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Drafting effects of the third-position cyclist on the second-position cyclist's power output in a three-man drafting line

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Abstract

The purpose of this study was to determine whether a second-position cyclist benefitted, in terms of decreased power requirement, from the presence of a third-position cyclist. It was hypothesized that the second-position cyclist would experience a decrease in power requirement with the presence of a third-position cyclist compared to the absence of a third-position cyclist, and that this decreased power requirement would be magnified during the faster trials. Twelve trained cyclists served as second-position subjects. Subjects completed 12 total trials each: 2 solo trials at a moderate speed (MS), 2 solo trials at a high speed (HS), 2 MS trials in a 2-cyclist line, 2 HS trials in a 2-cyclist line, 2 MS trials in a 3-cyclist line at, and 2 HS trials in a 3-cyclist line. Significant main effects were observed for speed ($p = 0.000$), condition ($p = 0.001$), and speed-condition interaction ($p = 0.017$). Post hoc analyses revealed significant differences ($p < 0.001$) in power production between the solo condition and 2-line condition and between the solo condition and the 3-line condition at both speeds; however, there was no significant difference between the 2-line and 3-line conditions ($p = 0.216$), despite an average power savings of 4.74% more in the 3-line condition. When the HS data for the eight fastest cyclists was compared, the 3-line condition required an average of 26.88 W less (a 9.18% power reduction) than the required power output of the 2-line condition ($p < 0.05$). Power output reductions within this range of 4.74-9.18% could prove beneficial to performance throughout the course of a long-distance race.

Introduction

Drafting, or slipstreaming, describes the method of performing an activity in a position sheltered from air resistance, thus, reducing drag force (Brisswalter & Hausswirth, 2008). This is common practice in endurance sports such as cycling (Broker, Kyle, & Burke, 1999; Edwards & Byrnes, 2007; Hagberg & McCole, 1990; Hausswirth, Lehenaff, Dreano, & Savonen, 1999; Hausswirth et al., 2001; Kyle, 1979; McCole, Claney, Conte, Anderson, & Hagberg, 1990), swimming, triathlon, and stock car racing, and it also has its merit in sports such as running, short-track skating, and cross-country skiing (Brisswalter & Hausswirth, 2008). In these events, one person will follow another at a short distance in order to receive a shielding affect from the air resistance. The research has consistently found that drafting decreases the energy expenditure requirement of one person drafting behind another. This has been found in cyclists (Broker, et al., 1999; Edwards & Byrnes, 2007; Hagberg & McCole, 1990; Hausswirth, et al., 1999; Hausswirth, et al., 2001; Kyle, 1979; McCole, et al., 1990), swimmers (Bassett, Flohr, Duey, Howley, & Pein, 1991; Bentley et al., 2007; Chatard & Wilson, 2003; Delextrat, Tricot, Bernard, et al., 2003; Delextrat, Tricot, Hausswirth, et al., 2003), runners (Kyle, 1979; Margaria, Cerretelli, Aghemo, & Sassi, 1963; Pugh, 1971; Shanebrook & Jaszczak, 1976), and cross-country skiers (Bilodeau, Roy, & Boulay, 1994), among others.

As for cycling, there is no questioning whether drafting is beneficial to trailing riders (Broker, et al., 1999; Edwards & Byrnes, 2007; Hagberg & McCole, 1990; Hausswirth, et al., 1999; Hausswirth, et al., 2001; Kyle, 1979; McCole, et al., 1990).

However, the magnitude of the drafting benefit is influenced by several factors such as lead rider size, distance from the lead rider (wheel gap), wheel alignment, speed, and skill to hold a draft position. The larger the lead rider (the larger the frontal area), the greater the drafting effect will be, and thus, the greater the benefit to the trailing rider (Edwards & Byrnes, 2007; Kyle, 1979). If cycling in a peloton, or a group of riders, the benefit of the trailing riders increase even more, although this is dependent upon positioning within the group (Hagberg & McCole, 1990; Jeukendrup, Craig, & Hawley, 2000; McCole, et al., 1990). A team of cyclists cycling in a pace line and alternating the leader is able to travel faster as a team than the cyclists could individually, assuming the cyclists are all of nearly equal status and ability (Broker, et al., 1999; Kyle, 1979). Furthermore, a large team of cyclists can travel faster than a small team; however, the relative amount of speed increase diminishes as the team size gets larger (Kyle, 1979). Also, the closer the trailing rider follows the lead rider, and the more aligned the wheels of the two bikes are the greater the shielding effect, and thus, the greater the benefit to the trailer (Kyle, 1979). This assumes that the cyclists are traveling in a straight line, as optimal drafting alignment may be different when riding around curves. The drafting effect is also magnified with greater speeds (Kyle, 1979). Other factors undoubtedly come into play, such as wind, equipment (bikes, helmets, clothing, etc.), and ground surface (McCole, et al., 1990).

While the benefits of drafting are well-founded (Broker, et al., 1999; Edwards & Byrnes, 2007; Hagberg & McCole, 1990; Hausswirth, et al., 1999; Hausswirth, et al., 2001; Kyle, 1979; McCole, et al., 1990), there is still some question as to whether or not the presence of a drafting rider benefits the cyclist that is positioned in front of him. In theory, having a drafter should help the cyclist being drafted by reducing the turbulence of the air flow behind him, thus creating a more laminar flow and less drag (Hagberg & McCole, 1990). Researchers that have attempted to determine if the presence of a drafting rider benefits the rider immediately in front have reported no differences or statistically insignificant differences in energy expenditure or power output (Broker, et al., 1999; Hagberg & McCole, 1990; Kyle, 1979; Sjogaard, Nielsen, Mikkelsen, Saltin, & Burke, 1986). The absence of an effect or a limited, but insignificant, effect may be related to inadequate sensitivity to detect relatively small changes in energy expenditure or power. Kyle (1979) estimated power reductions of drafting based on coasting deceleration and calculated total resistance force, and concluded that trailing cyclists have no effect on the power output of the cyclist positioned immediately in front of them. Other than noting that the experiments were conducted in a long hallway in order to limit the effects of relevant environmental factors (e.g., wind), Kyle (1979) did not provide any details regarding the specific methods or tools used to collect the power data. Despite Kyle’s findings (Table 1), Hagberg and McCole (1990) suggested that a cyclist riding immediately in front of another, drafting cyclist, may experience a 1 to 3% reduction in energy expenditure requirements due to the presence of the trailing rider. Hagberg and McCole (1990) attempted to uncover this benefit by measuring oxygen consumption via a portable metabolic cart during drafting trials. Although the typical margin of error observed with this method was not stated by the authors, others (Becque, Katch, Marks, & Dyer, 1993) reported a 4.3% average within-subject variability for VO_2 at lower workloads (50 W, 125 W, and 55% of maximum work rate) than those used by the drafting studies previously cited. Furthermore, within-subject VO_2 was associated with a larger range as workload increased (21.2-27.5% of VO2max at 50 W, 37.7-49.7% at 125 W, and 42.9-63.7% at 55% of max work rate) (Becque, et al., 1993). Additionally, the unique features of the equipment used by Hagberg and McCole (1990), namely the long air hose and the portable unit, may have led to even greater variability and/or error. Also, the top speed used in their study was just under 25 mph, and the benefit would be magnified with higher speeds; therefore, at higher speeds, a greater benefit than Hagberg & McCole's estimated 1-3% may exist. In contrast to Hagberg and McCole, others estimate that the lead rider in a team of cyclists may experience as much as a 5% reduction in energy expenditure (Iniguez-de-la Torre & Iniguez, 2009).

There is equipment presently available, such as the CycleOps PowerTap meter which is accurate to ± 1.5-3% (Bertucci, Duc, Villerius, Pernin, & Grappe, 2005), that may be more useful than oxygen consumption in more accurately detecting small differences in power output. The direct measurement of power output may also enhance the accuracy of the data in comparison to Kyle's (1979) study in which power was estimated via unspecified methods used to measure deceleration rates.

The purpose of this study was to investigate the possible benefits that a closely trailing cyclist has on another drafting cyclist. The specific question that was addressed was: Does the presence of a trailing (third-position) cyclist reduce the power requirement of the second-position cyclist in a drafting line of cyclists?

Hypotheses

The second-position cyclist will experience a greater decrease in power requirement with the presence of a trailing (third-position) cyclist compared to the absence of a trailing cyclist, and this decreased power requirement will be magnified in the faster trials.

Assumptions, Delimitations, and Limitations

Assumptions were that:

1. The power meters that were used to measure power output were valid and reliable.
2. The trailing cyclists were capable of drafting the desired 0.5 meters or less behind the cyclist in front of them.
3. All cyclists were capable of maintaining the desired speed.

