The effect of fluid loss on Olympic distance triathlon performance in high thermoregulatory stress.

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The purpose of this study was to measure the effect of ad-libitum fluid intakes and sweat losses on Olympic distance triathlon (ODT) performance. Ten (3 female and 7 male) trained triathletes ($\dot{V}O_{2max}$ = 58.4 ± 7.7 $mL\bullet kg^{-1}\bullet min^{-1}$; Best ODT time = 131.5 ± 13.3 minutes) completed two ODT's (1.5-km swim, 40-km bicycle, 10-km run), two weeks apart. The average wet-bulb globe temperature outdoors ($WBGT_{out}$) was 28.0 ± 2.8 ^{o}C. ODT relative body mass change, sweat loss, sweat rate and fluid intake were found to be 3.86 ± 0.76 %BM, 4370 ± 937 mL, 1886 ± 503 $mL\bullet hr^{-1}$ and 1551 ± 550 mL, respectively. Run time was significantly influenced by ad-libitum fluid consumption during and the relative body mass change during that leg. Similarly, high sweat rate, high sweat loss but decreased relative body mass losses were all significantly correlated with increased bicycle leg performance. Although swim leg time was significantly related to ODT time, no measures of sweat or fluid intake correlated with swim performance.

The ODT requires participants to swim 1.5 kilometres, bicycle 40 kilometres and run 10 kilometres. With the introduction of the ODT as an official Olympic sport, it has become the major focus of competition for many triathletes. The competitive triathlon season in Australia extends through the summer months where typically the ambient air temperature and humidity are high. Additionally, the event requires participants to exercise aerobically at high percentage of their maximal aerobic capacity for approximately two hours for most well-trained triathletes. Consequently, the risk of hypohydration during ODT is high. Hypohydration causes greater heat storage and reduces the athlete's ability to tolerate heat strain. Sawka (1992) suggests that heat storage is mediated by reduced evaporative heat loss through sweating and reduced skin flow. Furthermore, hypovolemia is also associated with reduced performance in endurance events in hot and humid conditions.

Previous laboratory research has shown that triathletes lose between 1.7 and 4.1% of body mass during an ODT in hot and humid conditions (Millard-Stafford et al. 1990; Broad et al. 1997). These findings indicate that fluid replacement is critical for triathlon performance as endurance performance has been shown to decrease with hypohydration levels greater than 1.8% BM (Walsh et al. 1994). Therefore, the aim of this paper is to report on fluid loss during ODT. Furthermore, the results of the study will be used to present a predictive model for fluid balance measures and ODT performance. This will be done by constructing a path analysis of the effects of fluid intake and sweat loss on ODT performance.

Methods

Subjects

Ten acclimatised triathletes (3 female and 7 male) voluntarily participated in the study. The participants mean age body mass, maximal oxygen uptake, sum of nine skinfold sites and best ODT time were 33.3 ± 6.7 (SD) yr, 70.9 ± 9.7 kg, 58.4 ± 7.7 $mL•kg^{-1}•min^{-1}$ 84.3 ± 31.7 mm and 2:11:30 ± 0:13:20 (hr:min:sec), respectively.

Participants were requested to maintain normal training volume and intensity during the testing period and to abstain from physical training in the 24 hours prior to each test. Similarly, participants were instructed to abstain from alcohol, coffee and products containing caffeine during the 24-hour period prior to testing. During the 24 hours prior to each test, participants were requested to drink two litres of a six-percent carbohydrate solution (Gatorade®) to ensure that they were adequately hydrated and had adequate glycogen levels.

Prior to participation, each volunteer completed a medical history questionnaire and a written informed consent document. The experimental protocol was approved by the Central Queensland University (CQU) Human Ethics Research Review Panel.

Procedures

Preliminary measurements

In the week prior to the exercise-testing period, each subject was familiarised with the exercise testing protocols that were employed in the study. To ensure that all subjects were familiar with the exercise environment, each subject was transported around the ODT course.

Anthropometric measures

Prior to the initial $\dot{V}O_{2max}$ test, body mass, height and the sum of nine skinfolds (tricep, subscapular, bicep, iliac crest, supraspinale, abdominal, front thigh, calf and mid-axilla) of each participant were measured by a Level 1 Anthropometrist certified by the International Society for the Advancement of Kinanthropometry (ISAK).

