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Is the Sub-maximal Treadmill Test an Accurate Predictor of Oxygen Uptake in Table Tennis ?

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Abstract

This experiment sought to establish whether $\dot{V}o_2$ measured during a game of table tennis was consistent with that predicted by a progressive sub-maximal treadmill test for equivalent heart rates. The 3 male subjects (age range 20–23) were of intermediate playing standard. In the field, expired air was collected every third minute of a fifteen minute match, using Douglas bags and an extended length of tubing. Heart rate was also recorded every minute. In the laboratory, a twenty minute progressive treadmill test was conducted, during which expired air was collected every fifth minute (speed range 6.43–11.26km.h^{-1}), and heart rate every minute. The line of best fit was calculated for the treadmill measurements, and the field data interpolated against this line. The results showed that for all three subjects the treadmill oxygen uptake measurements over-predicted the field findings at a significant level ($p<0.05$). Total $\dot{V}o_2$ l.min^{-1} for the expired air (5 minutes) were; S1 predicted 7.52,field 6.12; S2 predicted 11.01, field 9.31; S3 predicted 12.20, field 10.29. It is therefore suggested that a steady state treadmill test is not suitable for predicting oxygen uptake during table tennis, and that the intermittent nature of physical exertion during tennis may account for this.

Introduction

The popular image of table tennis as a non-energetic sport demanding only low levels of physical exertion has perhaps mitigated against researchers seeing the need for studies on the physiological demands of the sport and the attributes of its players.

Durnin and Passmore (5), however, suggested that table tennis was merely light exercise for most participants and perhaps moderate exercise for enthusiasts,requiring energy expenditure of between 3.6 and 5.2kcal.min^{-1}. It would appear, however, that their assumptions are based on data for non-elite performers, and that in the light of advancements in player technique and ability over the past twenty years, are now of limited value.

Astrand and Rodahl (1) cite the work of Lundin (1973) in which $\dot{V}o_2$max test were conducted on seven elite Swedish players, giving a mean value of 4.41.min^{-1} or 65ml.kg^{-1}.min^{-1}. In the same research, oxygen consumption during match play, measured using the Douglas bag method averaged 50ml.kg^{-1}.min^{-1} representing 70% of the mean $\dot{V}o_2$max Heart rate varied considerably during matches, but was generally 20–30bts.min^{-1} below maximum. Work on elite England players has also been carried out by Hale (1987, in Houghton (7)), and results showed high levels of oxygen uptake, comparing favourably with elite performers from other sports demanding high levels of physical exertion.

The practical problem of measuring oxygen uptake during sporting activity has meant that the majority of assessments have been carried out in the laboratory on either a treadmill, cycle ergometer of simulated rowing machine. Di Prampero et al. (4), in examining the physiology of rowing stated that measurement of $\dot{V}O_2$ during rowing was technically too difficult, and assessed it indirectly via the heart rate/O_2 uptake relation-ship from a treadmill test. This may be a valid procedure for rowing, involving constant repetition of the same movement, since constant exercise forms the basis of steady state O_2 uptake laboratory tests. However, many sports, including table tennis, require inter-mittent exercise, and such tests therefore represent artificial situations. Field O_2 uptake has generally been predicted from the heart rate/$\dot{V}O_2$ relationship from laboratory tests, often when field exercises bear little relation to each other. Thus it has been assumed that there is a constant relationship between heart rate and sub-maximal $\dot{V}O_2$ regardless of the nature of the exercise.

Some researchers have therefore attempted to measure O_2 uptake in the field using a number of methods. Maron et al. (9) collected expired gas meteorological balloons during marathon running, via a lightweight gas collection system worn by the runner, while Holmer (6) compared O_2 uptake from experiments in a swimming flume with those from standard treadmill and ergometer tests. The latter found that for highly trained swimmers, significantly lower heart rates were recorded for a given O_2 uptake in swimming, than in both running and cycling. More recently in Japan, Ikegami et al. (8) have developed a telemetry system for measuring O_2 uptake during sporting activity using a portable "Oxygen" weighing approximately 3.89kg. However, its value is cur-rently limited since it has only been found to be consistent with Douglas bag measure-ment for $\dot{V}O_2$ values of up to $21.min^{-1}$. This is clearly inadequate for many sporting activities.

Holmer (6) found that $\dot{V}O_2max$ during swimming was on average 89% of $\dot{V}O_2max$ for running and suggested that the different emphases on arm and leg work for the two activities might account for this. No similar comparison was made for sub-maximal work. Vokac et al. (10) found that the adjustment of heart rate to sudden increases in energy demand varied between arm and leg work, while Cerretelli et al. (2) found that $\dot{V}O_2$ on-response time was longer for arm cranking than leg pedaling.

The current research sought to investigate whether the O_2 uptake demands of table tennis were consistent with those predicted from a progressive sub-maximal treadmill test, using heart rate as the independent variable.

