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Effects of Race-day Weather and Topographic Severity on Performance in Duathlon Races: Inter-race Comparisons from the Pacific Northwest

Abstract

We examined the influence of race-day weather and topographic variability of courses on performance of male athletes in a series of duathlon (run-bike-run) competitions held in Oregon and British Columbia. Subtraction matrices and ANOVA techniques are used to identify unique races and performance patterns among races. Enhanced or reduced performance in the overall race and individual race segments is then related to topographic severity of the courses and environmental conditions encountered by the athletes during the races. Results suggest that variations in race-day weather conditions have only a minor impact on performance. Topographic severity of individual race segments and the cumulative effects of topographically difficult races are the dominant controls of performance. Results from this study offer a scientific basis for race directors and organizers to develop a range of duathlon courses that can significantly enhance or reduce performance.

Introduction

The Pacific Northwest region of the United States and Canada has seen an increase in multi-sport competitions from the late-1980's until the present. Duathlon, the most recent addition, provides a new alternative for multi-sport enthusiasts looking for a complement to the triathlon (swim-bike-run event). The sport typically has three separate segments, usually in order of running, bicycling, and running with no rest periods between each segment. The most common and popular race has been the 5km run, 30km bicycle, and 5km run international duathlon (Graham 1990; Newkirk 1989).

Although there is a paucity of research on duathlons, examination of the swim, bicycle, and run segments of the triathlon is useful to duathlon researchers. Recent studies have emphasized the physiological (Kohrt *et al.* 1987; Kreider *et al.* 1988; Loftin *et al.* 1988) and medical (Hiller *et al.* 1987; Hiller 1989) aspects of the triathlon. Triathlon performance has been correlated with VO_{2max} , the maximum volume of oxygen an individual can use (uptake) (Kohrt *et al.* 1987; Kreider *et al.* 1988; Loftin *et al.* 1988), and cardiovascular/thermal responses (Kreider *et al.* 1988). Kohrt *et al.* (1987) found that VO_{2max} was significantly related to bicycling and running performance in a triathlete. Hiller *et al.* (1987) examined medical records for triathlons of various lengths and found the most common medical problems to be dehydration and heat exhaustion.

The effects of weather on performance in run-only events is much better understood (Costill 1972; Pugh 1974; Davies 1980; England *et al.* 1982). Both Pugh (1974) and Davies (1980) examined the effects of wind resistance on runners and found there is an increase in oxygen uptake (i.e. increasing stress) by athletes running in middle distance track events with increasing wind speed. Cross winds were also responsible for affecting performance in some middle distance runners (Davies 1980). Heat exhaustion and heat stroke are commonly encountered problems among competitors during high temperature and humidity conditions, as this combination tends to impair evaporative cooling.

In an analysis of the physiology of marathon runners, Costill (1972) suggested that environment and course topography may drastically influence marathon performance. Eyton (1987) examined a multi-stage, long-distance road race and found the most significant variables for performance were stage distance and the uphill component of the stage. Energy expenditure and run performance times of simulated orienteering conditions were compared on flat and hilly routes by Knowlton *et al.* (1988). They found that the same length route with a short, steep incline required less energy than a route with a longer, more gradual incline.

Because the first official duathlon took place less than ten years ago (1984), there has been a limited amount of research on inter-race variability in performance and the potential limiting factors

of performance. The primary purpose of this study is to examine how topographic variation and race-day weather affects the level of performance in male "middle-of-the-pack" (MMP) duathletes. Guiding research questions are: 1) what influences do variations in race course topography and race-day weather have on mean final race times among a sample of races based on a standard duathlon course of a 5km first run, 30km bicycle portion, and a 5km second run, and 2) how do the average split times (times for individual race segments) vary among races and are they a good indicator of the influence of course difficulty and atmospheric conditions on MMP performance.

Study Area and Races

The Pacific Northwest region of the United States and Canada was selected for this study because of the presence of four duathlon race series during the data collection period of May to September 1990. These series offered an excellent chance to study duathlon performance as they attracted many of the same duathletes to their races.

Eight of thirteen duathlon races selected for this study were clustered around Vancouver, British Columbia, and three near Portland, Oregon. Both cities enjoy marine west coast climates with adequate annual precipitation and mild temperatures throughout the year. One of the two additional sites was located on the high plains of eastern Oregon (Helix, Oregon) and the other in the higher, dryer

interior of British Columbia (Kamloops, B.C.). Both sites are leeward of the Cascade Mountains, resulting in deficits of atmospheric moisture year-round. The name, location, date, and actual race distances of each duathlon are recorded in Table 1.

Methods

Meteorological Data

Weather data were collected at the start of the race, midpoint, and the race finish. The race start was defined as five minutes before the official race start. For races that contained a 5km run, 30km bicycle, and a second 5km run or distances that closely approximate these, the recording of midpoint weather data took place exactly one hour and fifteen minutes after the first competitors left the starting line. The midpoint recording time was changed to one hour and thirty minutes when bicycle course lengths were ≥ 35 km. The final weather data were recorded as the last person crossed the finish line. This time varied from 35 minutes (Race #1) to one hour and 50 minutes (Race #11) after the midpoint recording. However, most of the final weather recordings were taken one hour and 30 minutes after the midpoint recording.

