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TITLE

Performance determinants of fixed gear cycling during criteriums

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1 **Performance determinants of fixed gear cycling during criteriums**

2

3 **Abstract**

4 Nowadays, fixed gear competitions on outdoor circuits such as criteriums are regularly
5 organized worldwide. To date, no study has investigated this alternative form of cycling. The
6 purpose of the present study was to examine fixed gear performance indexes, and to
7 characterize physiological determinants of fixed gear cyclists. This study was carried out in
8 two parts. Part1 (n = 36) examined correlations between performance indexes obtained during
9 a real fixed gear criterium (time trial, fastest laps, averaged lap time during races, fatigue
10 indexes) and during a sprint track time trial. Part2 (n = 9) examined correlations between the
11 recorded performance indexes and some aerobic and anaerobic performance outputs (VO_{2max} ,
12 maximal aerobic power, knee extensor and knee flexor maximal voluntary torque, vertical
13 jump height, and performance during a modified Wingate test). Results from Part1 indicated
14 significant correlations between fixed gear final performance (i.e. average lap time during the
15 finals) and single lap time (time trial, fastest lap during races and sprint track time trial). In
16 addition, results from Part2 revealed significant correlations between fixed gear performance
17 and aerobic indicators (VO_{2max} and maximal aerobic power). However, no significant
18 relationship was obtained between fixed gear cycling and anaerobic qualities such as strength.
19 Similarly to traditional cycling disciplines, we concluded that fixed gear cycling is mainly
20 limited by aerobic capacity, particularly criteriums final performance. However, specific skills
21 including technical competency should be considered.

22

23 **Keywords:** Strength; aerobic fitness; competition

24 **Introduction**

25 Fixed gear is a relatively new cycling discipline consisting of riding track bicycles outdoors
26 on roads, streets or circuits. Bicycles are brakeless, without freewheel, relying on one speed
27 only. Without any official instances, numerous competitions are organized worldwide. One
28 competition format is the criterium, which takes place in short closed circuits (< 2 km) with
29 several turns, accelerations, and decelerations. Usually, competitions are composed of
30 different steps such as qualifications (one lap), heats (< 20 minutes) and finals (> 40 minutes).

31 According to the competition format, the aerobic system should play a major role in fixed
32 gear performance (Craig & Norton, 2001). Indeed, cycling performance < 90 minutes was
33 shown to be strongly correlated to the maximum power output, and power at lactate threshold
34 (Bentley, McNaughton, Thompson, Vleck, & Batterham, 2001). Anaerobic power was also
35 found to be an important factor in cycling performance (Baron, 2001; Inoue, Sá Filho, Mello,
36 & Santos, 2012). As a consequence, it could be speculated that the energy used during fixed
37 gear criteriums would be mainly derived from both aerobic and lactic anaerobic systems.

38 However, fixed gear cycling specificity and the competition format require: (i) pedalling
39 constantly, (ii) regularly braking bicycles via isometric or eccentric muscle actions, while
40 blocking or slowing down the rear wheel, respectively and (iii) regularly re-accelerating that
41 requires other specific physical attributes such as muscle strength. Sprint cycling, for instance,
42 was shown to be strongly associated to maximum and explosive strength (Stone et al., 2004).
43 More specifically, high eccentric strength levels may characterise fixed gear riders who
44 frequently need to brake the bicycle. These frequent actions could influence muscle fatigue
45 (Garrandes, Colson, Pensini, & Legros, 2007). Finally, one should acknowledge that cyclists
46 require excellent technical and tactical skills to control and stabilize the bicycle during
47 frequent direction changes.

48 However, to date no study investigated fixed gear cycling. Consequently, the aim of this study
49 was to examine fixed gear performance indexes and to describe the physiological
50 determinants of fixed gear cyclists. According to the multifactorial nature of fixed gear
51 cycling, we hypothesized that performance requires both strength (to decelerate and accelerate
52 bicycle for direction changes) and anaerobic and aerobic attributes (for long-duration
53 cycling). For that purpose, we tested potential relationships between performance indexes
54 obtained during a real fixed gear criterium, measurements of maximal and explosive strength,
55 anaerobic power, and aerobic capacity.