Methods

Three subjects took part in this experiment which sought to assess and compare only the intra-individual differences or similarities found. Subject details are given in Table 1.

Field Procedure

This took part in a college gymnasium (ambient temperature 18c). Subjects were allowed a five minute period to acclimatise to wearing the respiratory apparatus during match play. Each subjects then underwent a 15 minute experimental period against an opponent of similar ability, with instructions to play a "normal" game of table tennis match between players of approximately equal standard.

Expired air was collected in Douglas Bags every third minute via lightweight tubing (length 4.25m), and later analysed for O_2 and CO_2 content using Beckmann OM-11 and LB-2 gas analysers $\dot{V}_E$ was measured with a Harvard dry gas meter and $\dot{V}O_2$ was calculated using the Haldane transformation. Heart rates, averaged over one minute intervals were recorded with a Sports Tester PE3000 watch.

A video recording of each subject was also made to assess the relationship between the number of strokes played during collection and the physiological data. Finally, in order to assess any restrictive qualities of the experimental apparatus, subjects played a

TABLE 1: SUBJECT DETAILS					
Subject	Age (yrs)	Height (cm)	Weight (kg) (field)	Weight (kg) (lab.)	Playing Standard
1 (D.R.)	20	173	59.4	58.4	Ex county-ranked junior
2 (M.T.)	23	174	68.7	69.5	Ex county/England ranked junior
3 (T.H.)	22	182	84.2	84.5	Ex county-ranked junior + 3rd division National League.

TABLE 2: MEAN HEART RATES FROM BOTH FIELD EXPERIMENTS.		
	Heart rate (bts.min^{-1}) O_2 consumption experiment.	Heart rate (bts.min^{-1}) HR only experiment.
SUBJECT 1	112.1	111.1
SUBJECT 2	123.9	124.2
SUBJECT 3	148.4	148.2

TABLE 3: OXYGEN CONSUMPTION DATA FROM FIELD EXPERIMENT (l.min^{-1})			
Minute	Subject 1	Subject 2	Subject 3
3	0.98	1.92	2.19
6	1.09	1.90	1.76
9	1.34	2.12	2.11
12	1.08	1.74	1.77
15	1.63	1.63	2.46
TOTAL	6.12	9.31	10.29

TABLE 4: OXYGEN CONSUMPTION DATA FROM TREADMILL EXPERIMENT (l.min^{-1})			
Minute	Subject 1	Subject 2	Subject 3
5	1.04	1.08	1.56
10	1.58	1.91	2.52
15	1.81	2.12	2.70
20	2.13	2.54	3.08
EQUATION	$y=0.018x-0.513$	$y=0.024x-0.899$	$y=0.023x-1.037$

further fifteen point match against the same opponent 2 days later, with only heart rate being recorded.

Laboratory Procedure

This was conducted ten days later at the same time of day as the field experiment (ambient temperature was 24c). Each subject completed a progressive sub-maximal treadmill test of twenty minutes duration, on a level motor-driven treadmill. Treadmill speeds (6.43–11.26km.h^{-1}) were selected to cover the range of heart rates recorded during the field experiment. Speed was increased every five minutes, and $\dot{V}O_2$ and heart were recorded in the final minute of each load, using apparatus identical to that employed during the field experiment.

The line of best fit for $\dot{V}O_2$ against heart rate was calculated using the least squares method of linear regression, and field heart rates were then interpolated against this line to give the predicted $\dot{V}O_2$ values from the treadmill test. A paired t-test was used to defeat significant difference between predicted and actual $\dot{V}O_2$ values for the field heart rate.

Results

Heart rate data from the main field experiment was not significantly different to the data from the heart rate experiment ($p>0.05$), thus strengthening the validity of the field protocol. Mean heart rates are shown in Table 2.

The O_2 consumption data from the field experiment is shown in Table 3, while table 4 shows O_2 consumption from the treadmill experiment for all subjects, and the calculated linear regression equation, used subsequently to predict field O_2 consumption from the heart rate date.

The total measured O_2 consumption for the five minutes of data collection, together with the predicted O_2 uptake is shown in Table 5 and Figure 1. Paired t-tests revealed that the treadmill-based prediction significantly over-predicted actual O_2 consumption for all subjects (t=3.07(S1), 7.21(S2), 3.35(S3), df=4, $p<0.05$), and the levels of over-prediction are shown in Table 5 and as a percentage in Figure 1.

Finally, the correlations studied are shown in Table 6. Moderate to strong relationships were found in all subjects for heart rate and number of shots, and heart rate and $\dot{V}O_2$. However, there was no trend towards a relationship between number of shots and $\dot{V}O_2$.

Discussion and Conclusion

The laboratory experiment over-predicted field O_2 consumption, and the level of over-prediction was consistent for all three subjects (range 18.26–22.87%;mean 19.96%). Two possible reasons are suggested for the discrepancy. First, the intermittent nature of physical exercise during table tennis, and second, the different emphases on arm and leg work between table tennis and running.

