ORIGINAL ARTICLE

The physiological effects of cycling on tandem and single bicycles

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Objective: The purpose of this field study was to compare the physiological responses from cycling on a tandem road bicycle to those from cycling on a single road bicycle.
Methods: Nine pairs of experienced, recreational tandem cyclists rode a tandem or their single bicycle for 5 min at each velocity of 19.3, 22.5, 25.8, and 29.0 kph on a flat, paved surface. Heart rate (HR), rating of perceived exertion (RPE), and lactic acid (LA) data were collected after each interval.
Results: Riding a tandem resulted in lower HR, RPE, and LA mean values across the four velocities compared to the single bicycle. Mean (SD) HR, RPE, and LA for tandem and single bicycles were 126 (20.7) *v* 142 (20.1) bpm, 10.1 (1.7) *v* 11.3 (2.6), and 1.46 (1.0) mM/L *v* 2.36 (1.7) mM/L, respectively. No position differences were observed between the captain and stoker (front and rear positions) when both were on the tandem. Stokers had significantly lower HR, LA, and RPE values when they rode a tandem compared to a single bicycle. No statistical differences were observed between bicycles for the captains. When on the single bicycle, captains exhibited significantly lower HR, RPE, and LA values than stokers.
Conclusion: Cycling on a tandem resulted in lower physiological stress than when cycling at the same velocity on a single bicycle. Cyclists were able to ride from 4.8–8.0 kph faster on a tandem than on a single bicycle at similar physiological stress. Apparently, stokers can add to power output on a tandem without adding significantly to wind resistance.

Air, rolling, and frictional resistances, as well as the influence of gravity, are forces that must be overcome when riding a bicycle. While cycling on flat roads, the influence of gravity is virtually eliminated. Kyle reported that rolling resistance remains fairly constant during single bicycle cycling regardless of velocity.[1] Likewise, mechanical friction is a small component of the total resistance.[1 2] Air resistance to cycling is by far the largest factor and demands the vast majority of energy expenditure when cycling velocities exceed 19.3 kph.[1 3] In fact, air resistance at 29.0 kph makes up over 80% of the total resistance.[1] Martin *et al* confirmed Kyle's calculations when they reported that aerodynamic drag accounts for 56%–75% of the total resistance during on road cycling.[4] Mathematically, drag created by air resistance increases as the velocity squared. However, the power or energy expenditure to overcome resistance during cycling increases as the velocity cubed. Thus, as velocity increases, an exponentially greater level of power must be produced in order to attain that speed.

In order to minimise air resistance and reduce physiological stress while cycling at higher velocities, cyclists will often draft. Drafting involves cycling in close formation behind another cyclist's rear wheel (within about 0.5 m). Drafting is a key strategy in reducing energy expenditure while riding on a single bicycle. McCole *et al* reported that energy expenditure may be reduced by up to 27% when drafting in tight formation.[5] There is ample research data on the physiological responses during cycling.[1 5–12] However, the primary focus of those previous data involves the role of body position and aerodynamic frames in the hope of reducing wind resistance while cycling on single bicycles.

Tandems have 50% less wind resistance than two single bicycles.[1] Kyle calculated that tandem riders use 20% less power per rider than two separate cyclists when cycling at the same velocity.[1] In essence, the stoker (rear position) is drafting off of the captain (front position) while contributing to power output and adding minimally, if at all, to air resistance.