56

57 **Methods**

58 *Study overview*

59 This study was divided into two distinct parts. Part1 consisted in analysing results from a
60 fixed gear competition, namely ‘the National Moutarde Crit #5’. Part2 consisted in analysing
61 results from the same fixed gear criterium followed by aerobic and anaerobic physical
62 performance measurements. Riders were compared as a function of their results during the
63 main race day, and correlations were made to establish performance determinants. This study
64 was conducted according to the declaration of Helsinki, and approval for the project was
65 obtained from the local Institutional Review Board.

66

67 *Participants*

68 Part1 involved the analysis of publicly available results of a fixed gear criterium. Accordingly
69 no consent was required. Data were retrieved from the online competition datasheet and from
70 direct contact with the race director. Based on the competition results, values were extracted

71 from the 39 riders that competed during the two events (see below). Twenty-two were in the
72 superfinal, 14 in final A, and three in final B. Due to huge differences between riders, values
73 from the riders in final B were excluded from analysis. A total of 36 riders were considered.

74 Part2 included nine-male fixed gear riders. Fixed gear experience was depicted using a short
75 survey to determine history (i.e. years of practice), fixed gear bicycles use (i.e. exclusive,
76 recurrent or occasional with practice > 75% of all cycling types, ranging from 50 to 75% or <
77 50%, respectively), and estimated kilometres per week. Participants were all free of injury
78 within the three months preceding the experiment. All read and signed a written informed
79 consent document outlining the procedures of the experiment. This experiment was conducted
80 during three different sessions. The first session consisted in the fixed gear competition. After
81 at least one-week recovery and during the following month, individuals were tested in two
82 separate occasions. One session was dedicated to a maximal aerobic power test. The other
83 session was used to evaluate power during maximal vertical jumps, strength of the leg
84 extensor and flexor muscles, and a modified anaerobic cycling power test in that order. The
85 two tests sessions were randomized with at least one week in-between. Participants were
86 requested to abstain from any fatiguing exercise, and to have similar food/drink intake during
87 the 24h before each testing session.

88

89 *Fixed gear competition (Part1 and Part2)*

90 The main fixed gear competition, ‘the National Moutarde Crit #5’ took place in Dijon on
91 September the 9th 2017. This competition included ~180 males from 15 different countries
92 (women races were also performed but not considered here) involving top-class cyclists. The
93 track was flat, 980 m long with eight turns (Figure 1). The competition included three
94 different stages: 1. time trial, 2. heats and, 3. finals. All stages were performed after a free

95 warm-up generally including cycling on a roller (lasting various durations), and cycling on the
96 competition track during 10 to 15 min. Time trial was performed individually. Riders had to
97 perform one lap as fast as possible starting from a stationary position with feet set on the
98 pedals. Cyclists were held by one of the competition organizers. Heats consisted in five laps
99 performed by groups of 40 riders. The position on the starting grid was dependent on the time
100 trial performance. Finals and starting positions during finals were dependent on the
101 performance during heats. Lap numbers were different according to the finals considered (28,
102 22 and 18 laps for the superfinal, final A and final B, respectively). During such a
103 competition, riders were stopped when the leader of the race was close to them (i.e. no late lap
104 was allowed). At least 90 minutes rest was allowed between each stage of this competition.
105 Riders used their own bicycles (track bikes) with no brakes. They were free to choose their
106 own development ratio (generally 48 x 14). From this competition, the time trial, the time of
107 the fastest lap for each stage, the average lap time (total time divided by lap numbers) during
108 heats and finals, and lap numbers during finals were extracted. Average lap time was used for
109 analysis due to the fact that riders had different lap numbers. Also, to provide a fatigue index
110 (i.e. decline in cycling velocity over a race) the percentage difference between the fastest lap
111 and average lap time was calculated during heats and finals.

112 The day after this main event, some riders participated in a second competition on an outdoor
113 bike track (250 m). It consisted in a 1000 m time trial. Riders first performed a free warm-up
114 generally including cycling on the track and then on a roller (with various durations). Time
115 trial was performed individually and riders had to perform four laps as fast as possible starting
116 still with feet set on the pedals. Cyclists were held by one of the competition organizers. This
117 event was used for Part1 study. From this time trial, the fastest lap (250 m), the total time to
118 achieve the four laps (1000 m) and the fatigue index were retained.