Weather variables examined include temperature, relative humidity, wind speed, direct radiation, cloud cover, Temperature-Humidity Index, and wind chill. Temperature and relative humidity were recorded using a digital hygrometer

TABLE 1. Location, name, date, and duathlon distance for races used in this study.

Race #	Race Name	Location	Date (1990)	Distances (run#1-bicycle-run#2)
1	Canadian Endurance Series	Langley, B.C.	05/27	3km-20km-3km
2	PTA Rose Festival Biathlon	Hillsboro, Oregon	06/03	5km-30km-5km
3	Prestige Series-Stanley Park	Vancouver, B.C.	06/08	5km-29.7km-5km
4	BC Tel International Duathlon	Victoria, B.C.	06/09	5km-30km-5km
5	Heart of the Country Biathlon	Helix, Oregon	06/16	4.8km-40.2km-3.2km
6	Canadian Endurance Series	Vancouver, B.C.	06/24	5km-40km-5km
7	BC Tel International Duathlon	Whistler, B.C.	07/01	4.5km-32.5km-4.5km
8	PTA Firecracker Biathlon	Wilsonville, Oregon	07/08	5km-30km-5km
9	BC Tel International Duathlon	Kamloops, B.C.	07/15	5.5km-30km-5.5km
10	PTA Midsummer Biathlon	Fairview, Oregon	08/12	5km-30km-5km
11	Prestige Series-Whistler	Whistler, B.C.	09/01	5km-35km-5km
12	Canadian Endurance Series	Vancouver, B.C.	09/08	5km-40km-5km
13	Canadian Endurance Series	North Vancouver, B.C.	09/29	5km-30km-5km

housed inside a standard meteorological shelter. Wind speed was recorded with a digital anemometer. Direct radiation was measured using a solar radiation meter and was estimated to the nearest five $W m^{-2}$. Cloud cover was a subjective estimate from 0% (no clouds visible) to 100% (sky completely covered). This variable was estimated to the nearest 10% by viewing the sky for approximately two minutes before each recording time. The Discomfort Index (Thom 1959), otherwise known as Temperature-Humidity Index (THI), was used to evaluate the amount of human discomfort felt with the race conditions encountered. Wind chill was calculated using a Standard Wind Chill Equivalent Equation (Dixon and Prior 1987).

Topographic Data

On-site run and bicycle topography data were acquired either before or immediately after each race. A mountain bicycle was ridden over each run course using a cyclocomputer to measure course distance. The type of running surface encountered, path width, and the sinuosity (Mueller 1968) of the course were also recorded. The bicycle course was measured similar to the run course. In addition, topographic maps were used for analyses of run and bicycle course topography. The Earth Resources Data Analysis System (ERDAS) was used to measure race distances and changes in elevation from topographic maps.

Because of scale limitations on available topographic maps (1:50,000 for Canadian maps, 1:24,000 for United States maps), detailed topographic variables could not be calculated for the run courses. Instead, a subjective topographic rank variable (run rank) was devised based on observations taken at the race site. After considering all aspects of course topography and layout (e.g. slope, net gain or loss, sinuosity, running surface), difficult courses were assigned a rank of three, moderate courses a two, and easy courses a rank of one.

Topographic map detail was sufficient for analyzing bicycle course topography. Four variables are used to describe bicycle course topography. Local relief (meters) for this study was defined as the difference in elevation between the highest and lowest points on the bicycle course. These points were read directly from the topographic map(s) or interpolated if they were between two contour lines. Net gain or loss (meters) in the first half of the course was defined as the difference

in elevation between the start and the midpoint of the bicycle course. Average course slope (degrees) was calculated by modifying an existing average slope formula (Wentworth 1930). An undulation ratio was calculated by dividing the digitized bicycle course distance by the straight-line (flat) distance. This ratio provides an estimate of the vertical deviation of a bicycle course compared to a hypothetically flat course.

Performance Data

The variables first run time and second run time were used in their original format. Run disparity was measured as the difference between the first run time and the second run time. The recorded overall and bicycle split times included run/bicycle and bicycle/run transition times (the time used by competitors to change from one event to the next). These transition times were subtracted from the originally recorded bicycle and overall times before any statistical analyses were performed.

Mathematical interpolation was used on race times where course distances did not match the 5km first run, 30km bicycle, 5km second run standard used in this study. This was done to simplify statistical comparisons among races and create a standard for the Scheffe post hoc test. To interpolate, a non-standard race distance was divided by the standard race distance to calculate a standardizing coefficient. A standardized race time for each MMP duathlete was then calculated by multiplying this coefficient by each non-standard race time.