Delimitations were that:

1. The power meters were used to measure power output.
2. The sample consisted of many triathletes who had limited experience as drafters since drafting is not permitted in triathlons.

Limitations were that:

1. Power output was the only measure used to determine the benefit, or possible benefit, of having a trailing cyclist.
2. The conclusions of this study may not be directly applied to cyclists very experienced in the art of drafting, due to the inexperience of some of the volunteers.
3. Since an indoor facility was not available to conduct this study, the study had to take place outside. While this may be more applicable as most cycling events take place outdoors, this allowed additional factors, most notably wind, to effect the results of the study.

Definition of Terms

The term *second-position cyclist* is defined as the middle cyclist in a three-cyclist drafting line. The term *third-position cyclist* is defined as the back cyclist in a three-cyclist drafting line. *Drafting*, in regards to this study, is defined as keeping the closest possible distance, within 0.5 meters, behind the closest cyclist, and it will only apply to the second- and third-position cyclists.

Literature Review

Drafting and the Benefits of Drafting Across Sports

Drafting is common practice in endurance sports such as cycling (Table 1), swimming, triathlon, and stock car racing. The research has consistently found that drafting decreases the power output and energy expenditure requirement of the participant in the drafting position. This has been found in the sports of cycling (Table 1), swimming (Bassett, et al., 1991; Bentley, et al., 2007; Chatard & Wilson, 2003; Delextrat, Tricot, Bernard, et al., 2003; Delextrat, Tricot, Hausswirth, et al., 2003), running (Kyle, 1979; Margaria, et al., 1963; Pugh, 1971; Shanebrook & Jaszczak, 1976), and cross-country skiing (Bilodeau, et al., 1994), among others.

Drafting in front crawl swimming has been shown to significantly reduce HR during swimming (by approximately 6.2%) and post-exercise oxygen consumption (by about 8.65%), as well as blood lactate (31% reduction) and rating of perceived exertion (21% reduction) compared to swimming solo (Bassett, et al., 1991). Triathlon-related performance studies have concluded that drafting during swimming improves subsequent cycling performance/efficiency (Bentley, et al., 2007; Delextrat, Tricot, Bernard, et al., 2003; Delextrat, Tricot, Hausswirth, et al., 2003). In one of these studies, sustained power output during subsequent cycling was about 9.24% higher following the drafting swim compared to solo swim (Bentley, et al., 2007).

Drafting has also been shown to decrease heart rate by about 5.5% during cross-country skiing compared to skiing alone (Bilodeau, et al., 1994), and the authors concluded that this energy-saving strategy should be practiced and used in races, as it would be very advantageous.

According to Pugh (1971), running 1 meter directly behind another runner reduced oxygen consumption by 6.5% compared to running solo. Pugh stated that this 1 meter draft "virtually eliminated air resistance"; however, this test was only preformed on one subject.

The Benefits of Drafting in Cycling

Drafting is unquestionably beneficial to trailing cyclists (Table 1); however, the magnitude of the benefit is largely dependent upon several factors such as lead rider size, size of the wheel gap, wheel alignment, speed, and skill to hold a draft position. If cycling in a peloton, the benefit the trailing riders receive increases even more, although this is dependent upon positioning within the group (Table 1) (Hagberg & McCole, 1990; Jeukendrup, et al., 2000; McCole, et al., 1990). A team that is cycling in a pace line and alternating the leader is able to travel faster as a team than the cyclists could individually, assuming the cyclists are all of nearly equal status and ability (Broker, et al., 1999; Kyle, 1979). Furthermore, a large team of cyclists can travel faster than a small team; however, the relative speed increase diminishes as the team size gets larger (Kyle, 1979). The closer the trailing rider follows the lead rider, and the more aligned the wheels of the two bikes are, the greater the shielding effect, and thus, the greater the benefit to the trailer (Kyle, 1979). The drafting effect is also magnified with greater speeds (Table 1) and larger lead cyclists (Edwards & Byrnes, 2007; Kyle, 1979).

The benefits of drafting are well-established (Table 1), but there is still some question as to whether or not the presence of a drafting rider benefits the cyclist that is being drafted. It has been proposed that having a drafter would help the cyclist being drafted by reducing the turbulence of the air flow, thus creating a more laminar flow and less drag. Previous studies that have attempted to find this proposed benefit have found that the front cyclist in a pace line was unaffected by the presence of a drafter or drafters, nor were other positions within a pace line effected by having a drafter or drafters (Broker, et al., 1999; Hagberg & McCole, 1990; Kyle, 1979; Sjogaard, et al., 1986). However, Hagberg and McCole (1990) estimate that it may provide a 1-3% benefit, while others estimate about a 5% benefit for the lead rider in a team of cyclists (Iniguez-de-la Torre & Iniguez, 2009). A similar relationship exists in NASCAR, where the trialing car benefits from decreased air resistance and the leading car benefits from decreased drag at the rear of the car (Ronfeldt, 2000). Thus, both of the cars are able to travel faster than either could alone. While NASCAR cars are much bigger and faster than cyclists on bikes, it is reasonable to believe that the same type of benefit exits, though likely smaller in magnitude. If so, a second-position cyclist in a group of 3 cyclists would benefit from both the reduced air resistance, as a result of drafting the lead cyclist, and the reduced vacuum-like drag effect, as a result of having a third-position cyclist following closely behind. Moreover, the benefit of a third-position cyclist on a second-position cyclist is likely to be greater at higher velocities.

Table 1. Studies investigating the effects of drafting on cyclists.

Study	Subjects	Speed/ Wheel Gap	Drafting Positions	Results
Reduction of wind resistance and power output of racing cyclists and runners traveling in groups (Kyle, 1979)	Cyclists only (*n* not specified)	24, 32, 40, 48 and 56 kph (approximately 15, 20, 25, 30, and 36 mph, respectively) 0.30 m wheel gap	Position 2 (in either a 2-man, 3-man, or 4-man pace line)	Position 2 estimated power reduction: 24 kph: 29% 32 kph: 31% 40 kph: 33% 48 kph: 34% 56 kph: 35% Presence of third and fourth riders had no effect on position 2
The effect of drafting and aerodynamic equipment on energy expenditure during cycling (Hagberg & McCole, 1990) Energy expenditure during bicycling (McCole, et al., 1990)	28 trained competitive cyclists or triathletes	25 mph 6-18 inch wheel gap	Position 2 (in 2-man pace line), Position 3 (in 3-man pace line), Position 5 (in 5-man pace line), Middle-back position (in 8-man peloton with two front riders, three middle riders, and three back riders), Behind a truck	VO_2 reductions: Position 2: 26 ± 8% Position 3: 27 ± 6% Position 5: 27 ± 7% Peloton: 39 ± 6% Truck: 62 ± 6%
Racing cyclist power requirements in the 4000-m individual and team pursuits (Broker, et al., 1999)	7 male U.S. cycling pursuit team members	60 kph (37.3 mph)	All 4 positions in a 4-man pace line	Power (% of the leader): Leader: 607 W (100%) Pos. 2: 430 W (70.8%) Pos. 3: 389 W (64.1%) Pos. 4: 389 W (64.0%)
Aerodynamic characteristics as determinants of the drafting effect in cycling (Edwards & Byrnes, 2007)	13 trained competitive male cyclists	45 kph (28 mph) < 0.5 m wheel gap	Solo (no drafting) vs. Position 2 (in a 2-man pace line)	Power output required while drafting was 131 W (33.25%) less compared to cycling solo

Table 1(continued). Studies investigating the effects of drafting on cyclists.