119 During both events, time was measured electronically (Chronolec Prottime, Norges-la-ville,

120 France) using sensors placed on the starting/finishing line and on the bike. Time was
121 measured at a 1,000 Hz sampling frequency.

122

123 *Physical performance measurements for Part2*

124 At least one week after the competition, participants came to the laboratory for two different
125 sessions randomly assigned. One session was designed to test maximal aerobic power. During
126 this visit, anthropometric data were first measured. Body fat was estimated using a
127 bioelectrical impedance analysis system (TBF 410GS, Tokyo, Japan). Then, participants were
128 equipped with a heart rate monitor (Polar Electro Oy, Finland) and with a gas exchange
129 measurement system (Cosmed K5, Roma, Italy). Afterwards, the maximal aerobic power test
130 was performed on an indoor ergocycle (CyclOps 400 Pro equipped with PowerTap, Madison,
131 USA) with saddle and handlebar settings individually adjusted. The incremental maximal
132 aerobic test started at a power of 100 W during two minutes and increased with 25 W
133 increments every two minutes. Tests were interrupted when participants were unable to
134 maintain the requested cycling rate. The pedalling rate ranged between 80 and 90. Maximal
135 aerobic power was calculated according to the duration of the last step. The maximal heart
136 rate value was recorded during the test, and the maximal VO_2 value ($\text{VO}_{2\text{max}}$) was calculated
137 as the average over the last 30 seconds of the test.

138 During the second test session, vertical jump height, maximal knee extension and flexion
139 torque and anaerobic power using a modified Wingate test were measured. A short warm-up
140 was first performed. It consisted in submaximal cycling during 10 minutes at a 150 W,
141 submaximal vertical jumps and submaximal knee flexion and extension performed on an
142 isokinetic dynamometer (submaximal concentric and eccentric knee extension, knee flexion
143 with increasing intensity). After five minutes rest, vertical jump height was measured during a

144 counter movement jump using the Optojump system (Optojump, Microgate, Bolzano, Italy).
145 The counter movement jump was performed starting from a standing position, then squatting
146 down to a 90° knee flexion angle and then extending the knees in one continuous movement.
147 Arms were free to move. Subjects were asked to jump as high as they could for three times,
148 and the best performance was retained. After five minutes rest, participants were tested for the
149 right knee extension and knee flexion torque, on an isokinetic dynamometer (Biodex 4
150 Quickset, Biodex Corporation, Shirley, NY, USA). Participants were seated with the hip at
151 100°. Straps were applied tightly across the chest, pelvis and midthigh to minimize hip and
152 thigh motions during contractions. The leg was secured to the dynamometer apparatus and the
153 dynamometer rotation axis was aligned to the knee joint rotation axis. Arms were always
154 positioned across the chest with each hand clasping the opposite shoulder. Measurements
155 consisted in a series of five consecutive concentric knee extensions and flexions from 90° of
156 flexion to full extension (0°). After one-minute rest, a series of five eccentric knee extensions
157 and flexions was achieved. Contractions were performed at a 60 °.s⁻¹ angular velocity. The
158 peak torque (gravity corrected) was measured directly from the Biodex software. The best
159 trial was retained for analysis. After 5 minutes rest, participants performed a modified
160 anaerobic test according to the ergocycle possibilities (CyclOps 400 Pro equipped with
161 PowerTap, Madison, USA). It consisted in pedalling as fast as participants could during 30
162 seconds. A constant 750 W power was used for all participants. Performance was quantified
163 according to pedalling frequency decreasing that corresponded to the percentage decrement
164 between the first five seconds and last five seconds.

165

166 *Statistical analyses*

167 Data are presented as mean values ± standard deviation (SD). For Part1, cycling performance

168 outcomes were compared between riders from the different finals using a Student t-test.
169 Standard parametric regressions were achieved to compare the degree of association between
170 all outcomes. It involved all riders together, then riders from superfinal or final A, separately.
171 For Part2, cycling performance during the race was analysed using parametric statistics: a
172 repeated analysis of variances (ANOVA) for the fastest lap performance and a Student t-test
173 for average lap time and fatigue index. Standard parametric regressions were also achieved to
174 compare the degree of association between all outcomes. For correlations analyses from Part1
175 and Part2, time trial performance and average lap time during finals were considered as the
176 most important performance indicators. Statistical analyses were conducted using Statistica
177 v8.0 (StatSoft Inc., Tulsa, USA). $P < 0.05$ was set as the level of statistical significance for all
178 tests.

