

L. R. Mc Naughton¹
 D. Thompson¹
 G. Philips²
 K. Backx³
 L. Crickmore³

A Comparison of the Lactate Pro, Accusport, Analox GM7 and Kodak Ektachem Lactate Analysers in Normal, Hot and Humid Conditions

Abstract

This study aimed to compare the performance of a new portable lactate analyser against other standard laboratory methods in three conditions, normal ($20 \pm 1.3^\circ\text{C}$; $40 \pm 5\%$ RH), hot ($40 \pm 2.5^\circ\text{C}$; $40 \pm 5\%$ RH), and humid ($20 \pm 1.1^\circ\text{C}$; $82 \pm 6\%$ RH) conditions. Seven healthy males, ([Mean \pm SE]: age, 26.3 ± 1.3 yr; height, 177.7 ± 1.6 cm; weight, 77.4 ± 0.9 kg, $\dot{V}\text{O}_2$ max, 56.1 ± 1.9 ml \times kg \times min⁻¹) undertook a maximal cycle ergometry test to exhaustion in the three conditions. Blood was taken every 3 min at the end of each stage and was analysed using the Lactate Pro LT-1710[®], the Accusport[®], the Analox[®] GM7 and the Kodak[®] Ektachem[™] systems. The MANOVA

(Analyser Type \times Condition \times Workload) indicated no interaction effect ($F_{(42,660)} = 0.45$, $p > 0.99$, Power = 0.53). The data across all workloads indicated that the machines measured significantly differently to each other ($F_{(4,743)} = 14.652$, $p < 0.0001$, Power = 1.00). The data were moderately to highly correlated. We conclude that the Lactate Pro is a simple and effective measurement device for taking blood lactate in a field or laboratory setting. However, we would caution against using this machine to compare data from other machines.

Key words

Lactate pro · lactate · enzymatic · testing · environmental · hot · humid

Introduction

Lactate analysis (La) is a common procedure in exercise physiology laboratories worldwide. Researchers commonly use lactate analysis from either whole blood (La_b) or from plasma (La_p) to measure the anaerobic thresholds (AT) and to set training intensities [16,19]. It is also used in recovery as a means to measure the anaerobic contribution from the formation of lactic acid [5,7,9,12]. Research in the field has determined that there is a strong relationship between the AT as measured by lactate profiling and endurance performance [6,15].

Athlete testing utilising blood lactate measurement in both field and laboratory settings requires instruments that are accurate, linear and reliable. Typically the analysis of blood/plasma lactate is undertaken either manually or with semi/fully automated ma-

chines such as those manufactured by Yellow Springs Instruments (YSI[®]), Kodak[®] Ektachem[™], Analox[®] or Roche[®].

Lactate measurement in the field setting requires that machines are also portable, battery operated, capable of operating under a wide variety of environmental extremes and are able to process samples quickly, whilst still maintaining the normal levels of accuracy, linearity and reliability. In 1994, Boehringer Mannheim (BM) introduced the hand held Accusport[®] lactate analyser, to be used primarily in a sporting setting [8]. This hand held device uses reflectance photometry to measure colour development in a drop of blood in a time of 60 s. This machine is reported to be both highly accurate [8], linear with an $r^2 = 0.99$, and reliable with a coefficient of variation (CV) of between 7 and 4.6% low and high concentrations, respectively [11,18].

Affiliation

¹ University of Bath, Great Britain

² Amateur Swimming Association of Great Britain

³ Kingston University, Great Britain

Correspondence

Prof. L. Mc Naughton · University of Bath · Claverton Down · Bath BA2 7AY · England ·
 Phone: +44 (1225) 323545 · Fax: +44 (1225) 826696 · E-Mail: l.mcnaughton@bath.ac.uk

Accepted after revision: May 31, 2001

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Int J Sports Med 2002; 23: 130–135 © Georg Thieme Verlag Stuttgart · New York · ISSN 0172-4622

In 1997, a Japanese company, Arkray KDK, introduced the Lactate Pro LT-1710[®] hand held lactate analyser. Working on a similar principle as the Accusport[®] this credit card sized, lactate analyser uses an ampero-metric method with an enzyme electrode (potassium ferrocyanide + voltage = potassium ferricyanide + e⁻ [14]). It automatically aspirates a 5 µl sample and analyses it within 60 s giving quick feedback to the coach or sports scientist.