The intermittent nature is evident both from previous knowledge of the sport and more specifically from analysis of the video recordings. Rallies involving several powerful drives or loops may be followed by prolonged pushing exchanges. The demands of attacking play might typically be met anaerobically, whilst the demands of defensive play would probably be met aerobically. Clearly, such exercise contrasts sharply with the steady state sub-maximal treadmill test. In table tennis, therefore, O_2 demand is constantly fluctuating, but the adaption of O_2 supply to work-load is not instantaneous (2). $\dot{V}O_2$ on-response times have been found to vary between 30s and 74s depending on the extent and location of the active muscle, whilst off-response times have been found to be faster (20–32s) (2,3). When increased physical activity occurs during attacking play, greater O_2 is required in the active muscles, but by the time it can

FIGURE 1: COMPARISON OF PREDICTED AND ACTUAL OXYGEN CONSUMPTION

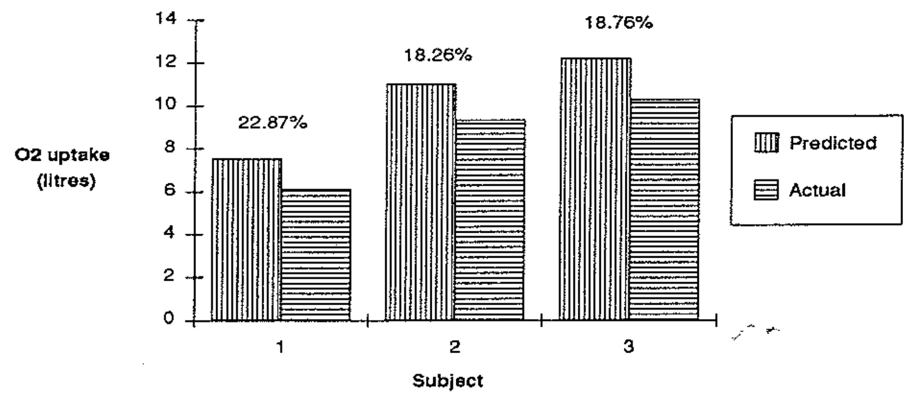

TABLE 5: COMPARISON OF PREDICTED AND ACTUAL OXYGEN CONSUMPTION			
	OXYGEN CONSUMPTION - 5 MINUTES (litres)		
	PREDICTED	ACTUAL	ERROR
SUBJECT 1	7.52	6.12	+1.40
SUBJECT 2	11.01	9.31	+1.70
SUBJECT 3	12.22	10.29	+1.93

TABLE 6: CORRELATIONS AMONGST HEART RATE, VO_2 AND NUMBER OF SHOTS EACH MINUTE			
RELATIONSHIP	Subject 1	Subject 2	Subject 3
Heart rate and No. of shots	0.77	0.91	0.80
Heart rate and VO_2	0.84	0.47	0.61
No. of shots and VO_2	0.07	-0.14	0.51

be delivered, demand may well have decreased. This constant rise and fall in O_2 demand is reflected in the $\dot{V}o_2$ figures for all three subjects during the field experiment.

It may also be argued that table tennis involved a higher ratio of arm to leg work than treadmill running. Cerretelli et al. (3) found that the level of specific muscle training had an effect on $\dot{V}o_2$ on–response times. Subjects trained in predominantly arm work (swimmers) displayed much faster $\dot{V}o_2$ on–response times for specific arm exercise than those involved in predominantly leg work (runners). If arm muscles of table tennis players were considered to be better–trained than those of predominantly leg–trained athletes, this could contribute to the differences on O_2 consumption between field and treadmill work.

Of the correlations studied, only the heart rate/O_2 uptake relationship produced at least a moderate correlation for all three subjects. To validate suggestions made about differences in O_2 demand of attacking and defensive play, it may be advisable to re-analyse the video recording and sub–categorise shots as either attacking or defensive. Further correlations could then be calculated, based on the proportion of attacking and defensive shots.

It is recognised that the Douglas bag technique only provides averages data for the period of expired air collection. To study further the specific demands of attacking and defensive play it would be beneficial to use a method allowing continuous analysis, such as the telemetry system developed by Ikegami et al. (8). However, as previously stated, the equipment is not yet reliable for level of O_2 consumption in excess of $2l.min^{-1}$. An additional reservation concerns the carrying of equipment weighing nearly 4kg during a sport demanding agility and speed.

In conclusion then, this preliminary study has found that a steady state treadmill test is not suitable for predicting accurately O_2 consumption during table tennis, and that the intermittent nature of physical exertion during play may be the principle reason for this. Since table tennis lends itself more readily than many sports to Douglas bag field collection, it is recommended that this method be used in preference to treadmill–based predictions about the O_2 demands of table tennis players.

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