C02 RESPONSES AND BREATH-HOLD TIMES IN UNDERWATER HOCKEY PLAYERS

Mike Davis

Four years ago I was rung by the Manager of the New Zealand Underwater Hockey Team to ask whether I could in any way assess his team's progress during their pre-World Championship work-up in terms of their fitness and their ability to breath-hold, and what should they be doing in training, anyway.

We got to thinking about the situation and with the little bit of reading I had done in this area including Rahn's book,[1] we really do not have much information to go on about breath-hold diving and CO$_2$ responses apart from some early work on the Ama divers and from submarine escape petty officers using steady state techniques. In underwater hockey two teams, wearing fins, mask and snorkel, breathhold dive to use a short stick to hit a bronze or lead puck across the bottom of the swimming pool towards the opponent's goal, which is a flat trough about 2 m long. It is an extremely energetic sport. In my opinion it is the best way I know of keeping divers fit and a good sport for "veterans". We have quite a lot of people in New Zealand playing in their 40's and 50's. There are 2 versions of the game: in South Africa a mini hockey stick is held with two hands, a game which is no longer recognised internationally; and the recognised version of the game in which a shorter triangular-ended stick held in one hand.

What we managed to do was, first of all, get the New Zealand team into the respiratory laboratory at Princess Margaret Hospital in Christchurch and then about 18 months later we took part of the laboratory to the Queen Elizabeth Swimming Stadium during the National Championships to study a whole bunch of people at the pool side. At the same time we collected data from dry-land athletes as a control group.

There are basically four adaptations which may be relevant to the human ability to breath-hold dive effectively. First, people over many years have reported an increase in vital capacity in divers. Secondly, it is thought that CO$_2$ responses may be diminished. Thirdly, the hypoxic drive to respiration may also be depressed, but I have never seen any good information on this whatsoever. Fourthly, the diving bradycardia, by reducing metabolic rate, may be important as well. This has recently been shown not to be the case. Apparently diving bradycardia in human beings is not associated with a reduction in metabolic rate.

We studied a total of 62 people. Of the 34 underwater hockey players 7 were internationals and the rest were A and B grade regional representatives or good club players. We compared them with a group of 28 dry-land athletes, marathon runners, javelin throwers and a miscellany of active young male sportsmen. This is an important point because in the only other comparative diving studies, the non-divers were not necessarily active sportsmen and any differences seen could merely be a reflection of active sporting participation. The two groups were well matched for age, weight and height but were not assessed for aerobic capacity. Forced vital capacity in both groups was elevated above the normal predicted for their age and height based on recent New Zealand demographic data, and what is of more interest is that there was no significant difference between the two groups. So the first conclusion to draw from our study in relation to past work is that an increase in vital capacity is not a characteristic of breath-hold diving per se. It is a characteristic of athletes in general and there are many studies through the respiratory literature to support that contention.

CO$_2$ responses were measured using the standard re-breathing method of Reid.[2] Basically, the subject re-breathes from a 5 l bag containing an initial mixture of approximately 7% C0$_2$/50% 0$_2$/43% N$_2$ until they have either reached an expired end-tidal C0$_2$ of 10% or they have been re-breathing for 4 minutes. Signals from an Ohio Spirometer and a mass spectrometer are taken on line into the computer. Then with interactive data handling programmes which were developed locally we plotted breath by breath end tidal CO$_2$ and instantaneous minute volume. Then a least squares regression line was drawn from the point where the response started to the end of the re-breathing period (Figure l).

The mean C0$_2$ response curves for the two groups are shown in Table 1. For the underwater hockey players, the mean is 1.08 ± 0.05 1 per minute per mm Hg C0$_2$. The mean response for the dry land athletes was 1.68 ± 0.72 1 per minute per film Hg C0$_2$. The difference between the two groups is highly significant ($p<0.005$). I would point out that this is a relatively low figure. Andy Pilmanis mentioned a couple of nights ago that the normal CO$_2$ response is approximately 3 to 4 l per minute per mm Hg C0$_2$. This is not entirely correct, although responses of that level are seen. The normal for young, fit males without respiratory disease is around 2 to 2.5 l per minute per mm Hg. In most athletic studies, and particularly in marathon runners, a reduced C0$_2$ response has been seen compared to non-athletic but fit young males. That is why I think it is very important that when we study divers for adaptive physiology like this, we should use well-matched dry land athletes as a control and not just any Tom, Dick and Harry who might be working in the laboratory.

There is considerable individual variability in CO$_2$ response, but intra-subject variance was relatively small and certainly within the range of previously reported studies. Many of the underwater hockey players had very low CO$_2$ responses of the sort you might see in a 70 year old chronic bronchitic who has just received morphine!