It was the aim of this study, on the basis of previous work in the area, to compare the accuracy, reliability and linearity of the Lactate Pro LT-1710[®] versus the Accusport[®], the Analox[®] GM7 and the Kodak[®] Ektachem[™] systems. Furthermore we also wished to investigate the response of these analysers in both hot and humid conditions.

Materials and Methods

Subjects

Seven healthy male subjects agreed to participate in this study after being informed verbally and in writing as to the nature of the experiment and possible risks. All signed informed consent and the Departmental Ethics Committee approved the protocol. The physical characteristics of the subjects was (Mean ± SE): age, 26.3 ± 1.3 yr; height, 177.7 ± 1.6 cm; weight, 77.4 ± 0.9 kg, $\dot{V}O_2$ max, 56.1 ± 1.9 ml × kg × min⁻¹. All were currently undertaking aerobic type training (minimum 4 d/wk) and were asked to continue with this but to refrain from training 24 h prior to the test session.

Protocol

The seven subjects each undertook three random tests separated by at least two days but no more than seven days. The test consisted of a maximal exercise test which commenced at 50 Watts (W) and then progressed in 25 W × 3 min⁻¹ stages to voluntary exhaustion. This test was completed in one of three environmental conditions; thermoneutral (20 ± 1.3 °C; 40 ± 5% RH), hot (40 ± 2.5 °C; 40 ± 5% RH), and humid (20 ± 1.1 °C; 82 ± 6% RH). All testing took place on a Lode Excalibur Sport (v1.5, Groningen, Netherlands). Subjects undertook the test 4 hr post-prandial and were dressed in light clothing.

On the day of testing the subject reported to the laboratory and had a fingerprick blood sample taken which was then analysed in duplicate on the five different analysers (2 × Lactate Pro Analysers which were randomly designated as Lactate Pro 6 and Lactate Pro 8, Kodak Ektachem, Analox and Accusport). The mean of the two samples was used. They then undertook the exercise test during which blood samples were taken in the last 30 s of each stage and were analysed by the five machines as described previously. In all test sessions the blood samples and analyses were carried out by the same individuals.

Reliability

As an aside we measured the reliability of one Lactate Pro machine across three samples nominally called low, moderate and high. The blood sample was taken from the same subject at rest, after 5 min during a workload of 200 W and after 5 min during a workload of 350 W.

Data analysis

Data were analysed in a number of ways. Correlational analysis was used to determine relationships between the different types of analysers across all workloads and in all conditions, as well as individually across all workloads in specific conditions. A multiple analysis of variance (MANOVA) was conducted on the pooled data Analyser Type × Condition × Workload (4 × 3 × 8) and an Analysis of variance (ANOVA) was then conducted on the simple main effects if the interaction effect was not significant. Post hoc analyses was undertaken using Fisher's PLSD. Finally descriptive data is presented in the form of limits of agreement (LOA) and coefficient of variation (CV) so that comparisons between analysers can be made [1, 3, 4, 12]. The significance level of p < 0.05 was accepted *a priori* and all computer analyses was carried out using Statview[®].

Results

When all the data were pooled for all machines and in all conditions, a correlation analysis was undertaken (on a total of 965 data points). This is shown in Table 1. Fig. 1 shows the response of the four (the data for the two Lactate pro machines is averaged as there was no statistical difference between Lactate Pro 6 and Lactate pro 8) analysers in the three different environmental conditions. The MANOVA (Analyser Type × Condition × Workload) indicated no interaction effect ($F_{(42,660)} = 0.45$, p > 0.99, Power = 0.53). Of the three possible, two-way interactions, Condition × Workload was not significant ($F_{(42,660)} = 1.3$, p > 0.21, Power = 0.78), while both Analyser × Condition and Analyser × Workload were significant ($F_{(6,660)} = 9.03$, p < 0.0001, Power = 1.0; $F_{(21,660)} = 5.21$, p < 0.0001, Power = 1.0 respectively). The simple main effects indicated that, as expected, workload was a significant factor, and lactate levels rose as workload increased ($F_{(7,660)} = 327.71$, p < 0.0001, Power = 1.0). Furthermore, Analyser Type was also significant ($F_{(3,660)} = 54.35$, p < 0.0001, Power = 1.0), but Condition was not significant ($F_{(6,660)} = 0.15$, p > 0.86, Power = 0.07).