Maximal aerobic power testing

In the week prior to initial testing, maximal oxygen uptake ($\dot{V}O_{2max}$) was determined using an incremental treadmill test to exhaustion. The test was conducted on a motorised treadmill (Precor, USA). Maximal oxygen uptake was measured using a Medgraphics® Gas Analysis System (Medgraphics®, Parkway, USA).

The participants arrived at the Human Performance Laboratory at least two hours post-prandial. Following a ten-minute warm-up at 70% of age predicted maximal heart rate, the exercise protocol commenced at a workload of 10 $km•hr^{-1}$. The workload was increased by one $km•hr^{-1}$ every five minutes until volitional fatigue. Maximal oxygen uptake was considered the highest oxygen volume recorded during the last minute of exercise. Heart rate was recorded throughout the protocol via Polar® Vantage NV™(Polar OY, Finland).

Following $\dot{V}O_{2max}$ testing, each participant was provided with a training diary and dietary guidelines to complete over the three-day period before each ODT. These guidelines were to ensure that all participants had similar glycogen and hydration status at the time of testing.

Experimental design

Prior to the warm up, a measure of nude, towel dry, body mass was taken post-micturition. This was repeated at each transition and then after both ODT's using electronically calibrated scales (Mercury, Australia) accurate to 50g.

Participants were required to complete an ODT in an uncontrolled environment on two separate days, seven days apart. The 1.5-km swim was completed in a 25-metre swimming pool, the 40-km bicycle leg was completed on an accurately measured 10-km road loop, and a 2.5-km road loop was used for the 10-km run. Performance time was taken as the total ODT time minus experimental intervention time.

Environmental conditions

$WBGT_{out}$ was measured at 30-minute intervals during each trial using a heat stress monitor (QUESTEMP^{o}10, Oconomowoc, WI, USA).

Fluid Intake and Sweat loss

During each test, participants were provided with half-strength Gatorade® for ad-libitum intake. Individual fluid intakes were calculated as the difference in the volume of fluid in each subject's water bottle at the beginning and end of each test. Urinary fluid loss was measured using a volumetric cylinder accurate to 10 ml. Sweat loss (SL) was assessed using the method of Noakes and co-workers (1988).

Statistical analysis

Means and standard deviations were calculated for each variable. A hierarchical multiple regression was used to determine if swim time, bicycle leg time and run leg time, and the sweat loss, sweat rate, relative body mass change and fluid intake were significantly related ODT time. A multiple regression was also performed to measure correlations between sweat loss, sweat rate, relative body mass change and fluid intake for each leg with performance time for each leg. Finally, a partial correlation was completed correlating total race fluid consumption to ODT time while controlling for sweat loss. An alpha level of 0.05 was accepted as showing statistical significance. All statistical analyses were completed using SPSS statistical software package (SPSS Inc., Chicago, Illinois).

Results

Table 1. Mean environmental conditions (^{o}C), ODT performance time (hr:min:sec)

	Mean ± SD
WBGT_{out} (^{o}C)	28.0 ± 2.8
WBGT_{in} (^{o}C)	29.8 ± 2.6
Relative humidity (RH)	49.9 ± 7.2
Performance time (hr:min:sec)	2:20:47 ± 0:10:15

Table 2. Mean relative changes in body mass (%BM), gross sweat loss (mL), sweat rate mL•hr^{-1} and ad-libitum fluid intake (mL) during each ODT ($\bar{X}$ ± SD).

ODT Leg	Relative Body Mass Change (%BM)	Gross Sweat Loss (mL)	Sweat Rate (mL•hr^{-1})	Ad-libitum Fluid Intake (mL)
Swim	-1.07 ± 0.36	783 ± 321	1975 ± 789	0 ± 0
Bicycle	-1.99 ± 0.72	2351 ± 602	2052 ± 621	899 ± 413
Run	-0.80 ± 0.85	1236 ± 435	1587 ± 621	651 ± 297
ODT	3.86 ± 0.76	4370 ± 937	1886 ± 503	1551 ± 550

Table 1 shows the environmental conditions and performance times for the two testing days. Table 2 shows the changes in markers of fluid balance during ODT

The hierarchical multiple regression revealed that swim-leg time, bicycle-leg time and run-leg time all significantly correlated with ODT time. No other variables significantly correlated with ODT time. Multiple regression failed to show any fluid balance marker as a predictor of swim-leg performance time. However, increased bicycle sweat rate, increased bicycle sweat loss and decreased relative body mass change were shown to be significantly correlated to bicycle leg time**.** Furthermore, increased fluid intake and decreased relative body mass change on the run leg were also shown to be significantly correlated with run leg performance. A simple model was constructed to demonstrate the effects of changes in fluid balance and ODT performance. Figure 1 shows a path analysis for the prediction of ODT performance time from the fluid balance markers monitored in the present study.