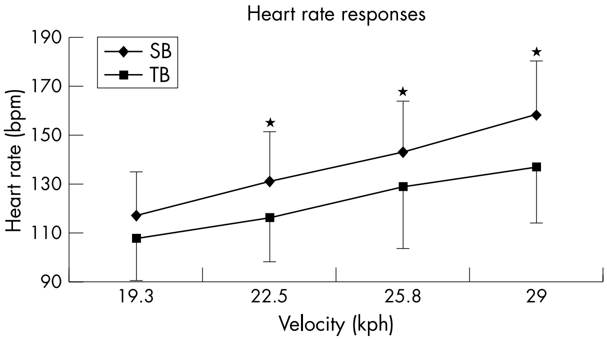
Tandem cycling is growing in popularity in the United States by about 5%–10% per year (personal communication with Burley Design Cooperative and CoMotion Cycles). Even with this rise in popularity, no other studies on tandems have been located. Little is actually known about the physiological responses when cycling on a tandem compared to a single bicycle. Therefore, the purpose of this study was to compare the basic physiological responses when experienced tandem cyclists cycled on a tandem bicycle and a single bicycle.

METHODS

Nine pairs of experienced, recreational road tandem riders volunteered to participate in this study. Average (SD) age and tandem riding experience were 45.5 (6.7) years and 8.3 (6.1) years, respectively. All captains were male and all stokers were female. Approval was obtained from the St. Cloud State University Institutional Review Board and all subjects provided informed consent before data collection began.

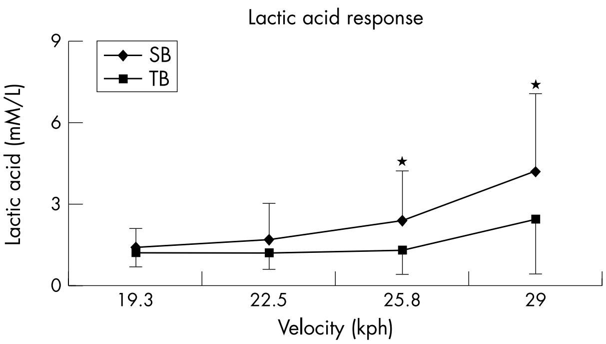
Cyclists rode for five minute intervals at four velocities (19.3, 22.5, 25.8, and 29.0 kph). The flat course had less than 2 m of vertical rise and the pavement was comprised of smooth asphalt. A calibrated bicycle computer was attached to the handlebars and monitored velocity (Cateye Bicycle Computers, Osaka, Japan). The two trials, one using a tandem (Burley Design Cooperative, Eugene, OR, USA) and the other using a single bicycle, were counterbalanced where half of the teams cycled on their own road frame single bicycle and half rode the tandem during the first trial. During the second trial, subjects switched treatments and repeated the test. Environmental conditions were similar for each of the between bicycle trials. Temperature range for these trials was less than 3°C. A slight breeze (< 8 kph) blew across the roadway, but it remained constant and from the same direction.

All riders were required to cycle with their hands on the brakes hoods and to maintain similar body positions during the trials to reduce variability in frontal area, and ultimately, air resistance, between bicycles. Handlebar widths were similar between tandem and the single bicycles. Subjects pedalled



	19.3	22.5	25.8	29
SB	117.5	131.6	143	158.5
TB	107.9	116.4	128.8	136.9

Figure 1 Heart rate responses. Mean (SD); TB: tandem bicycle; SB: single bicycle. *Significantly different from TB.



	19.3	22.5	25.8	29
SB	1.4	1.7	2.4	4.2
TB	1.2	1.2	1.3	2.4

Figure 2 Lactic acid responses. Mean (SD); TB: tandem bicycle; SB: single bicycle; *Significantly different from TB.

at self selected cadences, but were instructed to maintain cadence from one velocity to the next. All cyclists were accustomed to riding both tandem and single bicycles. Tyres were similar in size (700 × 25C) and inflated to manufacturer's specification. Drafting was not allowed during data collection. Subjects drank fluids consistently between the intervals to minimise the effects of dehydration on heart rate (HR) and perceived exertion (RPE). The trials were separated by a 30 min rest period.

Physiological stress was assessed by the HR and lactic acid (LA) responses. Heart rate was collected at 4:30 of each of the five minute intervals (Polar Electro, Polar USA Inc., Stamford, CT). Rating of perceived exertion[13] and a fingertip blood sample, for LA determination (YSI #2300, Yellow Springs, OH, USA), were collected at the end of each interval.