Study	Subjects	Speed/ Wheel Gap	Drafting Positions	Results
Effects of cycling alone or in a sheltered position on subsequent running performance during a triathlon (Hausswirth, et al., 1999)	8 male international level triathletes	Speed of the drafting trial was dependent on the speed of the solo trial. (Drafted a professional cyclist whose job was to reproduce all split times recorded in the solo trials)	Solo trial vs. drafting trial during the biking portion (20 km) of a sprint distance triathlon	Drafting vs. solo: VE: 112.1 vs. 162.2 L/min VO_2: 55.2 vs. 64.2 ml/kg/min HR: 155 vs. 166.8 bpm $[La^-]_b$: 4.0 vs. 8.4 mmol/L (all significantly lower for drafting trial) Drafting trials significantly improved subsequent running speed compared to solo trials (17.8 vs. 17.1 kph)
Effect of two drafting modalities in cycling on running performance (Hausswirth, et al., 2001)	10 male national level triathletes	Speed of the continuous draft trial was dependent on the speed of the alternating draft trial. (Drafted a professional cyclist whose job was to reproduce all split times recorded in the alternating draft trails)	Alternating between lead cyclist and drafting cyclist every 500 m vs. drafting continuously during the biking portion (20 km) of a sprint distance triathlon	Continuous vs. alternating draft: VE: 148.1 vs. 167.2 L/min VO_2: 49.9 vs. 59.8 ml/kg/min HR:154.7 vs. 173.1 bpm $[La^-]_b$: 3.5 vs. 6.3 mmol/L (all significantly lower for continuous drafting trial) Continuous draft bike trials significantly improved subsequent running speed (+4.2%) compared to alternating draft trials (17.87 vs. 17.15 kph)

The CycleOps PowerTap

The CycleOps PowerTap is a device that is attached to the rear hub of bicycle to measure the torque and power output that is generated by the cyclist. The PowerTap is manufactured by Saris Cycling Group, Inc., in Madison, WI; the manufacture claims that the PowerTap is accurate to within 1.5%.

In a study investigating the validity and reliability of the PowerTap power meters (Bertucci, et al., 2005), the power meters were compared to the most accurate power device available, the SRM power measuring crank system (manufacturer’s claim: ± 0.5% accurate), at power outputs of 100-420 Watts (W). The authors found that the reliability of the PowerTap meter is very similar to SRM system (with coefficients of variation of 0.9-2.9% and 0.7-2.1%) and concluded that PowerTap meters have an accuracy of ± 2-3% between 100-420 W, slightly greater than the manufacturer’s claim, but still an accurate and reliable device for measuring power output during both real road cycling and laboratory testing (Bertucci, et al., 2005). Additionally, and perhaps most importantly, the accuracy of this device may exceed that of the power estimation methods used by Kyle in 1979 and it exceeds the oxygen consumption measures used by Hagberg & McCole in 1990. Therefore, if that benefit of being drafted exists but was previously too small to be detected by available equipment, as Hagberg & McCole suggest, it may now be possible to observe with the use of the PowerTap power meters.

Methodology

Sample Selection

This study included a sample of 13 consenting cyclists (10 males, 3 females) from the Harrisonburg, VA area who were able to maintain a cycling speed of approximately 30 mph and a drafting distance of 0.5 meters or less over at least 0.5 miles of a 1% downhill grade stretch of road. Each subject was smaller, in both height and weight, than the designated lead cyclist.

Each subject served as a second-position cyclist in a line of 2 or 3 cyclists. Additionally, one lead cyclist was selected to participate in each trial, and 2 cyclists of similar height, weight, age, $VO_{2\ max}$ and drafting ability served as third-position cyclist.

Study Design

Trials were performed under 3 conditions; solo (just the subject without a lead or trailing cyclist), a 2-cyclist line (lead cyclist and one drafting cyclist), and a 3-cyclist line (lead cyclist and two drafting cyclists), and at two speeds, MS (target speed of 20 mph) and HS (target speed of 30 mph, or as fast as possible). Each subject performed 2 solo MS trials, 2 solo HS trials, 2 MS trials in a 2-cyclist line, 2 HS trials in a 2-cyclist line, 2 MS trials in a 3-cyclist line, and 2 HS trials in a 3-cyclist line. Therefore, each subject performed 12 total trials. Trials alternated between MS and HS, and the order of the conditions was counterbalanced. Each trial took place on the same 1% downhill stretch of road, with an acceleration phase, a 0.5-mile data collection phase, and a deceleration phase. Subjects were asked to keep a drafting distance of less than 0.5 meters. The close drafting distances, along with the high speeds, were used to maximize the drafting effects and magnify the proposed benefits. All subjects were required to maintain a constant racing position on the bike (gripping the dropped portions of the handlebars) for each of the 12 trials. Also, each subject used his or her same bike with the same seat height, handlebar height, and tire pressure, and each subject wore his same clothing for all 12 trials. All trials for each drafting cyclist were performed on the same day.

CycleOps PowerTap (Saris Cycling Group, Inc., Madison, WI) portable cycling power meters (manufacturer's claim: accurate to within ± 1.5%) were used to measure speed and power throughout the trials for each subject. Average speed and power was determined across each trial. A PowerTap was also used by the leading cyclist to monitor and maintain the proper speed, as speed is displayed on the unit mounted on the handlebars. An anemometer and a wind vane were used to measure wind velocity and wind direction, respectively. Wind velocity was measured parallel to the road and was recorded as a positive (backwind) or negative (headwind) number relative to the cyclists' direction of travel.

Statistical Analysis

Power output data for each speed by condition trial was analyzed for normality with a Shapiro-Wilkes test of normality. As there were no significant deviations from a normal distributions, power differences between trials were analyzed via repeated measures ANOVA (2 speeds x 3 conditions) with two within-subject factors. Post hoc, multiple comparisons with *Bonferonni* correction were used to analyze differences between trials carried out at the same speed. Given the expected directional differences between power outputs, a 1-tailed test was used for the multiple comparisons of power output; other comparisons (speed and wind) were analyzed using a 2-tailed test. An *a priori* level of significance was set at $p < 0.05$. All data was reported as means ± S.D.

Results

The designated lead cyclist was 190.5 cm tall, 99 kg with an absolute $VO_{2\ max}$ of 6.14 L/min, and a relative $VO_{2\ max}$ of 60.8 mL/kg/min. The 2 designated third-position cyclists were 180 cm tall, 70 kg with an absolute $VO_{2\ max}$ of 4.826 L/min, and a relative $VO_{2\ max}$ of 69.0 ml/kg/min; and 178 cm tall, 67.27 kg, with an absolute $VO_{2\ max}$ of 4.871 L/min, a relative $VO_{2\ max}$ of 71.6 mL/kg/min. The lead cyclist and third-position cyclists were selected, in part, for their ability to maintain a constant cycling speed of up to 30 mph over a 0.5-mile distance for repeated trials. Second-position cyclists were on average 175.46 ± 5.23 cm in height, 68.57 kg ± 4.45 kg, and 23.75 ± 7.57 years old. Data analysis was based on 12 subjects since one subject did not complete all solo trials. Nine of the twelve subjects agreed to complete $VO_{2\ max}$ cycle tests; of these nine subjects, average absolute $VO_{2\ max}$ was 4.34 ± 0.42 L/min and average relative $VO_{2\ max}$ was 62.25 ± 7.85 mL/kg/min.

Significant main effects were found for speed ($p = 0.000$), condition ($p = 0.001$), and speed * condition ($p = 0.017$). Post hoc analyses revealed significant differences ($p < 0.001$) in power production between the solo condition and 2-line condition and between the solo condition and the 3-line condition at both speeds (Figure 1); however, there was no significant difference between the 2-line and 3-line conditions ($p = 0.216$).

Table 2. Average speed for each condition.

	Moderate Speed (MS)	**High Speed (HS)**
Condition	**Speed ± S. D. (mph)**	**Speed ± S. D. (mph)**
Solo	20.73 ± 0.41	28.22 ± 2.27
2-line	20.56 ± 0.61	27.78 ± 1.37
3-line	20.66 ± 0.54	27.79 ± 1.35

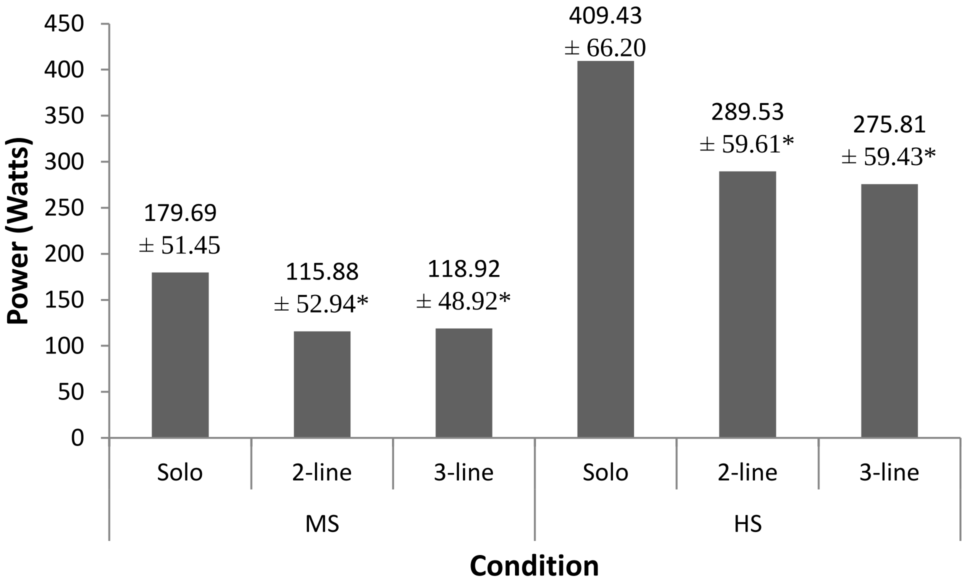

Figure 1. Average power output for each condition at each speed. *Power is significantly lower during the drafting trials compared to the solo trials at the $p < 0.05$ level.