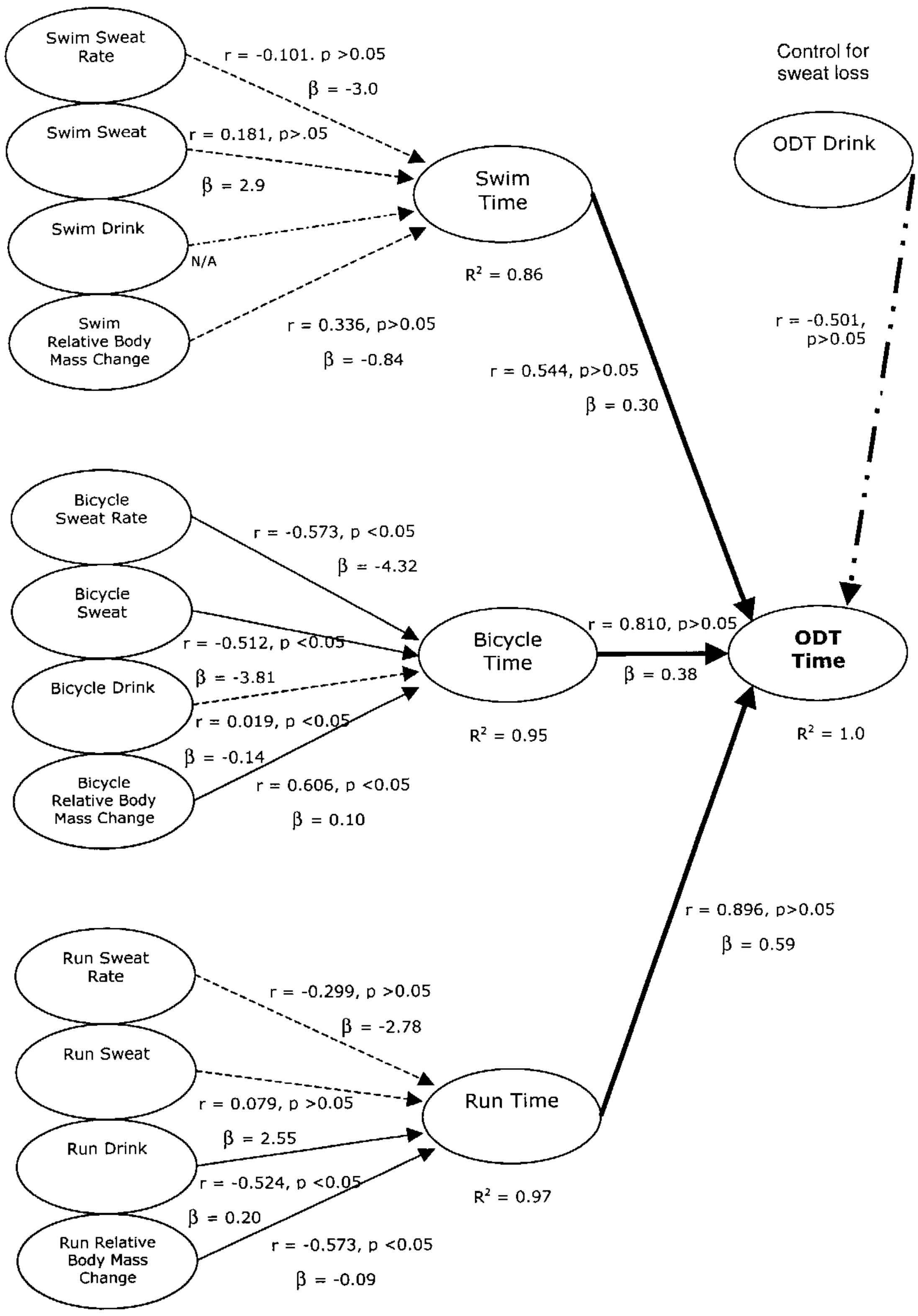

Figure 1: Path analysis of the significant correlations between measures of fluid balance and ODT performance.

