.min^{-1}) during the 20 km cycle and 5 km run using a 73° (■) and 81° (♦) seat tube angle for each 1 km interval.

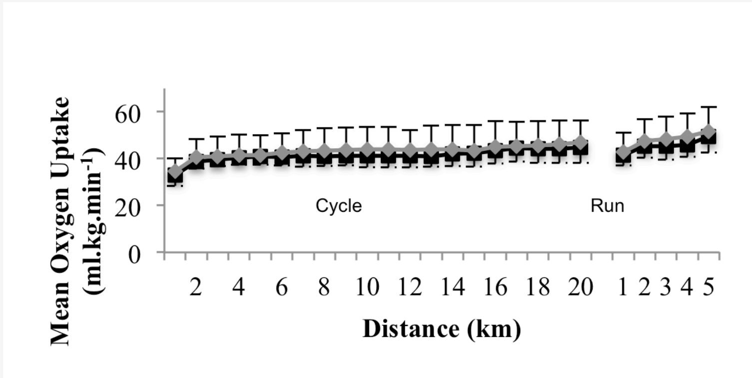

Figure 3. Temporal responses (mean ± SD) in oxygen uptake (ml.kg.min^{-1}) during the 20 km cycle and 5 km run using a 73° (■) and 81° (♦) seat tube angle for each 1 km interval.

Results

No significant differences were found during the cycling phase between the two conditions for any of the recorded variables. However, 5 km run performance was significantly faster following cycling with a steeper 81° STA when compared with the 73° STA ($p=.006$; ES=0.25). Overall cycle-run performance was also significantly faster following the 81° STA when compared with the 73° condition ($p=.042$; ES=0.15). Mean data for the cycle and run phases are presented in Table 1.

Heart rate and $\dot{V}O_2$ response gradually increased over the duration of the 20 km cycle and 5 km run phases (Figures 2 and 3). However, no significant differences were observed during cycling trials for these or any other variables between the two seat tube conditions. Similarly, no significant differences in HR, $\dot{V}O_2$, SF or RPE were found between conditions during the run phase. However, running velocity was significantly faster following use of the 81° STA when compared with the 73° condition ($p=.007$; ES=0.24). Stride length was also significantly greater following cycling with the 81° STA ($p=.007$; ES=0.30).

Discussion

The aim of this study was to investigate the effects of two different bicycle seat tube angles on running performance following a simulated sprint triathlon cycle-run transition. Key findings indicate that a steeper 81° STA did significantly improve subsequent run performance, with 7 of the 10 triathletes running quicker times. Likewise, overall cycle+run time was also significantly improved when compared with a more typical 73° STA found on road bicycles following a self-paced all-out cycle, with 6 of the 10 triathletes recording a quicker time. Additionally, running velocity and SL were also significantly improved in 7 of the 10 triathletes following cycling with the steeper STA. However, SF and RPE were not significantly altered between conditions.

Influence on cycling performance

As observed in Figures 2 and 3, no differences were found in $\dot{V}O_2$ and HR responses for the cycle between conditions, further supporting the findings of Jackson et al. (2008) and Garside and Doran (2000). This may be due to the familiarity of cycling in a more extreme position with the steeper 81° STA by several triathletes. However, mean 20 km cycle time varied by only around 2 seconds between the normal 73° and steeper 81° STA conditions in the present study, while Garside and Doran (2000) observed approximately a 1 minute improvement over a 40 km cycle when using a steeper STA compared to a normal STA, despite no significant differences in physiological responses. The differences observed between the present study and Garside and Doran (2000) may be due in part to methodological differences and frame familiarity. Of the 10 triathletes in the present study, 7 were accustomed to using triathlon specific bicycles with steeper STA's, whereas in the Garside and Doran study most were more familiar with riding bicycles with shallower, normal STA's. This may in part explain the smaller improvements observed in the present study, as those familiar with steeper STA would have smaller scope for improvements. In addition, as those who were familiar with riding with steeper frame geometries most likely also rode bicycles with 'normal' STA, the physiological cost of riding with different geometries may have been somewhat attenuated, as supported by the data presented in Figures 2 and 3. Interestingly, the 3 triathletes who were unfamiliar with steeper STA's all reported slower times during the cycle phase when riding with the steeper STA and small but none significant increases in HR and $\dot{V}O_2$.

In contrast, Garside and Doran's triathletes improved cycling performance despite their lack of familiarity with steeper STA's. However, Garside and Doran allude to the use of a constant 70 % $\dot{V}$O2peak intensity during the cycle leg as being a limitation of their study. This is because $\dot{V}O_2$peak was assessed on a cycle ergometer with a normal 73° STA. Had the steeper 81° STA been used, $\dot{V}O_2$peak and peak power may have been higher. Therefore, riding at 70 % $\dot{V}$O2peak, as derived from the normal STA trial, during the steeper STA trials may have resulted in a lower percentage of $\dot{V}O_2$peak in reality. This may explain the small metabolic differences between studies. In addition, power output would have been higher for a lower metabolic cost in the Garside and Doran study, therefore leading to improved cycling economy and performance, despite triathletes not being adapted to the steeper STA. It should also be noted that though triathletes in the present study performance at a higher relative power output, those in the Garside and Doran study still performed the cycle leg at a higher absolute power output, which again would contribute to the greater improvements observed. These findings suggest that a period of adaptation between STA's may be necessary to see improvements in performance when using a self-paced maximal effort.