Once linear interpolation was performed on all non-standard races, the average and standard deviation was calculated for the total race population of each race. The MMP sample was taken as any duathlete fitting in a range of plus or minus one standard deviation from the overall race mean. This group of duathletes was used to calculate the average and standard deviation for the first 5km run, 30km bicycle, overall, second 5km run, and 5km run disparity.

Statistical Analyses

MMP average race times, topographic and race-day weather variables were checked for normality. All variables were tested at the 0.05 level of significance. Most variables were normally distributed, with a few exceptions (wind speed) falling between 0.05 and 0.07 level of significance.

Subtraction matrices were constructed using all MMP average race times. These subtraction matrices were used to identify unique races, races that appear to enhance or reduce MMP duathlon performance. A Scheffe post hoc test of ANOVA was performed on all MMP race times, allowing a multiple-comparison of means. The results of each Scheffe test were combined with the subtraction matrix results to simplify analysis. The primary use for the Scheffe test is to validate, statistically, unique races found from the subtraction matrix analysis.

Results and Discussion

MMP sample sizes, average race times and the respective standard deviations for each segment of the races studied are listed in Table 2. A summary of the overall topographic characteristics of each race is provided in Table 3. Topographic profiles of the 30km bicycle courses are shown in Figure 1. Average weather conditions for each race are summarized in Table 4.

First 5km Run Performance

The first 5km run subtraction/Scheffe matrix (Table 5) shows distinct groupings of slower and faster

average performance times. Races #5, #6, #7, #11, #12, and #13 display a significant reduction in run time from the rest of the races. These six races appear to correspond well with their difficult run ranks (run rank = 3) (Table 3). The exception is race #11 (run rank = 2), which was a borderline case between a moderate and difficult ranked course. Races #7 and #11 had similar run courses, both held on mountain trails/roads of gravel. This combination of gravel surface and hills resulted in a reduction in performance compared to races #4 and #9 (Table 5), which were held on flat, paved surfaces. Although there was a large difference in weather conditions (Table 4), races #4 and #9 (both run ranks = 1) had similar race averages. First 5km run performance appears to be more strongly influenced by run course topography than by race-day weather.

Races #6 and #12 are of particular interest because they were held on the same difficult run course (run rank = 3) at different times of the year. No significant difference exists between race #6 and #12 according to results from a Scheffe post hoc test (Table 5). Despite being run under different weather conditions (Table 4), only seven seconds separates the first 5km run segment of these two duathlons (Table 5).

TABLE 2. Mean race times and standard deviation of race time. Race times in seconds** (standard deviation).

Race # (# of MMP)	Run #1	Bike	Run #2	Overall	Disparity*
1 (n=70)	1219 (114)	3228 (214)	1324 (118)	5663 (362)	105
2 (n=84)	1167 (77)	3243 (169)	1267 (88)	5679 (243)	100
3 (n=226)	1181 (91)	3106 (203)	1282 (108)	5579 (352)	101
4 (n=127)	1121 (84)	3164 (221)	1227 (105)	5511 (347)	106
5 (n=55)	1276 (116)	3671 (354)	1389 (231)	5972 (535)	112
6 (n=71)	1276 (109)	3101 (204)	1475 (159)	5516 (348)	198
7 (n=114)	1312 (95)	3071 (214)	1494 (130)	5647 (362)	183
8 (n=117)	1195 (106)	3219 (233)	1308 (143)	5724 (395)	113
9 (n=62)	1105 (67)	3183 (204)	1205 (82)	5537 (281)	101
10 (n=123)	1235 (98)	3050 (235)	1341 (119)	5626 (388)	107
11 (n=155)	1299 (106)	3191 (228)	1446 (153)	5754 (399)	147
12 (n=66)	1269 (80)	3101 (200)	1435 (150)	5477 (314)	166
13 (n=65)	1283 (91)	3208 (228)	1425 (114)	5920 (382)	142

* First 5km run/Second 5km run disparity calculated from race averages.

** Times for races 1, 3, 5, 6, 7, 9, 11, 12 are interpolated to the international distance (5km run, 30km bike, 5km run).

TABLE 3. Topographic characteristics of individual races.

Race#	Local Relief (meters)	Gain or Loss (meters)	Undulation Ratio	Average Slope (degrees)	Run Rank
1	28.04	-22.86	1.000046	0.47	2
2	88.39	8.53	1.000443	1.33	2
3	55.00	0.00	1.001132	1.20	1
4	23.00	1.00	1.000120	0.32	2
5	146.96	-39.93	1.000439	1.81	3
6	66.04	-31.00	1.000085	0.42	3
7	152.40	-128.02	1.001534	1.75	3
8	73.15	0.00	1.001034	1.39	1
9	33.53	-21.34	1.000047	0.29	1
10	12.51	6.70	1.000001	0.09	2
11	179.83	-167.64	1.001574	1.79	2
12	66.04	-31.00	1.000085	0.42	3
13	25.00	0.00	1.000082	0.30	3