The post hoc analysis carried out indicated that the Lactate Pro (6 and 8) measured significantly lower than the Kodak Ektachem system (p < 0.0002), higher than the Analox (p < 0.005) and no different to the Accusport (p > 0.23). The Analox measured lower than the Kodak and Accusport (p < 0.0001 and p < 0.001, respectively) while the Kodak measured significantly higher than the Accusport (p < 0.0001). The two Lactate Pro machines were not

Table 1 Correlations of the five lactate analysers across all workloads and the three conditions

	Lactate Pro 6	Lactate Pro 8	Analox	Kodak	Accusport
Lactate Pro 6	1.00	0.986	0.948	0.901	0.765
Lactate Pro 8		1.00	0.955	0.907	0.785
Analox			1.00	0.917	0.807
Kodak				1.00	0.827

All values significant at p < 0.005

Table 2 Regression analysis and variance (**bold**) for the 4 analysers in the three different conditions

	<i>Lac Pro '6'</i>	<i>Lac Pro '8'</i>	<i>Analox</i>	<i>Kodak</i>	<i>Accusport</i>
a) Normal					
Lactate Pro '6' =		$0.053 \pm 0.997 \times X$	$0.1 \pm 1.314 \times X$	$-0.891 \pm 0.876 \times X$	$-0.24 \pm 1.184 \times X$
Lactate Pro '8' =	$R^2 = 0.982$		$0.14 \pm 1.231 \times X$	$-1.04 \pm 0.89 \times X$	$-0.67 \pm 0.664 \times X$
Analox =	$R^2 = 0.811$	$R^2 = 0.917$		$-0.67 \pm 0.664 \times X$	$-0.488 \pm 0.922 \times X$
Kodak =	$R^2 = 0.821$	$R^2 = 0.831$	$R^2 = 0.854$		$0.695 \pm 0.543 \times X$
Accusport =	$R^2 = 0.741$	$R^2 = 0.678$	$R^2 = 0.706$	$R^2 = 0.689$	
b) Hot					
Lactate Pro '6' =		$-0.004 \pm 1.01 \times X$	$0.07 \pm 1.271 \times X$	$-0.917 \pm 0.886 \times X$	$-0.404 \pm 1.18 \times X$
Lactate Pro '8' =	$R^2 = 0.992$		$0.085 \pm 1.255 \times X$	$-0.987 \pm 0.897 \times X$	$-0.367 \pm 1.159 \times X$
Analox =	$R^2 = 0.927$	$R^2 = 0.928$		$-0.393 \pm 0.603 \times X$	$-0.387 \pm 0.943 \times X$
Kodak =	$R^2 = 0.868$	$R^2 = 0.884$	$R^2 = 0.886$		$-0.036 \pm 1.605 \times X$
Accusport =	$R^2 = 0.602$	$R^2 = 0.602$	$R^2 = 0.634$	$R^2 = 0.563$	
c) Humid					
Lactate Pro '6' =		$0.061 \pm 0.998 \times X$	$0.262 \pm 1.253 \times X$	$-1.002 \pm 0.886 \times X$	$-0.715 \pm 1.144 \times X$
Lactate Pro '8' =	$R^2 = 0.967$		$0.246 \pm 1.241 \times X$	$-0.99 \pm 0.876 \times X$	$-0.822 \pm 1.155 \times X$
Analox =	$R^2 = 0.922$	$R^2 = 0.932$		$-0.737 \pm 0.653 \times X$	$-0.722 \pm 0.907 \times X$
Kodak =	$R^2 = 0.860$	$R^2 = 0.857$	$R^2 = 0.829$		$0.690 \pm 1.233 \times X$
Accusport =	$R^2 = 0.787$	$R^2 = 0.834$	$R^2 = 0.809$	$R^2 = 0.801$	