179

180 **Results**

181 *Part1*

182 Significant differences ($P < 0.05$) were obtained between cyclists from the superfinal ($n = 22$)
183 and final A ($n = 14$) for the 250m and 1000m track, race time trial, fastest lap and average lap
184 time during heats and finals (Table 1). Correlations analyses indicated significant associations
185 (Table 2) between time trial and track performance (250m and 1000m) as well as race
186 performance (fastest lap and average lap during heats and finals). The average lap time during
187 finals was significantly correlated with track performance (250m and 1000m) as well as race
188 time trial, fastest lap and average lap during heats.

189 When considering riders from the superfinal, correlations were only obtained between race
190 time trial and the final's fastest lap ($r = 0.559$, $P = 0.007$) and average performance ($r = 0.584$,
191 $P = 0.004$). The average lap time during the final was associated with race time trial ($r =$

192 0.584, $P = 0.004$), the fastest lap ($r = 0.891$, $P < 0.001$) and average lap time during heats ($r =$
193 0.801 , $P < 0.001$). When considering riders from final A, correlations were obtained between
194 time trial and average lap time during heats ($r = 0.553$, $P = 0.04$) and between average lap
195 time during the final with average lap time during heats, heats and final fatigue indexes ($r =$
196 0.639 , $P = 0.02$; $r = 0.556$, $P = 0.039$; $r = 0.715$, $P = 0.004$; respectively).

197

198 *Part2*

199 All cyclists included in the study performed all stages of the criterium. From the nine riders,
200 five were in the superfinal, two in final A and two in final B. Anthropometric characteristics,
201 cycling performance during the criterium race and physical performance are presented in
202 Table 3. The fastest lap was significantly slower during the time trial than during heats and
203 finals ($P < 0.001$). The average lap time was significantly slower during heats as compared to
204 finals ($P < 0.05$). Finally, we observed a slightly greater fatigue index during heats as
205 compared to finals that did not reach significance ($P = 0.071$).

206 Correlation analyses only revealed few associations between variables (Table 2). Time trial
207 performance was associated with the fastest lap during finals, maximal aerobic power and
208 VO_{2max} . The average lap time during finals was associated with the fastest lap during heats
209 and fatigue index during finals.

210

211 **Discussion**

212 The present study was conducted to describe fixed gear performance during criteriums
213 performed on outdoor closed circuits, and to depict physiological determinants of fixed gear
214 cyclists. Results did not confirm our initial hypothesis because competition performance was

215 mainly related to aerobic attributes but not to strength parameters. Fixed gear cycling,
216 therefore, presents numerous similarities to common cycling disciplines but with specificities
217 that should be considered during training.

218 The first part of our study aimed at analysing results from a fixed gear criterium in
219 combination with a track time trial. Our main findings revealed that fixed gear performance
220 (i.e. average lap time during finals) was related to time trial performance and fastest lap time.
221 In other words, the final performance (> 40 min total duration) is highly correlated with
222 cycling efforts shorter than 2 min. The second part, which attempted to determine
223 physiological characteristics (including anaerobic and aerobic attributes) of fixed gear riders,
224 confirmed Part1 results. Indeed, significant correlations were obtained between circuit time
225 trial and aerobic attributes (maximal aerobic power and VO_{2max}) and the averaged
226 performance during finals was correlated with fatigue index during finals.

227 At first these findings are surprising but are in general agreement with previous data (Black,
228 Durant, Jones, & Vanhatalo, 2014; Craig & Norton, 2001; Dantas, Pereira, & Nakamura,
229 2015; Støren, Ulevåg, Larsen, Støa, & Helgerud, 2013). Firstly, while considering the
230 contribution of the different energy systems, short distance track events have been shown to
231 predominantly involve the aerobic system. For example, the aerobic system was estimated to
232 contribute to half of the power production during a 1000 m track time trial (Craig & Norton,
233 2001). Certainly, increasing the competition duration increases the contribution of the aerobic
234 system until > 95% for an hour time trial (Craig & Norton, 2001). Similarly, the aerobic
235 system was shown to be predominantly involved in BMX performance (multiple very short
236 races) (Louis et al., 2012). Secondly, other authors concluded that short duration events could
237 predict endurance performance distance (Black et al., 2014; Dantas et al., 2015). For instance,
238 a 3-min all-out test has been validated to anticipate cycling performance longer than 20
239 minutes (Black et al., 2014).