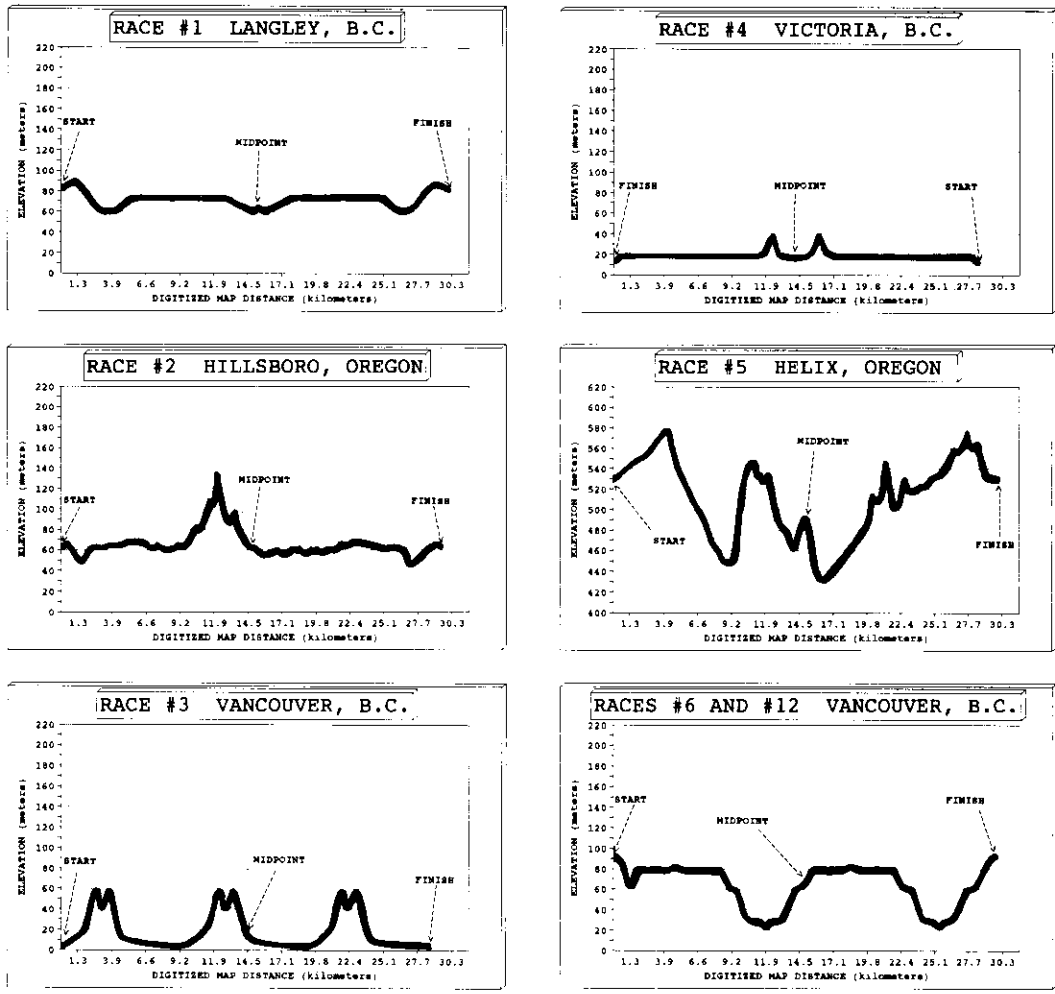


Figure 1A. Bicycle course elevation profile for race #1-6 and race #12. Vertical exaggeration is 80x.