Average speeds were 28.22 ± 2.27 mph, 27.78 ± 1.37 mph, and 27.79 ± 1.35 for the solo, 2-line, and 3-line conditions, respectively. There were no significant differences in speed (Table 2) between trials ($p = 0.549$). Average wind speeds were 5.01± 11.44 mph, 3.92 ± 11.42 mph, and 6.36 ± 11.26 mph for the solo, 2-line, and 3-line conditions, respectively, in the direction of travel (tailwinds). There was a significant main effect for wind (p = 0.016). While there was no significant differences between the solo condition and the 2-line condition (p = 1.000) or between the solo condition and the 3-line condition (p=.636), there was a significant difference (p = 0.012) between wind speeds at the 2-line and 3-line condition.

Discussion

As expected from previous studies (Broker, et al., 1999; Edwards & Byrnes, 2007; Hagberg & McCole, 1990; Hausswirth, et al., 1999; Hausswirth, et al., 2001; Kyle, 1979; McCole, et al., 1990), drafting significantly reduced the power output required of the subjects to hold a given speed in comparison to the solo trials (Tables 2 & 3, Figures 1 & 2). This held true for both speeds and for both the 2-line and 3-line conditions. At MS, the 2-line condition resulted in a 35.51% power reduction compared to the solo condition, and the 3-line condition resulted in a 33.82 % power reduction compared to the solo condition. According to Kyle (1979), at 20 mph, drafting resulted in a 31% decrease in power output, similar to what was found in this study. At HS, the 2-line and 3-line conditions resulted in 29.28 % and 32.64% power reductions, respectively, compared to the solo condition. Other researchers report that drafting at 28 mph resulted in a 33.25% benefit compared to solo trials (Edwards & Byrnes, 2007), and a 34% benefit at 30 mph (Kyle, 1979). The literature shows an increase in percent power reduction as the speed increases, however, the results of this study show a slight decrease at HS compared to MS. This may be due to the subjects having a more difficult time keeping ideal drafting distance and position at greater speeds. This, in addition to the fact that the subjects were actually traveling slightly less than 28 mph on average, may also account for the slightly smaller percent power reductions at HS than those reported in the literature. Also, given that the 2-line benefit of drafting (drafting effect) at HS is lower (29.28%) than the effect at MS (35.51%), the potential benefit of reducing the drag with a third rider may be greater. At MS, the 2-line condition required, on average, 3.0 ± 13.8 W less than the required output of the 3-line condition; and, at HS, the 3-line condition required, on average, 13.7 ± 30.2 W less than the required power output of the 2-line condition (Figure 2). Although, a t-test for paired comparisons between these means showed no significance (p = 0.13), the required increase in power output as one increases speed from about 20 mph to around 28 mph may be disproportionate to the drafting effect associated with the same increase, making the presence of a third rider all the more important.

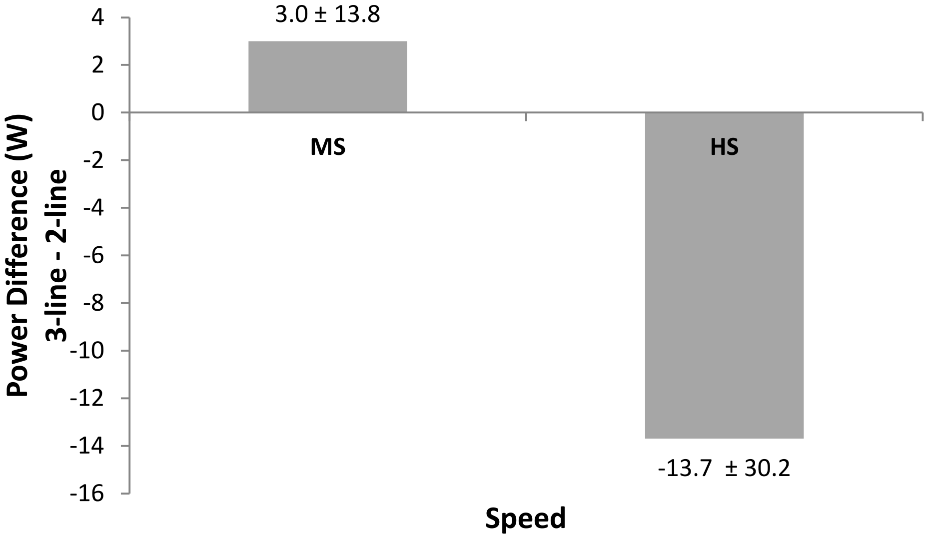

Figure 2. Power difference (power at 3-line minus power at 2-line) at MS and HS.

While the power difference of 13.7 ± 30.2 W between conditions at HS was not significant (p = 0.216), the power requirement of the 3-line condition was 4.74% less than that of the 2-line condition. This 4.74% reduction in power output falls in between the 1-3% estimate by Hagberg and McCole (1990) and the 5% estimate by Iniguez-de-la Torre and Ingiguez (2009). A 4.74% decrease in energy expenditure could potentially have a sizable influence on performance during long-distance cycling events.

Since the benefits of drafting have been shown to be magnified at greater speeds (Kyle, 1979), and some subjects had trouble maintaining 28-30 mph over all of the HS trials, the subject pool was reduced to the fastest subset of riders that still provided a normal distribution of the power output data and a reasonable degree of statistical power (n = 8) (Figure 3). Also, it seems reasonable to assume that the faster cyclists also represent the stronger, more experienced cyclists who are more likely to be skilled drafters. Therefore, the subset of the 8 fastest cyclists may be a better representation of the population of highly trained, competitive cyclists. For the 8 fastest cyclists, average speed for the HS trials was 28.45 ± 1.09 mph for the 2-line condition and 28.43 ± 0.94 mph for the 3-line condition; and, the power output for the 3-line condition was significantly less than that of the 2-line condition ($p = 0.0325$) (Figure 3). Importantly, there was no difference in wind ($p = 0.071$) or speed ($p = 0.368$) across the 3 conditions (Table 3); and, a Shapiro-Wilkes test of normality found that the power data for this subset of subjects was normally distributed. It should be noted that there was no difference ($p = 1.00$) in power output between the 2- and 3-lines conditions for these 8 subjects at MS.

Table 3. Average speed and wind speed for the 8 fastest cyclists at HS for all conditions.

Condition	Speed ± S. D. (mph)	Wind ± S. D. (mph)
Solo	29.21 ± 2.14	3.71 ± 12.12
2-line	28.45 ± 1.09	2.56 ± 11.52
3-line	28.43 ± 0.94	4.99 ± 11.76

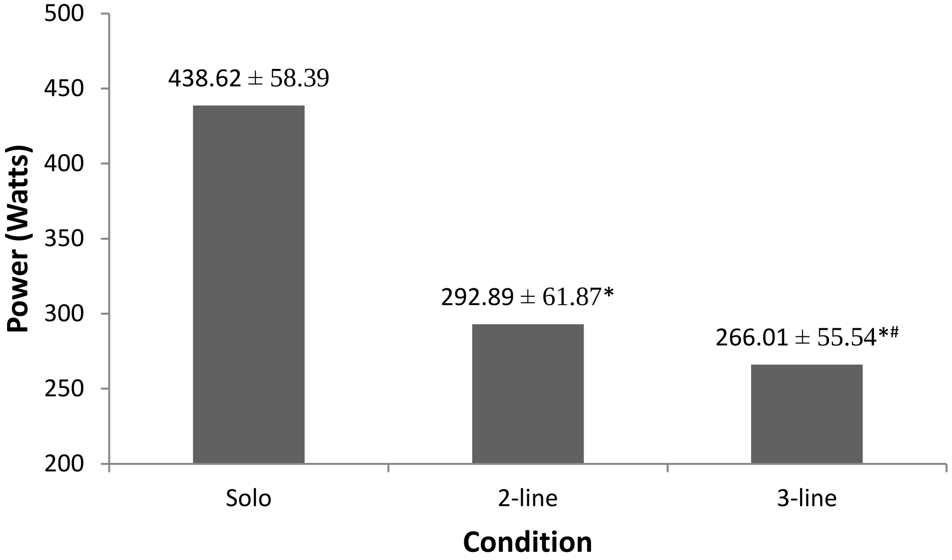

Figure 3. Average power output for the 8 fastest cyclists at HS for all 3 conditions. *Power is significantly lower during the drafting trials compared to the solo trials at the $p < 0.05$ level. #Power is significantly lower in the 3-line condition compared to the 2-line condition ($p = 0.0325$).