Figure 1 shows that path analysis of the significant correlations between measures of fluid balance and each triathlon leg time and ODT performance. As expected swim times, cycle times and run times predict 100% of ODT time ($Y = 0.3$ (swim time) $+ 0.38$ (bicycle time) $+ 0.59$ (run time) $+ 4.787 \times 10^{-13}$). Change in run performance times was predicted from run leg sweat loss, run sweat rate and run drink intake. This model accounted for 97% of the variance ($Y = 2.545$ (run sweat loss) $- 2.776$ (run sweat rate) $+ 0.203$ (run drink) $+ 2625.738$). Similarly, bicycle leg performance time was predicted using bicycle leg sweat loss and sweat rate. This model predicted 96% of the variance ($Y = 3.81$ (bicycle sweat loss) $- 4.315$ (bicycle sweat rate) $+ 4145.948$). Furthermore, a similar prediction equation was developed for swim performance time. This model accounted for 86% of the variance ($Y = 2.988$ (swim sweat loss) $- 3.003$ (swim sweat rate) $+ 1429.502$)

Finally these prediction equations were combined to provide a predictive model for ODT performance using markers of fluid balance ($Y = 0.3$ (2.988 (swim sweat loss) $- 3.003$ (swim sweat rate) $+ 1429.502$) $+$ (0.38 (3.81 (bicycle sweat loss) $- 4.315$ (bicycle sweat rate) $+ 4145.948$) $+ 0.59$ (2.545 (run sweat loss) $- 2.776$ (run sweat rate) $+ 0.203$ (run drink) $+ 2625.738$) $+ 4.787 \times 10^{-13}$).

A partial correlations showed that ad libitum fluid intake during the ODT is significantly correlated with performance time when sweat loss was controlled for ($r = -0.501$, $p < 0.05$) (see figure 1).

Discussion

The purpose of the current study was to examine the relationships between fluid intake, sweat loss, body mass changes and sweat rates on ODT performance. Results show that changes in sweat loss, sweat rates, fluid intakes and relative body mass changes were effective predictors of performance in the bicycle leg and run legs of ODT. However, these measures of total body water deficit do not effectively predict 1500-m swim time in ODT.

The relative body mass changes in the present research are in agreement with previous findings (Millard-Stafford et al. 1990; Broad et al. 1997). In the present investigation a reduction in mean body mass from the start to the finish of the ODT of between 2.3 %BM and 5.2 %BM of pre-ODT body weight was observed. Other laboratory-based research investigating fluid losses during ODT in hot and humid conditions, noted a mean body mass change of approximately three kilograms (approximately 4.0 %BM) (Millard-Stafford et al. 1990).

Present results show that the greatest body mass changes in the ODT occurred during the 40-kilometre bicycle leg. In contrast, Broad and colleagues (1997) observed the greatest body mass losses during the run leg. The differences in these results may be attributed to a greater availability of fluids during the run leg in the current study. Broad and colleagues (1997) made one cup of fluid available very 2.5-kilometres during the run leg. The current study had drink stations positioned every 1.25-km on the run leg. Previous research has shown that fluid consumption is increased when athletes are presented with fluids more frequently (Burke and Hawley 1997).

The findings in the present study show that although the athletes lost approximately 1% of their body mass during the 1500-m swim leg that measures of fluid balance cannot reliably be used to predict swim performance time. Sweat loss, sweat rate, relative body mass change and fluid intake did not significantly correlate with performance time. The absence of a correlation with performance in the swim leg may be due to its brief nature. Although the swim leg lasted approximately 24 minutes, the thermoregulatory demand was quite high. Body mass changes of 1.07 ± 0.36 percent and sweat rates of approximately two litres per hour suggest that there was high thermoregulatory load. This finding is converse to the research of Broad and colleagues (1997) who reported that approximately 0.1% BM was lost during a 20-minute swim in hot and humid conditions. The abnormally large sweat losses calculated during the swim leg in this study may have been due to the subjects urinating in the pool during the swim, which would have compromised sweat loss calculations.