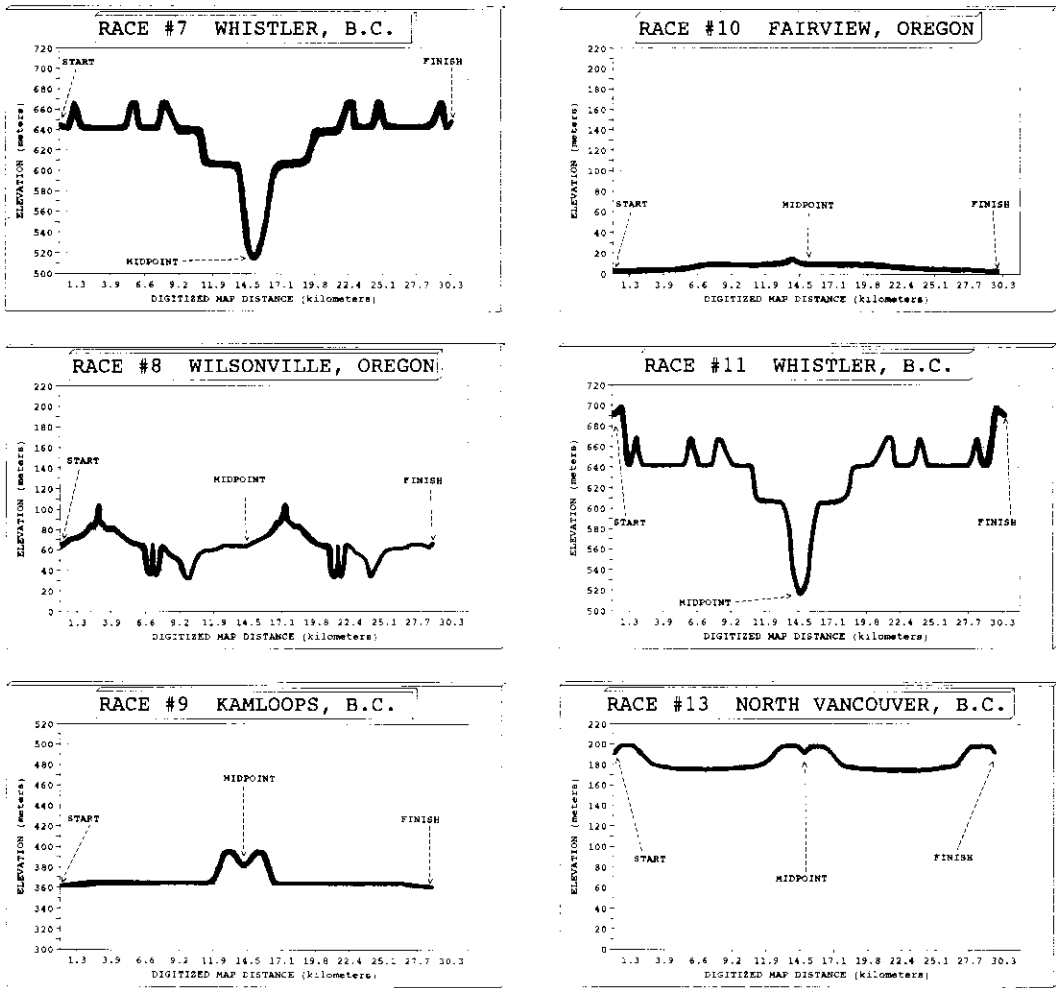


Figure 1B. Bicycle course elevation profile for race #7-11 and race #13. Vertical exaggeration is 80x.

TABLE 4. Mean weather conditions recorded at each race.

Race#	Temperature °C	Relative Humidity (%)	Wind Speed m sec ⁻¹	Direct Radiation W m ⁻²	Cloud Cover (%)	Temp-Humidity Index (THI)	Wind Chill
1	15.19	78.67	0.43	275.00	100.00	15.05	14.38
2	16.11	73.00	1.92	580.00	80.00	15.80	12.54
3	13.70	91.33	0.00	181.67	100.00	13.72	13.70
4	10.00	82.67	1.47	413.33	93.33	10.38	7.27
5	20.00	45.33	5.17	1013.33	30.00	18.20	10.37
6	20.00	58.00	0.40	290.00	36.67	18.60	19.25
7	14.63	63.33	0.05	566.67	86.67	14.50	14.54
8	23.33	54.67	0.40	980.00	10.00	21.01	22.59
9	26.11	29.67	0.50	996.67	0.00	21.43	25.18
10	22.78	66.00	1.42	925.00	6.67	21.14	20.14
11	11.85	77.00	0.00	218.33	10.00	12.12	11.85
12	17.04	71.67	0.42	216.67	10.00	16.56	16.26
13	16.11	68.33	0.38	485.00	66.67	15.74	15.40

TABLE 5. Subtraction and yes/no matrix for MMP first 5km run performance. The difference in average race times is given in seconds. "Y" indicates a significant difference between race means at the 0.05 level of confidence based on a Scheffe post hoc test.

		R A C E #												
		1*	2	3	4	5*	6	7*	8	9*	10	11	12	13
	Time (sec.)	1219	1167	1181	1121	1276	1276	1312	1195	1105	1235	1299	1269	1283
1*	1219	-	51	38(Y)	98	-57	-57	-93(Y)	24	114(Y)	-16	-80(Y)	-50	-64
2	1167		-	-14	46	-109(Y)	-109(Y)	-109(Y)	-28	63	-67(Y)	-132(Y)	102(Y)	-115(Y)
3	1181			-	60(Y)	-95(Y)	-95(Y)	-130(Y)	-14	77(Y)	-54(Y)	-118(Y)	-88(Y)	101(Y)
R 4	1121				-	-155(Y)	-155(Y)	-191(Y)	-74(Y)	16	-114(Y)	-178(Y)	-148(Y)	-162(Y)
A 5*	1276					-	0	-36	81(Y)	171(Y)	41	-23	7	-7
C 6	1276						-	-35	81(Y)	172(Y)	42	-23	7	-6
E 7*	1312							-	116(Y)	207(Y)	77(Y)	13	43	29
# 8	1195								-	91(Y)	-39	-104(Y)	-74(Y)	-87(Y)
9*	1105									-	-130(Y)	-194(Y)	-164(Y)	-178(Y)
10	1235										-	-64(Y)	-34	-48
11	1299											-	30	16
12	1269												-	-14
13	1283													-

* indicates the race time was interpolated to the international (5km-30km-5km) distance

30km Bicycle Performance

Two races (#2 and #5) have a distinctly different pattern from the rest of the races (Table 6). These two races possessed the two highest average wind speeds (Table 9), had topographically challenging course designs (Figure 1A), and had the slowest average race times (Table 6). A main factor in reducing 30km bicycle performance for race #2 appears to be the challenging hill near the midpoint (Figure 1A). The undulating course and midpoint wind speed of 2.50m sec⁻¹ also likely contributed to the reduction in performance. Besides a challenging first half, race #5 had a long continuous climb for the cycling duathlete from the midpoint almost to the start/finish area (Figure 1A). The long, challenging climbs of race #5 coupled with the midpoint wind speed (5.90m sec⁻¹) account for the large reduction in performance compared to other races (Table 6).