We also measured breath-hold times, something divers always want to know about. I am not going to go into the intricacies of where you take the end point of breath-holding, but certainly there are at least two different end points that are generally acceptable. We took voluntary termination of the breath-hold as the end point. The subjects were asked to not utilise rhythmic diaphragmatic movements to enhance their breath-hold time. Duplicate breath-hold times were measured at functional residual capacity and at total lung capacity on air, and in a few subjects, 8

FIGURE 1

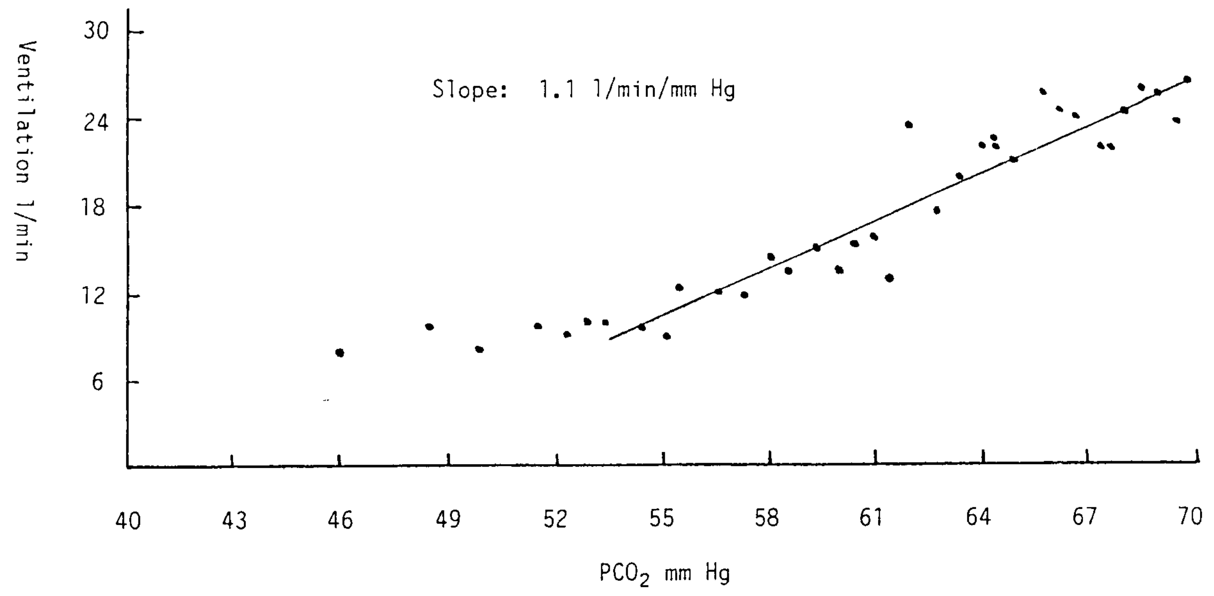

TABLE 1

CO2 VENTILATORY RESPONSES AND BREATH-HOLD TIMES IN UNDERWATER HOCKEY PLAYERS AND DRY-LAND ATHLETES

UNDERWATER HOCKEY PLAYERS ATHLETES

	International Players	Other Players	
1. Ventilation response (1 per min per mm Hg CO2)	1.08 ± 0.55		1.68 ± 0.72
2. Breath-hold Times			
- FRC/Air (sec)	55 ± 18	38 ± 13	37 ± 10
- TLC/Air (sec)	132 ± 37	81 ± 21	90 ± 20

international players and 10 of the athletes, a total lung capacity on oxygen. It was not possible at the poolside to perform breath-holds on oxygen in the rest of the diving group which was a pity.

The breath-hold times in the two groups were very similar (Table 1). However, in the international players, breath-holds were significantly prolonged compared both with the non-international players and the dry land athletes. Now, this was incomplete data, and should be interpreted cautiously, but it was still interesting. I had expected to see a significant difference between the divers and athletes in breath hold ability. Neither did breath-hold times correlate with the CO_2 response. There is an area here that is worth further study.

Finally, just out of interest, we also looked at face immersion diving reflex responses in a few of the top line breath-hold divers and local triathletes. During a 30 second immersion in water at 17°C or 30°C at FRC and TLC, the bradycardia was both temperature and volume dependent in much the same way as shown by others.