On average, the triathletes lost approximately 2% of body mass at the completion of the 40-km bicycle leg. These body mass losses have previously been shown to decrease endurance performance capacity in endurance athletes (Sawka 1992; Walsh et al. 1994). Furthermore, the present results demonstrate that bicycle leg performance time can be reliably predicted from measures of bicycle leg sweat loss, sweat rate and relative body mass change. In particular, triathletes who completed the bicycle leg with the least body mass change had fastest ODT time. This finding highlights the importance of drinking during the 40-km bicycle leg. Additionally, triathletes with the greatest sweat rate and sweat loss also significantly correlated with faster ODT time. This suggests that fluid balance is critical for performance on the cycle leg. Therefore, it seems reasonable to suggest that performance is increased in athletes who can best prevent the deleterious effects of hypohydration on endurance performance through maintaining the best possible fluid balance. This may be achieved through greater heat acclimatisation. Research has shown that heat acclimatisation is associated with increased blood volume, enhanced ability to sweat, earlier onset of sweating and an increase in sweat rate (Maughan and Sherriffs 1997). These physiological adaptations may reduce the thermal load during ODT in hot conditions.

The present results show that run leg performance time to be the strongest predictor of overall race time. This is particularly interesting as the race examined was non-drafting, which often allows athletes to enter the run leg in a group. Therefore, in drafting-legal races, the fastest finisher is often the best pre-fatigued 10 km runner. However, in non-drafting events such as the present study, the run leg performance is a significant predictor of ODT time because the faster athletes have entered the run leg with greater total body water which allows them to exercise at a higher intensity. This is supported by the relative body mass change results on the bicycle leg where the best performers maintain a body weight closer to their euhydrated state than the slower triathletes.

Therefore, importance must be placed on preventing negative fluid balance during ODT in order to maintain intensity. This is highlighted by the finding that bicycle sweat loss was also significantly correlated with run leg time. Fluid intake on the bicycle is difficult during the first 25 minutes of the race. The present findings suggest that if hypohydration is to be delayed in ODT then fluid consumption in the early stages of the bicycle leg are important.

Similar to the bicycle leg results, a strong correlation was observed between relative body mass changes and run leg time. Triathletes who had maintained their body mass during the run leg were faster, however, greater fluid consumption during the run leg also correlated significantly with run leg time. Relative body mass change is reflective of total hydration state and is the net product of fluid intake and loss. In the present study, triathletes entered the run leg hypohydrated by approximately two percent of their body mass. Sawka (1992) suggests that once body water deficit exceeds 2% BM, there becomes a disproportionate larger decrease in maximal aerobic power with an increased magnitude of body water deficit. Therefore, the athletes who enter the run leg with the least body water deficit are better equipped to complete the run leg in a faster time. This may explain that athletes who have a decreased body water deficit are better able to exercise at higher intensities and therefore complete the 10-km leg faster. Hence, the present results further support the need for protection of body water during ODT in hot conditions. Furthermore, ad-libitum fluid consumption during the run strongly correlated with faster ODT. This result also suggests that faster triathletes maintain total body water for longer than their slower counterparts during ODT. This is supported by the current results that indicate that when controlling for individual sweat fluid loss, that the triathletes who consumed the most fluid during the ODT was faster.

Taken together these results would suggest that the best triathletes competing in ODT have greater sweat capacity, however are also trained in fluid intake. Therefore, strategies for delaying hypohydration are critical for increasing ODT performance in hot and humid conditions. The predictive model presented can be used to highlight the importance of correct hydration methods during ODT.

Coaching Implications

The present study highlighted the deleterious effects of hypohydration on ODT performance. These results would suggest that athletes competing ODT in hot and humid conditions should take measures to prevent body water loss. Acclimatisation periods for longer than 14 days should be undertaken to best prepare the athlete for exercise in hot and humid conditions (see Maughan and Sherriffs (1997) for appropriate strategies).

Furthermore, triathletes should be trained to consume as much fluid as possible during the early stages of the bicycle leg to the completion of the ODT in order to prevent the deleterious effect of hypohydration. These strategies should be reinforced at training. Finally, pre-event hyperhydration with solutions such as glycerol should be considered to assist in the preservation of total body water during ODT (Coutts et al. 1999). These strategies will aid the athlete in increasing ODT performance when competing in hot and humid conditions.

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