After the subject pool was reduced to the 8 fastest cyclists, at HS, the 3-line condition required an average of 26.88 W less than the required power output of the 2-line condition. This 26.88 W reduction equates to a 9.18% power reduction which exceeds the 5% estimate by Iniguez-de-la Torre and Ingiguez (2009). It seems likely that this difference may have positive performance implications on long-distance cycling events.

This knowledge can be applied to endurance cyclists to aid in positioning during a race. While it is advantageous to draft behind another cyclist, it may also be advantageous to have another cyclist following closely behind to decrease turbulence. This potential reduction in energy expenditure could be essential in a close race, especially when the competitors are of equal or similar training status and/or ability.

Even though there was no main effect of wind speed (p = 0.071) for the 8 fastest cyclists' HS trials, the average wind speed for the 3-line condition was faster than it was for the 2-line condition in favor of the cyclists (tailwind) (Table 3).

In an attempt to account for the wind data in the power comparison of these 8 fastest cyclists, wind difference scores were computed for the difference in wind for any given subject in the 2-line versus the 3-line condition. Wind difference was then used as a covariate in a 1 speed (HS) x 2 conditions (2-line vs. 3-line) repeated measures ANOVA of power, and there was no longer any significant power difference between the conditions (p = .220). However, because the interpretation of the wind data is challenging, since the average wind among all conditions was a tailwind, it would seem that the wind would more positively affect the second-position cyclist (in terms of decreased power required to maintain speed) in the 2-line condition compared to the 3-line condition where the tailwind's effect may be partly nullified by the presence of the third-position cyclist. In other words, the tailwind should serve to decrease the power requirement of the second-position cyclist more so in the 2-line condition than in the 3-line condition (due to the third-position cyclist's wind-shielding effect). A Pearson-product moment correlation of the 8 fastest subjects at HS was used to determine whether or not there was a relationship between the difference in wind and the difference in power between the 2- and 3-line conditions. This test showed a non-significant (r = -0.268; p = 0.521) correlation. In summary, it is difficult to estimate the magnitude of wind's effect on the second-position cyclist in the 2- and 3-line conditions; however, it seems reasonable to believe that the subjects would experience, if anything, a greater power reduction in the 2-line condition compared to the 3-line condition with a tailwind.

A notable trend, especially evident in the subset of the 8 fastest cyclists, is that the subjects were, on average, slightly faster in the solo trials (29.21 mph), compared to the drafting trials (28.44 mph), suggesting that the drafting condition may require more speed adjustments to maintain speed and position.

In order to decrease variability among trials, it was beneficial to have only one lead cyclist and 2 trailing (third-position) cyclists. However, since one person served as the leading cyclist for each trial, and 2 cyclists of similar stature and skill served as the third-position cyclist for each trial, power output for those cyclists cannot be meaningfully compared to power output of the second-position-cyclist subjects. Future studies should investigate the differences between power outputs of the second- and third-positions within a 3-cyclist line in order to determine whether the second-position or third-position is more advantageous in terms of energy reduction. Future studies could also investigate the power output of the lead rider while riding solo, riding with one trailing cyclist, and riding with two trailing cyclists to determine the effects on the lead rider's power output.

In conclusion, this study, compared to those of the past, provides greater evidence for the energy-reduction benefits of being drafted on a bicycle while drafting another. The data suggests a power savings of 4.74-9.18% at about 27-28 mph. Power output reductions within this range could prove extremely beneficial to performance throughout the course of a long-distance race.

Appendix I
Data Sheet

Drafting Trials Speed x Condition #:____________

Subject Number: __________________________ Subject Height: ____________ inches

Shoulder Width: _____________ inches Shoulder Height on Bike: ____________ inches

Tire Pressure: _______________psi (100-110 psi)

Temperature: ____________^{o}F Humidity: ______________

Atmospheric Pressure: _______________

Wind:	Speed (mph)	Direction
Trial 1:	__________	________
Trial 2:	__________	________
Trial 3:	__________	________
Trial 4:	__________	________
Trial 5:	__________	________
Trial 6:	__________	________
Trial 7:	__________	________
Trial 8:	__________	________
Trial 9:	__________	________
Trial 10:	__________	________
Trial 11:	__________	________
Trial 12:	__________	________

Checklist:

___ Constant seat height

___ Constant handlebar height

___ Constant racing position (i.e. hand placement on dropped portion of handlebars)

___ Unaltered clothing/gear/bike

___ Constant/desired drafting distance from start to finish (within 0.5 meters between tires)

Appendix II
Informed Consent

Consent to Participate in Research

Identification of Investigators & Purpose of Study

You are being asked to participate in a research study conducted by M. Kent Todd, Mike Saunders, Will Norman, and Jess Zozos from James Madison University. The purpose of this study is to test the drafting effects of cyclists and to develop power profiles of the cyclists.

Research Procedures

This is a two part study that aims to evaluate specific training (Part I) and drafting (Part II) methods recommended for competitive cyclists.

In order to participate in the study you must be classified as a trained male cyclist, capable of performing multiple cycling trials at 30 mph, in a pace line over at least 0.5 miles of flat road.

In order to participate in the study you will also have to complete a health screening questionnaire and be determined to be at low risk for cardiovascular disease or have a physician's consent for participation if any risk factors or other heath issues are present.

If you are cleared to participate, you will report to room 209 or 217 Godwin Hall, James Madison University, at a time mutually agreed on by you and the researcher. When you arrive you will complete a lactate threshold/$VO_{2\ peak}$ cycling test. The procedure for this test is as follows:

Lactate threshold/$VO_{2\ peak}$ cycling test (needed for Part I and Part II):

You will cycle on a stationary cycle ergometer at a self-selected pace and workload that is comfortable, but not easy, for a one-hour ride. You will ride at this workload for three minutes then stop pedaling for a brief recovery period. Blood will be obtained after 1 minute of recovery. After the blood sample is obtained, the cycle test will resume by having the subject ride at the next stage (+25 W) for three minutes. Each stage lasts three minutes, each new stage is +25 W from the prior stage, and blood will be collected after one-minute of recovery period following the end of each stage. This procedure will continue until you exceed lactate threshold (> 4 mmol/L; or approximately after 3 to 6 stages). Once lactate threshold is exceeded, the test will switch to 1-minute stages (+25 W per stage) until $VO_{2\ peak}$ is reached. This testing session will take approximately one hour.

One to two drops of blood will be collected via finger stick. The fingertip will be cleaned with an alcohol prep pad and then the finger will be pricked with a lancet. Blood will be collected in a capillary tube. Once the blood has been collected, the bleeding fingertip will be covered with sterile gauze until the bleeding stops. Adhesive bandages will be available if needed.

You will then meet on another date to perform drafting trials at a time and place mutually agreed on by you and the researcher. The procedure for the drafting trials are as follows:

Drafting trials (Part II only):

You will perform 12 short field trials of 3 to 4 minutes each in a single testing session. The session will include 3 trials for each condition (2 riders or 3 riders) and speed (20 mph and 30 mph) combination. Condition will be randomly counter-balanced from trial to trial, while speed will be counter-balanced, alternating uniformly between the two speeds from one trial to the next. Each trial will take place on the same flat stretch of road, with a 100-yard acceleration phase, a 0.5-mile data collection phase, and a 100-yard deceleration zone. You will draft the lead rider at a safe distance within 0.5 meters. You will be required to maintain a constant racing position on the bike (gripping the dropped portions of the handlebars) for each of the 12 trials. Also, you will need to use the same bike with the same seat height, handlebar height, and tire pressure, and you will wear the same clothing (cycling clothes) for all 12 trials. This will take approximately two hours.