There is a really quite productive area of physiological research in looking at underwater hockey players. One of the questions frequently asked, for instance by the Royal Life Saving Society in New Zealand, is whether these people are at risk of suffering from shallow water blackout. There "is absolutely no data whatsoever about how blood gases change during a game. The top hockey players probably spend something like 2/3rd of the match underwater and I would not be at all surprised to see some pretty frightening falls in PaO_2. This would be a fascinating area to look at. Clearly the hypoxic ventilatory response needs looking at because there is very little data on this in breathhold divers. One final point in discussing this area of physiology, I do not think we should mix scuba divers and breath-hold divers into one group because they may be totally different in their behaviour. We need more data on this.

REFERENCES

1. Rahn H Ed. Physiology of breath-hold diving and the Ama of Japan. NAS-NRC 1341: Washington DC, USA, 1985.

2. Reid DJC. A clinical method for assessing the ventilatory response to carbon dioxide. Australasian Annals of Medicine 1966; 16:20 32.

3. Schaeffer KE. Adaptation to breath-hold diving. In: Physiology of breath-hold diving and the Ama of Japan. NAS-NRC 1341: Washington DC, USA, 1985.

QUESTIONS

Question:

Does the repeated high $PaCO_2$ of multiple breath hold dives in underwater hockey lead to a reduced CO_2 response or do the good players come from those with a low CO_2 response?

Dr Davis:

That is a question I do not think anyone can answer clearly at this stage. It would appear from dry land studies that the CO_2 response in any individual is probably largely determined by his genetic make up. For instance, if you look at identical twins you have very close correlations in their $C0_2$ responses whether they are sportsmen or not. Secondly, people have looked at the effect of 6 to 8 weeks of intensive physical training on the $C0_2$ response and that sort of intense training programme does not alter the $C0_2$ response in dry land athletes. Now opposed to that, Schaeffer[3] many years ago showed in US Navy submarine escape tower instructors that when they had a break of several weeks from instruction work in the tower their response to 5% $C0_2$ appeared to be increased after the layoff. We have only looked at two of our international subjects after a layoff. It is very difficult to get underwater hockey players to lay off their sport. They are totally addicted to it, just like runners. In these two, at the end of a 6 week layoff, the duplicated CO_2 response had doubled from around 0.5 l per minute per mm Hg CO_2 to somewhere in the order of 1.3 to 1.5 l per minute per mm Hg $C0_2$. So I am not sure how much of it is adaptive and how much is pre-determined. This is another area we could look at taking new players through over a long time period.

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PREVENTING POST-DIVE HYPOTHERMIA

Rob Stephens

My qualifications for being in front of you are few and simple: I have been diving for a very long time, since before World War II in fact, and I have specialised in long distance diving with a small crew, the last two expeditions being from Auckland to the Kermadec Islands. My dive motto is the old Service one “Any fool can be uncomfortable”.

Small boat and small expedition diving requires rather a special form of safety precautions. My most common problem when diving from very small boats, eg. inflatables, has been the cold. A winter dive in a small boat miles from base means that a chilled diver must sit still in an icy blast for maybe a couple of hours during the journey home. Those who take “dry” clothes on such a trip usually find that instead of freezing in foam rubber, they freeze even worse in wet wool. Happily there is a simple answer, the large transparent plastic bag. The illustrations show two adults sitting in their own private greenhouse which maintains its configuration simply by wind pressure. Having got the occupants inside the bag, I usually simply pull one side of the opening over a projection such as the outboard motor, leaving a generous hole about a foot across for the wind to enter and maintain inflation of the bag. Three benefits accrue from this system:

1. Evaporative cooling of the wet diving suit virtually ceases as the air flow within the bag is very slow.

2. Body heat from the occupant(s) is largely retained within the bag’s microclimate.

3. Even only moderate sunshine produces a rapid temperature rise whereupon condensation is evident on the inner wall of the bag.

The illustrations inappropriately show the bag on the foredeck of a launch where need for the bag is obviated because there is a nice warm cabin, dry clothes and hot drinks. However, a chill problem can occur on large boats and frequently returning divers are incapacitated by cold.

On winter dives it is my custom to heat up a large pan containing about 10 litres of water so that each diver on return can have his suit filled with water as hot as he or she can bear it. This seldom seems hot to the person doing the pouring but the diver’s facial expression changes from tense apprehension to bliss and rapture as the water spreads from chin to toes. Some divers claim a bigger ‘buzz’ from the warm-up than from the dive itself!

Follow the external warm-up with a hot drink and within five minutes of return to the ship, your diver is a cheerful and efficient crew member once more. Should it be necessary to remove the suit, it is worth pointing out that a warm suit comes off far more readily than a cold one due to its increased elasticity.

Our oxygen routine management of possible bends differs in only one respect from the orthodox in as much as we carry a closed circuit oxygen diving set (courtesy Italian Navy 1942) as well as oxygen cylinder fitted with a standard diving regulator. A closed circuit system extends the duration of oxygen use