The fastest average 30km bicycle times for MMP duathletes are found on a variety of course designs. The topographic analysis (Table 3) and course profile (Figure 1B) suggest that race #10 had the fastest average 30km bicycle time because of a lack of topographic variability. In contrast, race #7 was perceived as a difficult course by du-

athletes, and this is backed by the topographic analysis of the course (Table 3). However, the second fastest bicycle time (Table 6) was recorded in race #7. The key to the fast average time appears to be net loss (-128m) in the first half of the course (Figure 1B). This large drop in elevation resulted in high racing speeds, allowing duathletes to perform at or above their capabilities for the first half of the course and negating the reduction in performance caused by the long climb back to the transition area. Race #11 used the same course as race #7 but included an extension onto the start (Figure 1B) that accounts for the longer actual (versus interpolated) distance. The result was a slower average race time for race #11.

Races #6 and #12 are of particular interest because they used the same bicycle course at different times of the year. Although there were differences in average weather conditions between race #6 and #12 (Table 4), with race #6 having a greater potential for heat stress, average race times for the two races are identical (3101 seconds). This represents a tie for the third fastest time among races sampled (Table 6). A small local relief, average slope, and a loss in elevation in the first half of the course contribute to the fast race times. Large losses in elevation in each loop

TABLE 6. Subtraction and yes/no matrix for MMP 30km bicycle performance. The difference in average race times is given in seconds. "Y" indicates a significant difference between race means at the 0.05 level of confidence based on a Scheffe post hoc test.

	R A C E #													
	1*	2	3*	4	5*	6*	7*	8	9	10	11*	12*	13	
Time (sec.)	3228	3243	3106	3164	3671	3101	3071	3219	3183	3050	3191	3101	3208	
1*	3228	-	-15	122	64	-443(Y)	127	157(Y)	8	45	178(Y)	37	127	20
2	3243		-	138(Y)	80	-427(Y)	142	172(Y)	24	60	194(Y)	52	143	35
3*	3106			-	-58	-565(Y)	4	34	-114	-78	56	-86	5	-103
R 4	3164				-	-507(Y)	63	93	-56	-19	114	-28	63	-44
A 5*	3671					-	569(Y)	599(Y)	451(Y)	487(Y)	621(Y)	479(Y)	570(Y)	462(Y)
C 6*	3101						-	30	-118	-82	51	-90	1	-107
E 7*	3071							-	-148(Y)	-112	21	-120	-29	-137
# 8	3219								-	36	170(Y)	28	119	11
9	3183									-	133	-8	83	-25
10	3050										-	-142(Y)	-51	-158(Y)
11*	3191											-	91	-17
12*	3101												-	-108
13	3208													-

* indicates the race time was interpolated to the international (5km-30km-5km) distance

of this two loop course (Figure 1A) enabled MMP duathletes to perform at or above their capabilities.

Second 5km Run Performance

The effects of run course difficulty (run rank) should become more significant after running and bicycling a total of 35km. The difference between difficult (run rank = 3) and easy (run rank = 1) courses is evident when looking at the subtraction matrix (Table 7). Second 5km run times for races #4 and #9 were the two fastest. The fast times are most likely related to the lack of difficulty in the preceding bicycle courses. Races #6, #7, #11, #12, and #13 show pronounced decreases in average run performance compared to races #4 and #9. Again, this appears to be primarily a function of the difficulty of these five run courses. Results from the Scheffe post hoc test (Table 7) support the findings from the subtraction matrix, as almost all race pairs having second 5km run time differences of greater than ± 94 seconds were significantly different at the 0.05 level. Second 5km run performance may be the best indicator of overall course difficulty. The assumption is that slower second 5km run times equate to a more difficult first run and/or 30km bicycle course experienced by the MMP duathlete.

Overall Performance

The apparent overall homogeneity among courses leads to a lack of usefulness when using overall race times to analyze performance. Although differences exist between the individual segments of each race, the resulting average overall race times are similar. For example, duathletes ran fast on the easy run course of race #4 but much slower for race #6, a difficult run course. In contrast, duathletes cycled the fastest on the bicycle course for race #6 while race #4 saw an intermediate time for MMP duathletes. Although the individual segments of each course contain different physical characteristics, the final overall race averages are approximately equal (Table 2).