240 When considering groups (i.e. cyclists involved in superfinal or final A), conclusions were
241 slightly different. Performance for cyclists from the superfinal was related to time trial and
242 fastest lap. In contrast, correlations for cyclists from final A were mainly obtained with heats
243 performance and some fatigue indexes. Taken together, these results would indicate that
244 fatigue limits the performance more with the decreasing level of the cyclists. The correlation
245 between the average lap time during finals and fatigue index during Part2 confirmed this
246 assumption. The greater the lap time (i.e. slower lap) the greater the fatigue. Different
247 hypotheses related to cyclists' level could explain such finding.

248 A first explanation could be related to pacing (Skorski & Abbiss, 2017). Authors previously
249 concluded that pacing during track cycling was dependent on athletes' performance level
250 (Wilberg & Pratt, 1988). Slow athletes usually started too fast relative to their performance
251 level and, as a consequence, developed greater fatigue. In contrast, others concluded on top-
252 level track athletes (world championship level) that pacing was similar between slow and fast
253 cyclists (Corbett, 2009). For these top-level athletes, the final performance was mainly related
254 to the first lap of a 1000 m. During longer events, the influence of training status on pacing is
255 unclear. For example, some authors obtained similar pacing strategies between different levels
256 of trained mountain bike cyclists (Viana, Pires, Inoue, & Santos, 2018). However, this
257 conclusion was obtained using a simulated laboratory design, i.e. excluding any packed race.
258 Another recent study, considering cyclo-cross world championships, demonstrated different
259 pacing strategies during races as a function of cyclists position (top-placed vs. bottom-placed
260 cyclists) (Bossi, O'Grady, Ebreo, Passfield, & Hopker, 2017). Authors showed that top-
261 athletes could slightly decrease intensity in the middle of the race as compared to others. As a
262 consequence, the fatigue effect on performance is reduced. Although not quantified here,
263 pacing strategy could have been different during the fixed gear criterium finals according to
264 cyclists' level. However, one should bear in mind that during such an event, tactics also

265 account for these pacing strategies. Moreover, other factors such as aerodynamic draft should
266 be considered (Peterman, Lim, Ignatz, Edwards, & Byrnes, 2015; Spence, Thurman, Maher,
267 & Wilson, 2012). The lower lap time during heats or finals as compared to the initial time trial
268 partly confirmed this phenomenon.

269 Interestingly, when considering groups separately, no significant correlation was obtained
270 between track time trial and time trial on the race circuit. This lack of dependency could be
271 attributed to technical skills. Indeed, high-technical and tactical skills as well as high-risk
272 tolerance are required (Figure 1), similarly to other cycling disciplines such as off-road biking
273 (Impellizzeri & Marcora, 2007; Mastroianni, Zupan, Chuba, Berger, & Wile, 2000; Miller,
274 Macdermid, Fink, & Stannard, 2017). Moreover, fixed gear cycling requires specific skills to
275 ride packed in a closed circuit minimising the loss of time during direction changes. Finally, a
276 lower cyclists level promotes mental fatigue (Martin et al., 2016). Obviously technical skills
277 or decision-makings, and therefore performance, are impaired over time.

278 In contrast with our initial hypothesis, fixed gear performance was not related to strength or
279 lactic anaerobic power. Such result is surprising because fixed gear cycling requires numerous
280 eccentric contractions to slow down bicycles as well as concentric force for re-acceleration
281 but it confirmed previous data obtained on road cyclists (Støren et al., 2013). Considering the
282 methodology used, our data are obtained using a small sample size meaning that additional
283 measurements are required. A control group, for example including road cyclists, would have
284 been of interest for comparison. Moreover, maximal strength was measured here in fresh
285 conditions. Because fixed gear performance during criteriums is long lasting, considering
286 strength measurements under fatigue state could be more interesting to understand this
287 cycling discipline. Also, eccentric strength was evaluated on an ergometer but eccentric
288 strength is produced using a specific action for braking bicycles on the bike. A more specific
289 assessment should be more accurate.