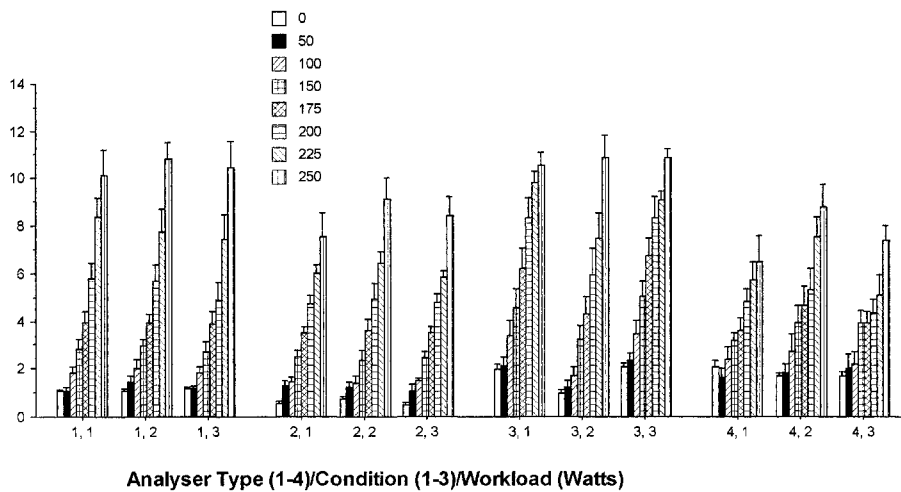


Fig. 1 The blood lactate concentration during the three tests (1 = Normal, 2 = Hot, 3 = Humid), in the four machines (1 = Mean Lactate pro 6/8, 2 = Analox, 3 = Kodak, 4 = Accusport) across the various workloads (Mean \pm SE).

significantly different from each other; thereafter the data for Lactate Pro was an average of these two machines. The response of the four analysers across the different workloads is shown in Fig. 2.

Normal data

The correlation between the four machines is shown in Table 2a, including the Lactate Pro 6 and Lactate Pro 8 analysers. An ANOVA carried out in the normal condition, across all workloads indicated that there were significant ($p < 0.001$) differences between the machines ($F_{(4,392)} = 5.033$, Power = 0.971). A post hoc analysis carried out indicated that the Lactate Pro analyser differed significantly ($p < 0.05$) from the Analox, with the Analox measuring consistently lower than the Lactate Pro. The Analox was also significantly lower than the Kodak ($p < 0.0001$). This was also true for the Accusport, which measured significantly lower than the Kodak ($p < 0.005$). Table 2a shows the regression equations for each of the analysers, against the other analysers.

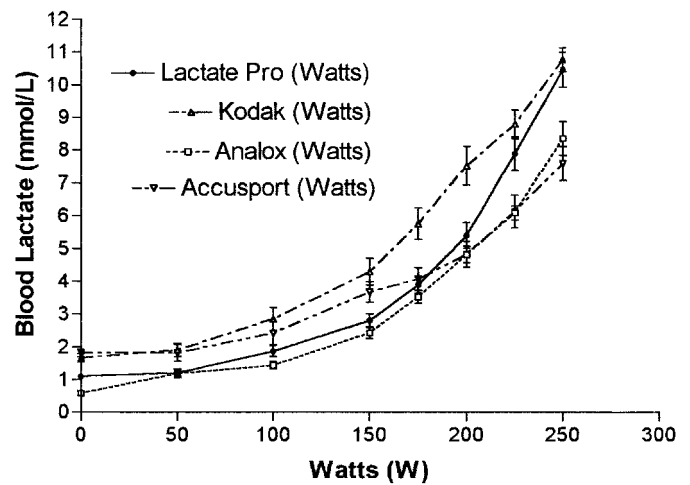


Fig. 2 The responses of the four analysers across the different workloads (Mean \pm SE).

Table 3 Limit of agreement data in the three conditions (LD = log difference, SD = standard deviation)