Races #5 and #13 display the only unique patterns (Table 8). Except for wind speed, average weather conditions were not largely different between the two races (Table 4). Both races had difficult run and bicycle segments to their respective courses (Table 3). The small difference between the two races can be accounted for by the more difficult bicycle course in race #5 (Figure 1A). The rest of the overall race times are clustered around 5500 seconds. Thus, examination of overall race times contributes little to the knowledge of the effects of weather and course topography on MMP duathlete performance.

TABLE 7. Subtraction and yes/no matrix for MMP second 5km run performance. The difference in average race times is given in seconds.

"Y" indicates a significant difference between race means at the 0.05 level of confidence based on a Scheffe post hoc test.

		R A C E #												
		1*	2	3	4	5*	6	7*	8	9*	10	11	12	13
	Time (sec.)	1324	1267	1282	1227	1389	1475	1494	1308	1205	1341	1446	1435	1425
1*	1324	-	56	42	97(Y)	-65	-151(Y)	-171(Y)	15	118(Y)	-18	-122(Y)	-111(Y)	-101
2	1267		-	-14	41	-121(Y)	-207(Y)	-227(Y)	-41	62	-74	-178(Y)	-167(Y)	-157(Y)
3	1282			-	-85	-324(Y)	-186(Y)	-382(Y)	-126	-125	-264	-360(Y)	-242(Y)	-280(Y)
R 4	1227				-	-162(Y)	-248(Y)	-268(Y)	-82(Y)	21	-115(Y)	-219(Y)	-208(Y)	-198(Y)
A 5*	1389					-	-86	-106(Y)	80	183(Y)	47	-57	-46	-36
C 6	1475						-	-20	166(Y)	269(Y)	133(Y)	29	40	50
E 7*	1494							-	186(Y)	289(Y)	153(Y)	49	60	70
# 8	1308								-	103(Y)	-33	-137(Y)	-126(Y)	-116(Y)
	9*	1205								-	-136(Y)	-240(Y)	-229(Y)	-219(Y)
	10	1341									-	-104(Y)	-94(Y)	-83
	11	1446										-	11	21
	12	1435											-	10
	13	1425												-

* indicates the race time was interpolated to the international (5km-30km-5km) distance

TABLE 8. Subtraction and yes/no matrix for MMP overall performance. The difference in average race times is given in seconds.

"Y" indicates a significant difference between race means at the 0.05 level of confidence based on a Scheffe post hoc test.

		R A C E #												
		1*	2	3*	4	5*	6*	7*	8	9*	10	11*	12*	13
	Time (sec.)	5663	5679	5579	5511	5972	5516	5647	5724	5537	5626	5754	5477	5920
1*	5663	-	-16	84	152	-309(Y)	147	16	-61	126	37	-91	186	-257
2	5679		-	100	167	-293(Y)	163	32	-45	142	53	-75	202	-241
3*	5579			-	68	-393(Y)	63	-68	-145	42	-47	-175	102	-341(Y)
R 4	5511				-	-460(Y)	-5	-135	-212	-26	-115	-242(Y)	34	-408(Y)
A 5*	5972					-	456(Y)	325	248	435(Y)	346(Y)	218	494(Y)	52
C 6*	5516						-	-131	-207	-21	-110	-238	39	-404(Y)
E 7*	5647							-	-77	110	21	-107	169	-273(Y)
# 8	5724								-	186	98	-30	246	-196
	9*	5537								-	-89	-217	60	-383(Y)
	10	5626									-	-128	149	-294(Y)
	11*	5754										-	276(Y)	-166(Y)
	12*	5477											-	-442(Y)
	13	5920												-

* indicates the race time was interpolated to the international (5km-30km-5km) distance

TABLE 9. Subtraction and yes/no matrix for MMP first and second 5km run disparity. The difference in average race times is given in seconds. 'Y' indicates a significant difference between race means at the 0.05 level of confidence based on a Scheffe post hoc test.

		R A C E #												
		1*	2	3	4	5*	6	7*	8	9*	10	11	12	13
	Time (sec.)	105	100	101	106	112	198	183	113	101	107	147	166	142
1*	105	-	5	4	-1	-7	-93(Y)	-78(Y)	-8	4	-2	-42	-61	-37
2	100		-	-0	-6	-12	-98(Y)	-83(Y)	-13	-1	-6	-46	-66(Y)	-42
3	101			-	-5	-12	-98(Y)	-82(Y)	-13	-0	-6	-46(Y)	-65(Y)	-41
R	4	106			-	-7	-93(Y)	-77(Y)	-7	5	-1	-41	-60(Y)	-36
A	5*	112				-	-86(Y)	-70(Y)	-1	12	6	-34	-53	-29
C	6	198					-	16	85(Y)	98(Y)	92(Y)	52	33	57
E	7*	183						-	69(Y)	82(Y)	76(Y)	36	17	41
#	8	113							-	12	7	-33	-53	-29
	9*	101								-	-6	-46	-65	-41
	10	107									-	-40	-59(Y)	-35
	11	147										-	-19	5
	12	166											-	24
	13	142												-