290 The specificity of fixed gear cycling is related to the repeated eccentric contractions. It is well
291 known that eccentric solicitation necessitates lower muscle activation levels than concentric
292 contractions (Babault, Pousson, Ballay, & Van Hoecke, 2001). It has also been shown that
293 eccentric pedalling requires reduced neuromuscular activation than concentric and could
294 lower metabolic cost (Peñailillo, Blazevich, & Nosaka, 2017). Despite a different cycling
295 pattern between the preceding study and fixed gear cycling, one can speculate that repeating
296 eccentric contractions during fixed gear cycling would produce different neuromuscular and
297 cardiovascular behaviours. The direct consequence is related to fatigue origins. Indeed, it was
298 previously demonstrated that specific fatigue as a result of eccentric conditions is reduced in
299 eccentric trained athletes (Michaut, Babault, & Pousson, 2004). Also, some authors observed
300 that road cyclists show greater fatigue in eccentric conditions as compared to triathletes
301 (Garrandes, Colson, Pensini, & Legros, 2007). Triathletes are indeed used to such contraction
302 mode. Moreover, while investigating power and endurance-trained athletes, the same authors
303 (Garrandes, Colson, Pensini, Seynnes, & Legros, 2007) suggested that the neuromuscular
304 fatigue profile is dependent on training background. Specific training (and more particularly
305 in eccentric conditions) could diminish eccentric-induced fatigue and also favour the repeated
306 bout effect that could protect the neuromuscular system from fatigue and muscle damage. To
307 investigate the different neuromuscular behaviour and fatigue during cycling, it could be
308 interesting to determine differences between the physiological demand while cycling fixed
309 gear bikes and road bikes, for example using electromyography. The only electromyographic
310 studies considering some fixed gear bicycles were performed during sprint track cycling
311 (Watanabe et al., 2016). However, none has considered fixed gear cycling on closed circuits
312 with repeated deceleration and acceleration phases.

313 The potential specific fatigue associated with fixed gear cycling is not only related to the
314 repeated eccentric contractions. It could also be related to cycling cadences. Fixed gear

315 bicycles have a unique gear (adapted to cyclists and to race circuits). As a consequence,
316 cycling on a closed circuit with numerous direction changes requires varying pedalling rates
317 (cadences). During road cycling, it is well known that cyclists use a preferred cadence that is
318 usually different from the cadence that minimize the pedalling energy cost (the so-called
319 optimal cadence) (Gregor, Broker, & Ryan, 1991). The preferred cadence has been shown to
320 be related with endurance training status of cyclists while the optimal cadence was related to
321 strength capacities (Bieuzen, Vercruyssen, Hausswirth, & Brisswalter, 2007). The different
322 cadences used during fixed gear cycling, in association with the different resistances would
323 alter the neuromuscular activation pattern (Katona, Pilissy, Tihanyi, & Laczkó, 2014) or
324 cardiovascular drift (Kounalakis & Geladas, 2012) and consequently neuromuscular fatigue.
325 Specific training with different cadences are therefore needed because cycling training
326 adaptations seem to be cadence specific (Paton, Hopkins, & Cook, 2009; Whitty, Murphy,
327 Coutts, & Watsford, 2016). Previous authors concluded that the optimal cadence was related
328 to strength capacities (Bieuzen et al., 2007), therefore, we can speculate that fixed gear
329 development ratio could be related to fatigue resistance strength capacities.

330 Taken together, the results of the present study indicate that fixed gear cycling is similar to
331 other cycling disciplines. Cycling performance during fixed gear criteriums (which are
332 performed on closed circuits with numerous direction changes) is predominantly dependent
333 on the aerobic system. Albeit this type of cycling involved several decelerations and
334 accelerations using eccentric and concentric muscle actions, strength, as measured in this
335 study, is not a key factor. More particularly, one can argue that fixed gear cycling resemble
336 cyclo-cross or mountain-bike cycling due to some technical skills similarities. However, some
337 specific fixed gear cycling actions that require specific training should be considered.

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449 Figure 1: A. Satellite view of the National Moutarde Crit #5 circuit. B. Picture illustrating two
450 consecutive direction changes during the Criterium (© 2017 Michel Udny, with permission).