Analysers	Mean LD	SD LD	SD LD×1.96	Exp SD LD	Corr Mean Diff
a) Normal					
Lactate Pro 6/Lactate Pro 8	0.001	0.07	0.12	0.13	0.043
Lactate Pro 6/Analox	0.151	0.26	0.52	1.67	0.665
Lactate Pro 6/Kodak	-0.190	0.19	0.37	1.44	-0.081
Lactate Pro 6/Accusport	-0.002	0.25	0.49	1.66	0.537
Lactate Pro 8/Analox	0.147	0.25	0.49	1.63	0.649
Lactate Pro 8/Kodak	-0.198	0.18	0.34	1.41	-0.055
Lactate Pro 8/Accusport	0.001	0.25	0.48	1.61	0.526
Analox/Kodak	-0.358	0.29	0.56	1.76	-0.683
Analox/Accusport	-0.152	0.25	0.48	1.62	-0.081
Kodak/Accusport	0.207	0.22	0.42	1.52	0.592
b) Hot					
Lactate Pro 6/Lactate Pro 8	0.010	0.06	0.11	1.12	-0.116
Lactate Pro 6/Analox	0.133	0.21	0.41	1.51	-0.094
Lactate Pro 6/Kodak	-0.224	0.13	0.26	1.29	0.616
Lactate Pro 6/Accusport	-0.061	0.28	0.54	1.71	0.448
Lactate Pro 8/Analox	0.122	0.19	0.37	1.45	-0.070
Lactate Pro 8/Kodak	-0.236	0.15	0.29	1.35	0.610
Lactate Pro 8/Accusport	-0.072	0.29	0.57	1.77	0.445
Analox/Kodak	-0.364	0.23	0.45	1.57	0.423
Analox/Accusport	-0.193	0.36	0.70	2.01	0.384
Kodak/Accusport	0.167	0.22	0.43	1.54	0.345
c) Humid					
Lactate Pro 6/Lactate Pro 8	-0.04	0.08	0.15	1.17	0.138
Lactate Pro 6/Analox	0.18	0.19	0.37	1.45	-0.305
Lactate Pro 6/Kodak	-0.22	0.16	0.32	1.37	0.586
Lactate Pro 6/Accusport	-0.37	0.25	0.49	1.63	-0.943
Lactate Pro 8/Analox	0.18	0.20	0.39	1.47	-0.346
Lactate Pro 8/Kodak	-0.22	0.14	0.27	1.31	0.609
Lactate Pro 8/Accusport	-0.09	0.20	0.39	1.48	0.441
Analox/Kodak	-0.55	0.35	0.68	1.97	-0.975
Analox/Accusport	-0.27	0.31	0.61	1.83	0.532
Kodak/Accusport	0.15	0.15	0.29	1.34	0.079

Hot data

The correlational analysis shown in Table 2b indicates that the highest correlation exists between the two lactate Pro machines, while the lowest correlation is between the Accusport and the Analox. The ANOVA conducted on the data shows no significant differences between the analysers in the measurement of blood lactate ($F_{(4,353)} = 0.124, p > 0.970, \text{Power} = 0.075$). In Table 2a the regression equations for each of the analysers against the other analysers are shown for this condition.

Humid data

The correlation data for the comparisons made during the humid condition are shown in Table 2c. The ANOVA undertaken on the data showed a significant difference between the machines ($F_{(4,295)} = 4.378, p < 0.002, \text{Power} = 0.942$). The post hoc, Fisher's PLSD analysis shows that the only significant difference ($p < 0.01$) between machines was between Analox and Kodak machines, with the Analox reading significantly lower than the Kodak.

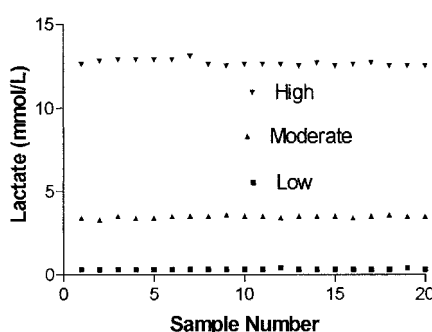


Fig. 3 Repeatability of assay on the Lactate pro at low, moderate and high blood Lactate concentrations.

Table 3 shows the limits of agreement (LOA) data between all of the analysers used in the experiment, in the three different conditions, Normal (3a), Hot (3b) and Humid (3c).

The reliability data is shown in Fig. 3 and produced co-efficient of variation (CV) figures of 10% for the low value, 4.1% for the moderate value and 3.1% for the high value.

Discussion

The results of this study support the use of the Lactate Pro as an accurate and reliable method of measuring blood lactate under a variety of environmental conditions. This supports the previous work of Pyne et al. [14]. In their work they investigated the Lactate Pro in a laboratory and field setting against a variety of other analysers as well as against another Lactate Pro analyser. The correlations between the two analysers in their work, when compared against the current work are the same ($r = 0.99$). The correlational data between the two Lactate Pro analysers would suggest that these analysers can be used interchangeably within the same testing sequence, although, of course, it is recommended that the same analyser is used with the same subjects throughout the testing condition.