You also will be asked to complete a functional threshold power test and a power profile test on another day. If you agree to participate, you will again report to room 209 or 217 Godwin Hall at a time mutually agreed on by you and the researcher. The procedures for these tests are as follows:

Functional threshold power test (Part I):

On a separate occasion, you will participate in testing for FTP in the Human Performance Lab. The FTP test involves cycling for approximately 90 minutes on a stationary cycle ergometer. The protocol includes, in order, cycling for 1) 20 min at 65% of maximal heart rate (warm-up) 2) 3 x 1 minute intervals at 100 rpm with 1 minute recovery between each, 3) 5 minutes at 65% of maximal heart rate, 4) 5 minutes at the fastest pace that can be maintained throughout those 5 minutes, with a little reserve to pedal harder in the last minute, 5) 10-minute ride at 65% of maximal heart rate, 6) 20-minute time trial, the main portion of the test, where the goal is to produce the highest average watts over the entire period, 7) 15 minutes of cycling at 65% of maximal heart rate, and 8) 10 minutes of cool-down at an easy pace. FTP is determined by subtracting 5% from the average power (Watt) for the 20-minute time trial.
60 Minute Field Trial.

You will also perform an all out, solo time trial on a 4.75 mile course that has been marked and is frequently used for cycling time trials. The course is relatively flat and located on Dry River Road between Ottobine Road and Clover Hill Road. During this trial you will repeatedly cycle the course for a total of 60 minutes. At 60 minutes you will record the distance cycled, average speed and average power output. You will complete the time trial on a calm day within 2 weeks of the FTP testing. This data will be used to compare how well FTP, VO2peak and lactate threshold predict performance in the field. This will take one hour.

Time Required

The time required for this study includes the following. Explanation of the study, informed consent and lactate/$VO_{2\ peak}$ testing will take approximately one hour. The field testing will take approximately 2 hours on a separate day. The functional threshold power test will take about 90 minutes (including warm-up and cool-down) and the power profile test will take about 30 minutes.

Therefore, total time commitment for each subject will be approximately 3 hours (over the course of two separate days) if you are only completing Part II (the lactate/$VO_{2\ peak}$ test and field tests). However, if you are completing both Part II and Part I (the lactate/$VO_{2\ peak}$ test, field tests, **AND** the functional threshold power test) total time commitment for each subject will be approximately 5 hours (over the course of four separate days).

Risks

Although the procedures utilized in this study are consistent with professional recommendations and precautions have been implemented to minimize the risk, you will be at increased risk for cardiovascular events during the $VO_{2\ peak}$ test. Based on data presented in the American College of Sports Medicine's, Guidelines for Exercise Testing and Prescription (ACSM, 2009) the risk of sudden cardiac death during vigorous exercise is estimated to be less than or equal to one event per year per 15,000 people and the risk of a cardiac event is approximately 6 in 10,000. Cardiac events include heart attack, hospitalization and death. There is a possibility of other physical changes during the graded exercise testing. These include abnormal blood pressure changes, fainting, and irregular, fast or slow heart rhythm. Every effort will be made to minimize these risks by evaluation of information relating to your health and fitness based on guidelines of the ACSM (2009) and by careful observation of the ACSM signs and symptoms of cardio-respiratory distress (2009) during testing.

There is minimal risk of a crash associated with participation in this study for the population of trained cyclists who possess the necessary skills, technique and drafting experience. Participation in this study will be under controlled conditions (e.g., specific speed and drafting distance parameters) and the investigators will be carrying cell phones that can be used to contact emergency services if needed. To further enhance your safety, you will be required to wear the necessary protection (i.e. helmets) and to participate in pilot testing to make sure that you are capable of safely cycling at the required speeds and distances.

There is a slight risk of infection as a result of the finger sticks; however all safety precautions will be followed to minimize this risk.

You should report any unusual shortness of breath, chest or muscular pain or other unusual symptoms experienced during or after the testing to the researcher. The researchers directly involved in data collection are trained to recognize the ACSM signs and symptoms of cardio-respiratory distress and are CPR certified. If an emergency occurs during laboratory testing the JMU emergency services will be contacted immediately by dialing 6911. If an emergency occurs during field testing an investigator will contact 911 on a cell phone.

Benefits

The benefits associated with this study include free VO2max and lactate threshold testing (greater than $100 value if paid for as a retail service) and the gathering new information that may contribute to a better understanding of the relationship between drafting positions and energy requirements to maintain a given speed.

After data has been collected from all subjects and analyzed, the summary data from this study may be shared with others as a professional presentation and/or publication. These summary results will be made available to you upon your request.

Confidentiality

All collected data and recording sheets, including the health history data, will be coded such that your identity will not be attached to the documents or the data spreadsheet. The data will remain anonymous and be kept in a locked cabinet or a password-protected computer. A document that links your identity to the code will also be kept in a locked cabinet until all subjects have completed the study. When the data collection is complete and the data has been recorded into the data spreadsheet the code sheet will be destroyed. Consent forms will be retained and kept in a locked cabinet. Subject codes will not be written on the consent form.

The researcher retains the right to use and publish non-identifiable data. While individual responses are confidential, aggregate data representing averages or generalizations about the responses as a whole may be presented at professional conferences, seminars and/or on the form of published papers. All data will be stored in a secure location accessible only to the researcher. Upon completion of the study, any information that matches up individual respondents with their answers will be destroyed.

Questions about the study

If you have any questions or concerns, please contact:

M. Kent Todd, PhD
Kinesiology
James Madison University
Telephone: [redacted]
toddmk@jmu.edu

Michael Saunders, PhD
Kinesiology
James Madison University
Telephone: [redacted]
saundemj@jmu.edu

Will Norman
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James Madison University
Telephone: [redacted]
normanwa@jmu.edu

Questions about Your Rights as a Research Subject

Dr. David Cockley
Chair, Institutional Review Board
James Madison University
[redacted]
cocklede@jmu.edu

Giving of Consent

I have read this consent form and I understand what is being requested of me as a participant in this study. I freely consent to participate. I understand that I have the right to withdraw from this study at anytime, for any reason and without any consequence of any kind. I have been given satisfactory answers to my questions. The researcher provided me with a copy of this form, and I certify that I am at least 18 years of age.

<u>Please read and initial the following:</u>

______ I understand that there is a risk of cardiovascular complications during the exercise test including heart attack, the need for emergency procedures, hospitalization and death.

____

Name of Participant (Printed)