Although this was a 2 × 2 × 4 design (bicycle, position, and velocity), we will report three of the analyses for HR, LA, and RPE data. These include analysing the bicycle × velocity interaction, position × bicycle interaction (including a within position analysis), and then a within bicycle analysis of position. Statistical significance was set at $p < 0.05$.

RESULTS

Bicycle × velocity interaction

A significant interaction was observed for the bicycle × velocity interaction where HR during the tandem trial were lower than the single bicycle trial (figure 1). Post hoc analysis revealed HR differences between bicycles occurred at 22.5 kph (116.4 (18.1) *v* 131.6 (19.8) bpm), 25.8 kph (128.8 (24.7) *v* 143.0 (20.6) bpm), and 29.0 kph (136.9 (23) *v* 158.5 (22.2) bpm).

Lactic acid concentrations at 25.8 kph and 29.0 kph were also significantly lower for the cyclists during the tandem trial compared to the single bicycle trial (figure 2). Values for the tandem trial at 25.8 kph and 29 kph were 1.3 (0.9) mM/L and 2.1 (2.0) mM/L while the values for the single bicycle trial were 2.4 (1.8) mM/L and 4.2 (2.9) mM/L.

No bicycle × velocity interaction was observed for RPE. Values at 19.3, 22.5, 25.8, and 29.0 kph for the tandem trial were 7.1 (1.1), 8.4 (1.5), 10.0 (2.1), and 11.9 (2.1) while RPE values for the single bicycle trial were 7.7 (1.6), 8.9 (2.2), 10.8 (2.9), and 13.4 (3.6), respectively.

Within bicycle analysis (table 1)

No difference in exercising HR was found between captain and stoker when both were on the tandem. Although LA concentration was about 27% greater for the captains, no significant differences were observed between captain and stoker when cycling together on the tandem. No difference between captain and stoker was found for RPE.

Table 1 Bicycle × Position × Velocity Data

		Velocity (kph)				
		19.3	22.5	25.8	29.0	32.0†
T_{CP}	HR	110.5 (14)	115.0 (17)	132.9 (25)	141.0 (27)	143.0 (17)
	LA	1.1 (0.4)	1.2 (1.0)	1.6 (1.2)	2.7 (2.6)	2.8 (0.9)
	RPE	7.4 (1.2)	8.1 (1.2)	9.5 (2.0)	11.6 (2.4)	12.3 (3.0)
S_{CP}	HR	109.4 (16)	120.5 (17.6)	129.5 (16.6)	147.5 (24)	160.1 (18.6)
	LA	1.2 (0.6)	1.0 (0.6)	1.4 (0.9)	3.0 (2.5)	3.3 (1.0)
	RPE	7.5 (1.6)	8.3 (2.3)	9.3 (2.5)	11.6 (3.0)	13.3 (2.3)
T_{ST}	HR	105.4 (20)*	117.9 (19)*	124.8 (24.5)*	132.9 (20)*	135.5 (26)
	LA	1.2 (1.0)	1.4 (0.7)	1.0 (0.5)*	1.6 (1.1)*	1.6 (1.2)
	RPE	6.8 (1.0)	8.8 (1.8)	10.5 (2.2)	12.3 (1.9)*	13.7 (1.6)
S_{ST}	HR	125.6 (16.4)	142.6 (15.9)	156.5 (14.8)	167.7 (14.9)	171.0 (8.5)
	LA	1.6 (0.9)	2.5 (1.4)	3.4 (2.0)	5.1 (3.2)	4.2 (0.3)
	RPE	7.9 (1.7)	9.6 (2.0)	12.3 (2.6)	15.3 (3.7)	17.7 (1.5)

Mean (SD); T_{CP}: captain rider during tandem trial; S_{CP}: captain rider during single bicycle trial; T_{ST}: stoker rider during tandem trial; S_{ST}: stoker rider during single bicycle trial; HR: heart rate (bpm); LA: lactic acid (mM/L); RPE: rating of perceived exertion.
*Values statistically less than S_{ST} ($p<0.05$).
†Three tandem teams (three captains and three stokers) not included in statistical analyses.