Makita and Satomi [11] have found the machine to have a coefficient of variation of two percent for low concentrations and 4.7 percent for high lactate concentrations. We however found much larger CV figures for the low concentrations based upon 20 samples and similar values for the moderate and high lactate concentrations (4.1 and 3.1% respectively). The reported CV for the instrument by the manufacturer [18] is 3%, which approximates our figures, especially within the 2–10 mM range, which is the training and testing range. We would conclude that these higher CV values are not particularly important for sports related testing, as use of this analyser would be predominantly in a field testing situation and lactate values would typically be in the lower regions. The reliability measurements are similar to those reported for the Accusport, 7.0% and 4.6% for similar values. These reliability values are considered acceptable for analysers that are portable and for use in predominantly field settings by untrained staff [2].

It was interesting to note that when a comparison of the pooled Lactate Pro data (from 6 and 8) was made with the Kodak, as per the work of Fell et al. [8], the regression line was $y = -1.009 + 0.887 \times X$, which would give significantly different values to that obtained in the Fell et al. study [8].

When a comparison of the machines was made, Lactate Pro number 8 only correlated highly with the Accusport ($r = 0.834$) in the humid condition, which is interesting since this was the only other portable analyser compared. This contradicts the work of Makita and Satomi [11]. In their work they found a high correlation ($r = 0.99$) whereas we found a much lower correlation ($r = 0.785$). Makita and Satomi's [11] work is also supported by Pyne and colleagues [14] who also found a correlation much higher than ours ($r = 0.973$). It may be possible that improvements in the data for the Accusport could be made by pipetting an exact amount of blood to the test strip rather than simply using a "drop" of blood.

The analysis of variance (ANOVA) that was undertaken on the pooled data from the machines across the three conditions indicated that the machines measured significantly differently, with only the Lactate Pro and Accusport not being significantly different. This is interesting given the low correlation between these two analysers. However, when a square root of the error component of the MANOVA conducted on the data was calculated, a value of 1.1 mmol/L was seen. This suggests that the random error from analyser to analyser is 1.1 mmol/L. The systematic bias,

however, is ruled out due to the non-significant MANOVA [3,10]. The difference in random error of 1.1 mmol/L may be due to errors in blood volume seen with Accusport analyser, as we did not pipette the volume to the analyser strip, whereas the Lactate Pro aspirates 5 μ L automatically, therefore eliminating volume error.

Significantly, the Analox measured lower and the Kodak higher than the Lactate Pro with the Analox measuring lower than the Kodak and Accusport. This data suggests that these machines, apart from the Lactate Pro and the Accusport, do not give the same result, despite being moderately or highly correlated.

An ANOVA carried out in the normal condition across all workloads indicated that there were significant differences suggesting that the machines measured lactate concentrations differently across the tests. The post hoc analyses carried out indicated that the Lactate Pro analyser differed significantly from the Analox, with the Analox also measuring significantly lower than the Kodak. This was also true for the Accusport, which also measured significantly lower than the Kodak. The same was not true for the analysers in the hot condition where there were no differences between the machines. Why this might be so is a reason for conjecture and as yet we are unable to quantitatively explain this difference. In the humid condition, although the ANOVA was significant, it was on the basis of a significant difference only between the Analox and Kodak machines.

The four machines, as shown in Fig. 2, cannot be used interchangeably across different workloads as they would give different results, since the slopes of the lines as shown are all different. Although speculative, we suggest this may be due to the method of measurement used by each machine. Certainly, the Kodak Ektachem uses plasma and it is well known that plasma values differ significantly to whole blood [17,20].

The use of correlational techniques has been questioned because they are measures of relation rather than agreement [1,3,13] and as such can be highly influenced by the range of subject measurement. Bland and Altman [1] have proposed a different method, which we have used, termed "limits of agreement" [4]. Our data shows that there are few of the data with a "perfect agreement" (equal to 1.00). In Table 3 (Exp SD LD) there is a great deal of variation between the data suggesting that few, if any, of the machines should in reality be compared to each other. In all of the three conditions, the two Lactate Pro analysers have the least amount of variation (17%, 13% and 12% in the normal, hot and humid conditions respectively). The worst combination to have would be the Analox/Kodak (normal and humid) and the Analox/Accusport in the hot condition [13].

In conclusion the Lactate Pro analyser has been shown to be a simple and effective measurement device for taking blood lactate in a field setting. Depending upon the method of statistical comparison, it compares favourably to other similar devices, as well as to those found on the laboratory bench. We would caution against using this machine, or for that matter combinations of other machines, to compare data until the individual laboratory has assessed the relationship between the two machines used for measurement under the conditions found within the laboratory or field situation. In real terms it would be best to use the same machine under all circumstances.

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