______________________________________ ______________

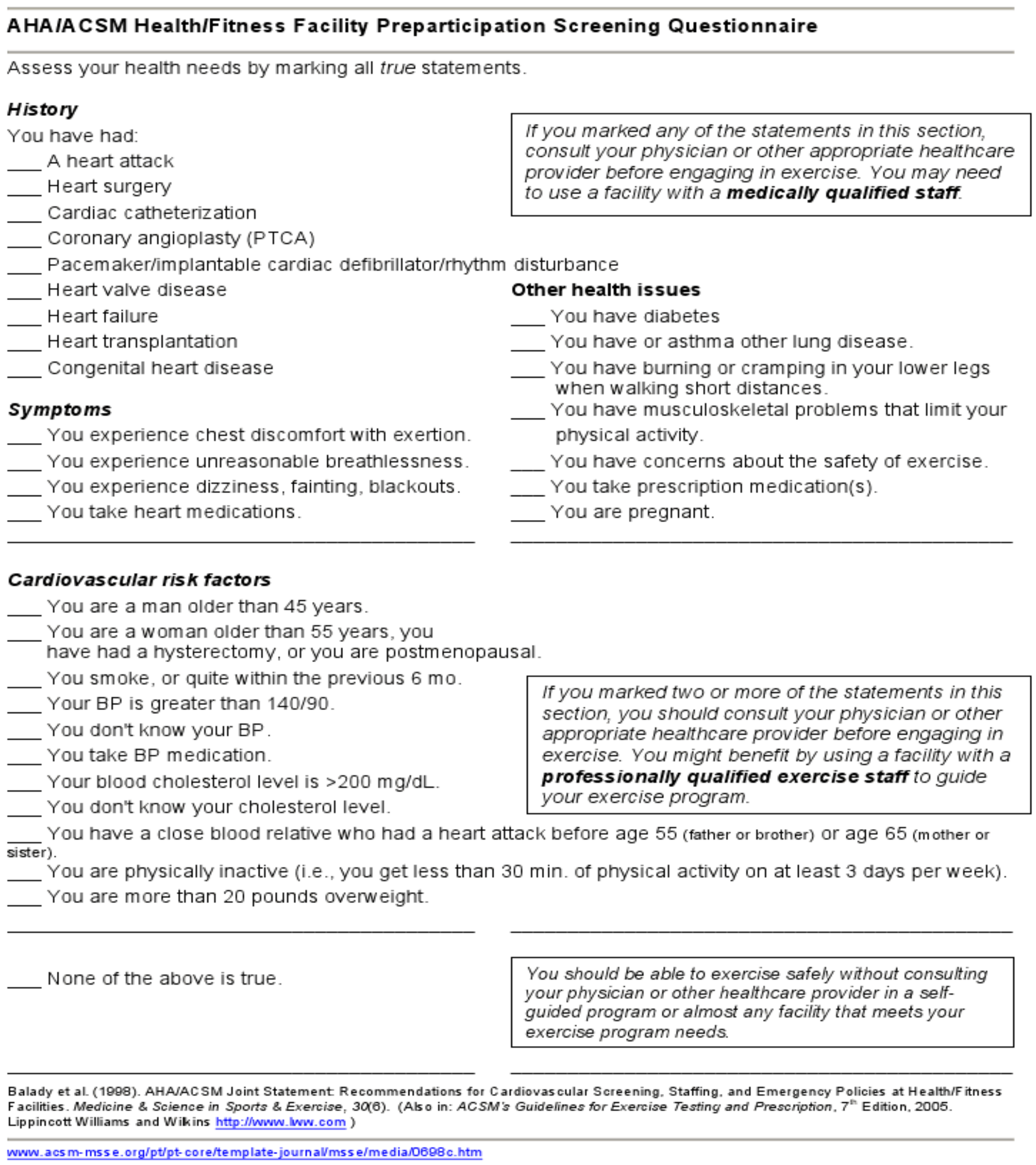
Name of Participant (Signed) Date

______________________________________ ______________

Name of Researcher (Signed) Date

Appendix III
Participation Screening Questionnaire

James Madison University
School of Kinesiology and Recreation Studies



AHA/ACSM Health/Fitness Facility Preparticipation Screening Questionnaire

Assess your health needs by marking all *true* statements.

History

You have had:
___ A heart attack
___ Heart surgery
___ Cardiac catheterization
___ Coronary angioplasty (PTCA)
___ Pacemaker/implantable cardiac defibrillator/rhythm disturbance
___ Heart valve disease
___ Heart failure
___ Heart transplantation
___ Congenital heart disease

If you marked any of the statements in this section, consult your physician or other appropriate healthcare provider before engaging in exercise. You may need to use a facility with a ***medically qualified staff****.*

Symptoms

___ You experience chest discomfort with exertion.
___ You experience unreasonable breathlessness.
___ You experience dizziness, fainting, blackouts.
___ You take heart medications.

Other health issues

___ You have diabetes
___ You have or asthma other lung disease.
___ You have burning or cramping in your lower legs when walking short distances.
___ You have musculoskeletal problems that limit your physical activity.
___ You have concerns about the safety of exercise.
___ You take prescription medication(s).
___ You are pregnant.

Cardiovascular risk factors

___ You are a man older than 45 years.
___ You are a woman older than 55 years, you have had a hysterectomy, or you are postmenopausal.
___ You smoke, or quite within the previous 6 mo.
___ Your BP is greater than 140/90.
___ You don't know your BP.
___ You take BP medication.
___ Your blood cholesterol level is >200 mg/dL.
___ You don't know your cholesterol level.
___ You have a close blood relative who had a heart attack before age 55 (father or brother) or age 65 (mother or sister).
___ You are physically inactive (i.e., you get less than 30 min. of physical activity on at least 3 days per week).
___ You are more than 20 pounds overweight.

If you marked two or more of the statements in this section, you should consult your physician or other appropriate healthcare provider before engaging in exercise. You might benefit by using a facility with a ***professionally qualified exercise staff*** *to guide your exercise program.*

___ None of the above is true.

You should be able to exercise safely without consulting your physician or other healthcare provider in a self-guided program or almost any facility that meets your exercise program needs.

Balady et al. (1998). AHA/ACSM Joint Statement: Recommendations for Cardiovascular Screening, Staffing, and Emergency Policies at Health/Fitness Facilities. *Medicine & Science in Sports & Exercise*, *30*(6). (Also in: *ACSM's Guidelines for Exercise Testing and Prescription*, 7th Edition, 2005. Lippincott Williams and Wilkins http://www.lww.com)

www.acsm-msse.org/pt/pt-core/template-journal/msse/media/0698c.htm

Appendix IV
Raw Data

SubID	Ht	Wt	Age	VO2max(L/min)	VO2max(ml/kg/min)
1	69	159	19	4.055	56.1
2	71	165	20	3.935	52.5
3	67	142	41	4.495	69.7
4	68	140	19		
5	70	150	21	4.996	73.3
6	70	140	19		
7	65	140	38	3.867	60.8
8	70	148	22	4.871	71.6
9	70	160	19	4.296	59.1
10	72	163	20	4.071	55.1
11	69	160	20	4.011	55.3
12	71	154	25	4.827	69
13	66	140	21		

Front Area (in^2)	Temp	Humid	2011W	2011D	2011S	2011P	2011T
573	51	0.75	-2.55	-65	20.656	145.613	5.24839
660	56	0.54	-1.86	-67	20.2043	221.281	8.18438
633	57	0.5	-2.35	-78	20.8	201.43	7.2
628	60	0.47	-12.66	-112	20.846	170.2	6.1
576	64.5	0.4	-16.87	-87	20.692	237.839	8.571
491	60	0.44					
473	48	0.39	5.66	117	20.346	92.29	3.406
631	50	0.38	3.51	90	20.9643	177.4	6.29667
405	61	0.34	19.66	40	20.55	220.516	7.99355
530	61.5	0.34	20.87	80	21.2536	202.9	7.10333
510	62	0.31	26.01	100	20.0725	204.75	7.68125
516	48.5	0.39	18.66	70	21.5782	113.964	3.8069
576	48	0.35	0.49	90	20.488	130.935	4.76452

2012W	2012D	2012S	2012P	2012T	201AW	201AD	201AS	201AP
0		20.7059	154.7	5.59333	-1.275	-65	20.68095	150.1565
0		20.52	206	7.477	-0.93	-67	20.36215	213.6405
-3.65	-72	20.496	191.484	6.984	-3	-75	20.648	196.457
-9.35	-95	20.869	223.1	7.977	-11.005	-103.5	20.8575	196.65
-21.88	-80	20.31	272.387	10.09	-19.375	-83.5	20.501	255.113
-0.49	150	20.062	85.484	3.203	2.585	133.5	20.204	88.887
5.5	93	22.0543	210.464	7.125	4.505	91.5	21.5093	193.932
17.87	100	20.8878	220.767	7.93333	18.765	70	20.7189	220.6415
17.87	108	21.016	228.613	8.14516	19.37	94	21.1348	215.7565
19.51	103	20.412	194.903	7.09355	22.76	101.5	20.24225	199.8265
8.66	32	21.0242	113.067	4.00667	13.66	51	21.3012	113.5155
10.65	45	20.752	92.4839	3.32258	5.57	67.5	20.62	111.7095

201AT	2021W	2021D	2021S	2021P	2021T	2022W	2022D	2022S
5.42086	2.66	45	20.456	51.9677	1.9	7	68	20.52
7.83069	-4	-67	20.8237	94.2667	3.37667	0		21.435
7.092	-0.65	-57	20.9581	80.2	2.85333	-5.66	-117	20.97
7.0385	-8.01	-108	21.264	97.5	3.425	-4.16	-102	20.54
9.3305	-18.16	-112	20.043	120.469	4.478	-19.35	-83	20.57
	-10.16	-102	20.148	106.581	12.262	-3	-100	20.608
3.3045	12.37	78	20.644	35.226	1.281	8.5	83	20.67
6.710835	6.15	125	21.0097	99.7333	3.55	5.14	105	21.111
7.96344	23.17	90	19.809	197.875	7.45313	21.88	97	19.8361
7.624245	14.52	82	19.4098	183.545	7.10909	21.36	100	19.406
7.3874	16.67	130	19.8943	200.844	7.525	20.67	103	19.5765
3.906785	13.02	37	20.9415	84.0667	2.99667	23.17	47	21.3218
4.04355	12.17	57	20.9415	77.2667	2.75	6.85	70	21.2123

2022P	2022T	202AW	202AD	202AS	202AP	202AT	2031W	2031D
82.9355	3.02903	4.83	56.5	20.488	67.4516	2.464515	-4.85	-80
166.345	5.772	-2	-67	21.12935	130.3059	4.574335	-7.65	-117
100	3.57	-3.155	-87	20.96405	90.1	3.211665	-2.86	-152
126.065	4.565	-6.085	-105	20.902	111.7825	3.995	-3.36	-98
123.355	4.484	-18.755	-97.5	20.3065	121.912	4.481	-16.87	-97
109.742	3.96452	-6.58	-101	20.378	108.1615	8.11326	-5.35	-120
57.194	2.068	10.435	80.5	20.657	46.21	1.6745	2.86	135
73.3667	2.59333	5.645	115	21.06035	86.55	3.071665	-3.36	133
203.563	7.625	22.525	93.5	19.82255	200.719	7.539065	13.51	137
174.333	6.70606	17.94	91	19.4079	178.939	6.907575	19.17	88
205.313	7.57576	18.67	116.5	19.7354	203.0785	7.55038	26.17	97
66.6	2.34667	18.095	42	21.13165	75.33335	2.67167	7	35
79.0333	2.78667	9.51	63.5	21.0769	78.15	2.768335	14	78