* indicates the race time was interpolated to the international (5km-30km-5km) distance

5km Run Disparity

Results suggest that races #6, #7, and #12 are significantly different from the other races (Table 9). There appears to be two distinct groupings for MMP duathlete 5km run disparity. One group displays large differences (>142 seconds) between first and second 5km runs (races #6, #7, #11, #12, #13). The remaining races are clustered around a smaller disparity of about 100 seconds (Table 9). These two groupings are evident on the subtraction matrix of raw data (Table 9). Although there are large 5km run disparities for races #11 and #13, the Scheffe post hoc test was unable to reveal any unique statistical patterns when compared to the other races. However, the subtraction matrix shows these races differ by as much as 57 seconds from the other races (Table 9). Most duathletes consider a reduction of 142 seconds (2 minutes and 22 seconds) and 147 seconds (2 minutes and 27 seconds) in 5km run performance substantial.

Conclusions

The focus of this study was on the relationship between performance in male athletes during duathlon events and the suite of topographic and weather conditions encountered at each race. Subtraction matrices and a series of Scheffe post hoc tests of ANOVA were used to identify unique races and race patterns. Aspects of race-day weather and topographic variability were examined in conjunction with the matrices to help explain MMP performance among the duathlon races. The findings suggest: 1) first 5km run times are primarily affected by run course topography, 2) 30km bicycle times are similar among races except those with large amounts of topographic variability or high wind speeds, 3) poor second 5km run performance is due largely to a combination of run and bicycle course difficulty, 4) 5km run disparity may be the best indicator of overall course difficulty as second 5km race times drop considerably following a difficult first 5km run and/or 30km bicycle course, and 5) other than wind speed, weather conditions have little influence on duathlon performance during the summer months in the Pacific Northwest.

Literature Cited

- Costill, D. L. 1972. Physiology of marathon running. *Journal of the Amer. Med. Assoc.* 221:1024-1029.
- Davies, C. T. M. 1980. Effects of wind assistance and resistance on the forward motion of a runner. *J. of Appl. Physiology* 48:702-709.
- Dixon, J. C., and M. J. Prior. 1987. Wind-chill indices—a review. *Meteor. Mag.* 116:1-17.
- England, A. C. III, D. W. Fraser, A. W. Hightower, R. Trinnanzi, D. J. Greenberg, K. E. Powell, C. M. Slovis, and R. A. Varsha. 1982. Preventing severe heat injury in runners: suggestions from the 1979 Peachtree road race experience. *Ann. of Internal Med.* 97:196-201.
- Eyton, J. R. 1987. Morphometrics of the Chasquis Invitational Rocky Mountain Road Race. *Sport Place* 1:39-47.
- Graham, R. 1990. State of the sport-Triathlete magazine ponders the triathlon: its current health and hopes for the future. *Triathlete* 80:32-48.
- Hiller, W. D. B. 1989. Dehydration and hyponatremia during triathlons. *Med. and Science in Sports and Exercise* 21:219-220.
- Hiller, W. D. B., M. L. O'Toole, E. E. Fortress, R. H. Laird, P. C. Imbert, and T. D. Sisk. 1987. Medical and physiological considerations in triathlons. *The Amer. J. of Sportsmedicine* 15:164-167.
- Knowlton, R. C., Ackerman, K. A. and L. A. Kaminsky. 1988. Physiological and performance comparisons of running flat and hill routes as applied to orienteering navigation. *J. of Sports Med. and Physical Fitness* 28:189-192.
- Kohrt, W. M., Morgan, D. W., Bates, B. and J. S. Skinner. 1987. Physiological responses of triathletes to maximal swimming, cycling, and running. *Med. and Science in Sports and Exercise.* 19:51-55.
- Kreider, R. B., T. Boone, W. R. Thompson, S. Burkes, and C. W. Cortes. 1988. Cardiovascular and thermal responses of triathlon performance. *Med. and Science in Sports and Exercise* 20:385-390.
- Lofin, M., B. L. Warren, S. Zingraf, J. E. Brandon, J. E. Skuldt, A. Skuldt, and B. Scully. 1988. Peak physiological function and performance of recreational triathletes. *J. of Sports Med. and Physical Fitness* 28:330-335.
- Mueller, J. E. 1968. An introduction to the hydraulic and topographic sinuosity indexes. *Ann. of the Assoc. of Amer. Geog.* 58:371-385.
- Newkirk, G. 1989. Biathlons take off—a survey of 1989's best biathlons. *Triathlete* 68:38-55.
- Pugh, L. C. C. E. 1974. The influence of wind resistance in running and walking and the mechanical efficiency of work against horizontal or vertical forces. *J. of Physiology* 213:255-276.
- Thom, E. C. 1959. The Discomfort Index. *Weatherwise* 11:57-60.
- Wentworth, C. K. 1930. A simplified method of determining the average slope of land surfaces. *Amer. J. of Science* 20:184-194.

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