Influence on running performance

Similar to the findings of the cycle section, there was no significant difference in $\dot{V}O_2$ responses between the STA conditions during the running phase. Jackson et al. (2008) also found no significant difference in running $\dot{V}$O2 between comparable conditions. In addition, HR responses were also not significantly different in the present study, supporting the previous findings of Garside and Doran (2000) who found that HR was higher in the first 5km of a 10 km run following the 81° condition, though not significantly. All triathletes in the present study saw increases in HR of ~ 2% with the 81° STA. This may be attributed to possible increases in muscle activation following cycling with the steeper STA. However, running time was shorter, SL larger and running velocity higher, with all reaching a level of significance following cycling with the 81° STA, compared with the 73° STA. These findings agree with those of Garside and Doran (2000) who found significantly faster run times with an increased STA, though over 10 km, with the greatest difference being observed in the first 5 km. They proposed this was due to triathletes being able to reach peak running velocity sooner. The present study looked specifically at a 5 km sprint triathlon run performance, as no studies have previously looked at this distance, particularly following a self-paced cycling effort. Whilst time, running velocity and SL were significantly improved following cycling with an 81° STA in the present study, improvements were not as great as those reported over the first 5 km by Garside and Doran (2000). This is possibly due to the greater familiarity with riding triathlon specific frames by the triathletes in the present study, unlike those in the Garside and Doran study, and also due to the shorter distances covered.

In addition, increasing the STA has also been shown to increase plantarflexion and reduce knee range of motion (Heil et al 1995), which may have subsequently aided running mechanics for the majority of triathletes in the present study. Silder et al (2011) reported that running necessitated longer musculotendon lengths in the hips, knee extensors and plantar flexors when compared to cycling, though changes in STA alone did not significantly alter muscle lengths during cycling. However, Ricard et al (2006) reported reduced bicep femoris activation in the 82° STA condition, which may help reduce hamstring tightness following the cycle leg of a triathlon, and therefore allow increases in SL. Bisi et al. (2012) also reported differing muscle activation patterns between triathletes during cycling with different STA's. Though not to a level of significance, they noted a trend for reduced activation of the gastrocnemius and biceps femoris when riding with a steeper STA in 60 % of the triathletes. Previous research by Heiden and Burnett (2003) also hypothesised that such reduction in gastrocnemius and biceps femoris activity could lead to a longer and more efficient SL. The results of the present study and previous research suggest it is the ability to reach optimum SL that is the greatest indicator of running performance in sprint triathlon and that increasing STA may be beneficial to achieving this.

Garside and Doran (2000) did not state the effect size of their results. However, in the present study, running velocity and time showed only low to moderate effect sizes (0.24 and 0.25, respectively) which may again be partly attributed to an element of familiarity with riding triathlon specific frame geometries by some triathletes, yet improvements were still ~2-3 %. Whilst the present study showed statistically significant improvements in running time, velocity and SL, 3 of the triathletes didn't report improvements in these variables. Interestingly, the three that didn't improve were the ones who reported being unfamiliar with triathlon specific frame geometries. For these triathletes' SL decreased on average 0.08 m following the cycle phase with the 81° STA, whilst SF was also decreased by a mean of 0.07 Hz and run time increased by an average of 25 s. Rate of perceived exertion did not differ between the 73° and steep 81° conditions. This suggests that although running performance differed, triathletes felt that they had exerted themselves equally in both conditions and that the change in STA did not have any influence on their perceived effort.

Whilst the observed improvements were statistically significant, in practical terms they may be considered small and possibly less impactful on eventual finishing position at an amateur level, where time differences between athletes tend to be bigger than at elite competition. However, such improvements at elite level could present a meaningful difference to finishing position. Despite this, the results of the present study still indicate that significant improvements in performance are to be gained by using a steeper STA during the cycling leg, even for amateur athletes.

Conclusions

The main findings of this study were that alterations in STA had a small to moderate, effect on sprint triathlon cycling performance. However, subsequent running performances were significantly improved following prior cycling with a steeper 81° STA, when compared with a shallower 73° STA. These results would indicate that a more aggressive/steeper seat tube angle can help improve running performance following a 'self-paced' effort during the cycling section in moderately trained triathletes. This is mostly likely due to increases in SL as a result of altered biomechanics and running kinematic and how quickly athletes can reach peak running velocity.

Practical application

The present study indicates that riding a bicycle with a steeper STA may prove advantageous to overall performance by altering the athletes' biomechanics more favourably for the subsequent run leg. Though the magnitude of the differences reported were small to moderate, they still present meaningful improvements. As races are often decided by only a few seconds, particularly at elite level, improvements in the order of 3-4 % should not be understated. Therefore, riders and coaches should consider the use of bicycle frames with steeper STA's or altering the saddle position and height to achieve a similar effect in order to maximise sprint triathlon running performance.

Limitations and future directions

It may be seen as a limitation to the present study to use triathletes already familiar with riding steeper seat tube angled bicycles, and the improvements observed were smaller in magnitude than those previously reported elsewhere. However, as several triathletes in the study were not habituated to these geometries and did not improve performance, the results indicate that a period of conditioning may be required before the benefits of riding triathlon specific frames on subsequent running performance are seen. In addition, though the present study adopted a self-paced strategy during the cycle leg, the power outputs observed were relatively low and could further be seen as a limitation to the study. However, the findings do indicate the possible benefits of changing frame geometry for amateur athletes. It would be of interest to repeat the study with elite or highly trained amateur triathletes to determine whether the same benefits would be evident in those populations also. In addition, like most previous studies, the present study did not take into account the effect of the swim leg on overall performance. Therefore, future research should seek to establish the swim legs influence on subsequent cycle and run phases.

Acknowledgements

The authors would like to thank the triathletes for their time to take part in this study and the laboratory technicians for their support. There were no conflicts of interest relevant to this manuscript.

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