2031S	2031P	2031T	2032W	2032D	2032S	2032P	2032T	203AW
20.392	82.9032	3.05806	0		20.9663	97.8333	3.45333	-2.425
20.82	133.7	4.8	-6.67	-70	20.857	113.933	4.073	-7.16
20.842	90.4	3.263	-0.13	-170	21.088	85.567	3.033	-1.495
21.303	88.2	3.117	-17	-78	20.6	106.613	3.845	-10.18
19.956	122.75	4.578	-13.67	-110	20.244	119.323	4.381	-15.27
20.376	101.355	3.71613	-0.25	-102	20.9415	63.4	2.25	-2.8
20.596	89.871	3.26452	-6.15	147	20.846	46.933	1.653	-1.645
21.2226	84.2	2.98	-3.13	113	21.3135	113.667	4	-3.245
20.244	203.032	7.48065	13.67	98	19.9369	213.281	7.9625	13.59
19.5281	174.212	6.66364	17.36	100	19.7819	199.875	7.59063	18.265
20.32	177.032	6.49355	23.17	108	20.0376	199.063	7.41563	24.67
21.1358	112.367	3.97667	13.35	72	20.8444	70.3	2.51667	10.175
21.7342	56	1.93103	11.86	42	21.1523	73	2.56	12.93

203AD	203AS	203AP	203AT	3011W	3011D	3011S	3011P	3011T
-80	20.67915	90.36825	3.255695	0		25.9367	332.5	9.49583
-93.5	20.8385	123.8165	4.4365	-1.86	-108	24.765	360.84	10.86
-161	20.965	87.9835	3.148	-6.5	-98	29.276	460.238	11.738
-88	20.9515	97.4065	3.481	0		26.256	369.174	10.452
-103.5	20.1	121.0365	4.4795	-14.85	-90	28.03	525.591	13.982
-111	20.65875	82.3775	2.983065	-7.52	-60	23.7842	326.462	10.2038
141	20.721	68.402	2.45876	8.86	87	30.29	429.1	10.56
123	21.26805	98.9335	3.49	7.52	100	29.1548	490.429	12.5048
117.5	20.09045	208.1565	7.721575	16.35	93	25.7817	344.667	9.9125
94	19.655	187.0435	7.127135	17.52	92	28.1057	414.864	10.9864
102.5	20.1788	188.0475	6.95459	16.87	113	27.4444	375.174	10.087
53.5	20.9901	91.3335	3.24667	18.16	85	31.9626	491	11.4895
60	21.44325	64.5	2.245515	0		30.69	367.15	8.89

3012W	3012D	3012S	3012P	3012T	301AW	301AD	301AS	301AP
0.65	90	25.1823	263.167	7.775	0.325	90	25.5595	297.8335
-7.16	-110	25.281	340.84	10.052	-4.51	-109	25.023	350.84
0		29.264	419.571	10.69	-3.25	-98	29.27	439.9045
-8	-97	25.973	372.167	10.65	-4	-97	26.1145	370.6705
-16.51	-100	28.34	521.667	13.695	-15.68	-95	28.185	523.629
					-7.52	-60	23.7842	326.462
0		29.996	421.4	10.46	4.43	87	30.143	425.25
0.36	140	29.6763	462	11.615	3.94	120	29.41555	476.2145
14.16	97	26.6843	376.391	10.4696	15.255	95	26.233	360.529
21.16	105	29.3939	442.095	11.219	19.34	98.5	28.7498	428.4795
20.67	87	26.6762	375.13	10.4565	18.77	100	27.0603	375.152
23.38	117	33.0047	493.278	11.1667	20.77	101	32.48365	492.139
9.35	75	30.1785	377.85	9.335	4.675	75	30.43425	372.5

301AT	3021W	3021D	3021S	3021P	3021T	3022W	3022D	3022S
8.635415	0		29.329	232.476	5.90476	-4	-80	25.5388
10.456	-1.34	-110	26.9	358.83	9.97	-4.5	-100	27.6097
11.214	-8.5	-95	28.241	312.909	8.245	-10.16	-50	27.257
10.551	-3.65	-75	25.454	222	6.479	-8.37	-107	26.326
13.8385	-16.87	-125	26.854	284.217	7.874	-16.51	-72	28.446
10.2038	-4.16	-113	26.9835	250.913	6.93478	-1.74	-105	28.4491
10.51	4.85	90	29.543	233.85	5.915	6.35	127	28.656
12.0599	3.65	142	28.8418	299.619	7.77143	4	127	27.9141
10.19105	16.35	132	26.1795	345.042	9.77917	18.66	98	25.5388
11.1027	16.15	92	28.0437	415.045	11.0864	19.01	63	27.0859
10.27175	17.16	102	26.2751	330.458	9.37083	17.02	108	26.9188
11.3281	14	70	29.9429	378.75	9.55	8.37	53	30.4017
9.1125	11.86	87	29.3378	210.524	5.34762	10.65	92	30.1072

3022P	3022T	302AW	302AD	302AS	302AP	302AT	3031W	3031D
233	6.7375	-2	-80	27.4339	232.738	6.32113	0	
289.409	7.80455	-2.92	-105	27.25485	324.1195	8.887275	-0.16	-85
190.636	5.177	-9.33	-72.5	27.749	251.7725	6.711	0	
224.913	6.383	-6.01	-91	25.89	223.4565	6.431	-0.36	-153
310.048	8.119	-16.69	-98.5	27.65	297.1325	7.9965	-19.17	-92
265.619	6.98095	-2.95	-109	27.7163	258.266	6.957865	-3.76	-125
212.714	5.543	5.6	108.5	29.0995	223.282	5.729	6.35	93
278.636	7.43182	3.825	134.5	28.37795	289.1275	7.601625	7.65	130
330.75	9.60833	17.505	115	25.85915	337.896	9.69375	16.51	67
330.696	9.06957	17.58	77.5	27.5648	372.8705	10.07799	15.5	102
343.87	9.48696	17.09	105	26.59695	337.164	9.428895	20.87	63
366.4	8.975	11.185	61.5	30.1723	372.575	9.2625	16.51	63
213.95	5.335	11.255	89.5	29.7225	212.237	5.34131	16.51	82

3031S	3031P	3031T	3032W	3032D	3032S	3032P	3032T	303AW
29.0691	307	7.84762	-1.99	-20	25.234	202.542	5.97917	-0.995
26.9457	253.348	7.02174	-4	-115	28.0522	254.409	6.77273	-2.08
28.437	221.095	5.771	-5.14	-123	27.672	205.227	5.518	-2.57
26.129	194.087	5.5	0		26.291	245.174	6.926	-0.18
27.331	300.273	8.168	-15.17	-82	27.288	312.435	8.539	-17.17
26.6627	243.522	17.777	-0.25	-100	26.908	205.261	5.67826	-2.005
29.174	187.45	4.79	10.51	93	29.596	204.25	5.155	8.43
29.2168	296.286	7.54286	4.5	145	27.4519	257.273	6.96364	6.075
25.7429	366.917	10.6667	17.67	107	24.2778	300.577	9.17692	17.09
28.0916	362.364	9.56364	20.67	105	27.4322	315.818	8.56364	18.085
28.0409	399.318	10.5773	20.02	97	27.3177	347.609	9.4913	20.445
29.7104	319.5	8.085	14.65	50	29.8102	338.238	8.48571	15.58
29.4057	224.619	5.68095	10.65	42	29.2758	203.619	5.18571	13.58

303AD	303AS	303AP	303AT
-20	27.15155	254.771	6.913395
-100	27.49895	253.8785	6.897235
-123	28.0545	213.161	5.6445
-153	26.21	219.6305	6.213
-87	27.3095	306.354	8.3535
-112.5	26.78535	224.3915	11.72763
93	29.385	195.85	4.9725
137.5	28.33435	276.7795	7.25325
87	25.01035	333.747	9.92181
103.5	27.7619	339.091	9.06364
80	27.6793	373.4635	10.0343
56.5	29.7603	328.869	8.285355
62	29.34075	214.119	5.43333

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