Position × bicycle interaction

There was a significant interaction for position × bicycle in HR ($p=0.000$). Analysis indicated that while on a single bicycle, the stoker had a significantly higher HR than when they on the tandem at all four velocities (table 1). No differences between bicycles for captains' HR were observed. A position × bicycle interaction was also statistically significant for LA. The stokers had significantly lower LA concentrations while cycling on the tandem than when they were on their single bicycle at 25.8 kph and 29 kph (table 1). As with HR, no differences between bicycles for LA were noted for the captains (table 1). There was a significant position × bicycle interaction for RPE ($p=0.03$). The stokers demonstrated a greater RPE while on a single bicycle (11.2 (0.35)) compared to when they were on tandem (9.6 (0.4)). No difference was observed for the captains' RPE.

DISCUSSION

The subjects used in this study were typical of tandem cyclists (personal communication with *Tandem Magazine* editor). They are slightly older than the typical single bicycle cyclist and husband/wife pairs frequently constitute tandem teams. Recreational tandem cycling appeals to cyclists who prefer cycling together for social reasons, but whose speed capabilities on single bicycles are mismatched or to those who want to cycle at velocities that normally wouldn't be possible when on a single bicycle. Tandem cycling is also growing among those who want to participate in a physical activity where one of the cyclists may have a physical impairment that prohibits them from riding a single bicycle. Even with this rise in popularity, very little is known about the basic physiological responses when cycling on a tandem. Thus, this field study was undertaken to document the physiological responses when experienced, recreational tandem cyclists rode a tandem and a single bicycle.

Stokers demonstrated significantly lower physiological stress cycling on the tandem than when they cycled on a single bicycle. Heart rate ranged from 16% to 22% lower while LA was from 23% to 70% lower over the four velocities. The energy savings demonstrated by the stokers in the present study confirm those calculated by Kyle[1] and from those obtained by McCole *et al* in a field study on cyclists who were drafting on single bicycles.[5]

Greater velocities than those used in this study are probably required to observe a difference in the physiological requirements of cycling on the tandem and the single bicycle for the captains. Data not included in the current analysis was collected from a 32 kph interval. Only three full tandem teams were able to complete a 32 kph interval on both the tandem and single bicycle (table 1). The results at 32 kph displayed a trend in which physiological differences between the tandem and single bicycle were even greater than those observed at 29 kph for those six riders. In fact, when velocity increased from 29 kph to 32 kph, captains' HR increased by 7 bpm (5%) on the tandem, but increased by 23 bpm (17%) when on their single bicycles. The stokers followed a similar pattern.

McCole and colleagues reported that energy expenditure, assessed by oxygen uptake ($\dot{V}O_2$), was from 18% to 28% lower in cyclists that drafted behind a lead rider at various velocities.[5] In the present study, the stokers' HR and LA responses averaged 19% and 53% lower when they bicycled on the tandem compared to when they bicycled on their single bicycle. While on a tandem, the stoker's body is located approximately 0.2 m to 0.5 m behind the captain. When drafting on a single bicycle, the rear wheel of the lead bicycle and the front wheel of the drafting bicycle need to be within about 0.5 m to be aerodynamically effective.[3] The drafting rider still has to overcome some wind resistance as the drafting cyclist is not directly behind the lead cyclist. While the wheels are very close to one another on a single bicycle, the riders' bodies are much farther apart than on a tandem. Thus, because they are so close to the captain, the stoker can add to the power output on a tandem without creating added air resistance.

Of interest is the linear rise over the four velocities in HR compared to the exponential rise in LA during cycling. McCole and colleagues reported that $\dot{V}O_2$ has linear relationships with rider weight, velocity, and wind speed.[5] However, they hypothesised that these relationships would probably become exponential at greater velocities. Nonetheless, HR followed a linear pattern across all four velocities for the tandem trial in the present study. Heart rate should increase linearly since it is related to $\dot{V}O_2$ via Fick's Principle.[14] In contrast, an exponential relationship between LA and velocity was observed when the deviation from linearity occurred at 25.8 kph. The exponential increase in LA is similar to what was expected on a single bicycle because of the power requirements posed by the exponential increase in air resistance as velocity increases. It is not known why HR did not respond similarly at what is apparently the LA threshold. A plausible reason is that more power from the stoker was put into generation of velocity rather than overcoming air resistance while on the tandem.

When cycling on a single bicycle with a stronger rider, a weaker rider is often pushed beyond his/her capabilities and may be dropped from the group due to fatigue. A tandem allows both cyclists, regardless of fitness levels, to cycle together at different intensities, and still exercise at a relative level needed for fitness improvement. These findings may have implications to exercise adherence. According to Estabrooks[15] and Carron *et al*,[16,17] people are more likely to maintain an exercise program if they exercise with someone else or in a group than if they exercise by themselves. A tandem, therefore, could aid in an individual maintaining an exercise program if they were able to cycle along with someone else regardless of each of the individuals' fitness level. In the present study, six out of nine stokers remarked that they would not ride with their partner on single bicycles because they could not keep up due to fitness differences.

In conclusion, recreational cyclists, specifically the stoker, exhibited lower physiological stress when bicycling on a tandem compared to a single bicycle at 19.3, 22.5, 25.8, and 29.0 kph. Heart rate averaged about 19% lower while LA was about 45% lower on a tandem compared to a single bicycle. In practical terms, when physiological stress was comparable between bicycles, cyclists were able to cycle from 4.8 to 8.0 kph faster on a tandem than when they cycled individually on a single bicycle. Apparently, stokers can add to power output without adding a significant amount of wind resistance. Thus, tandem cycling may allow individuals of mismatched fitness levels to cycle together with both individuals gaining exercise benefits because they can cycle at different workloads. Future research should include investigating relative outputs by using trained cyclists who are experienced in tandem cycling.

Take home message

Tandem cyclists demonstrated significantly lower HR and LA data. At higher velocities, the stoker can add to power output of the tandem because they only add minimally to wind resistance. This allows for cyclists with different fitness levels to cycle together and still enjoy the benefits of exercise.

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COMMENTARY

Physical activity is widely promoted as a healthful behaviour that promotes better health in individuals and populations. A great public health challenge is increasing the percentage of the population who become and remain physically active. Tandem cycling allows two persons to share a physical activity in a socially satisfying way even when their physical capabilities are dissimilar. Tandem cycling has the built in advantage of having an exercise partner to encourage the activity itself. This study investigated physiological effects of cycling on tandems or single bicycles. The findings quantifiably confirm that tandem cycling confers a speed advantage for a given intensity of effort. Or, viewed differently, travelling at a given speed elicits less physiological stress when riding a tandem compared to a single bicycle. While many physiological studies examine elite athletes, this study investigated recreational enthusiasts. Thus, the findings are of interest to a large number of tandem recreational cyclists.

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COMMENTARY

A good way for two people of somewhat different abilities to get together and perform some exercise might be with tandem cycling. For the lead rider (the captain and usually the man and/or the larger rider) tandem riding requires similar physiological stress (as measured by heart rate and lactate levels) as single riding. However, for the person in back (the stoker and usually the woman and the smaller rider), less physiological stress is required to ride at the same speed on a tandem than on a single bike. Therefore, with tandem cycling, two people of different aerobic abilities (as most men and women have) may be closer to working at their appropriate individual goals while doing the same activity together, than they would if they did an activity individually. With tandem riding, an added benefit is that by exercising with someone else, adherence to the exercise program is likely to be greater and therefore the overall benefits larger.

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